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THE IMPACT OF LAND DEGRADATION ON AGRICULTURAL PRODUCTIVITY: A MULTI-PERIOD ECONOMIC LAND USE MODEL

A case study of the Neguev settlement, Costa Rica

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CENTRO AGRONOMICO TROPICAL DE
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The Research Program on Sustainability in Agriculture (REPOSA) is a cooperation between Wageningen Agricultural University (WAU), the Center for Research and Education in Tropical Agriculture (CATIE), and the Costa Rican Ministry of Agriculture and Livestock (MAG). In addition, REPOSA has signed memoranda of understanding with numerous academic, governmental, international, and non-governmental organizations in Costa Rica.

The overall objective of REPOSA is the development of an interdisciplinary methodology for land use evaluation at various levels of aggregation. The methodology, based on a modular approach to the integration of different models and data bases, is denominated USTED (*Uso Sostenible de Tierras En el Desarrollo*; Sustainable Land Use in Development).

REPOSA provides research and practical training facilities for students from WAU as well as from other Dutch and regional educational institutions.

REPOSA's research results are actively disseminated through scientific publications, internal reports, students' thesis, and presentations at national and international conferences and symposia. Demonstrations are conducted regularly to familiarize interested researchers and organizations from both within and outside Costa Rica with the *USTED* methodology.

REPOSA is financed entirely by WAU under its Sustainable Land Use in the Tropics program, sub-program Sustainable Land Use in Central America. It operates mainly out of Guápiles where it is located on the experimental station *Los Diamantes* of MAG.

REPOSA (*Research Program on Sustainability in Agriculture*, o sea Programa de Investigación sobre la Sostenibilidad en la Agricultura) es una cooperación entre la Universidad Agrícola de Wageningen, Holanda (UAW), el Centro Agronómico Trópical de Investigación y Enseñanza (CATIE) y el Ministerio de Agricultura y Ganadería de Costa Rica (MAG). Además REPOSA ha firmado cartas de entendimiento con organizaciones académicas, gubernamentales, internacionales y non-gubernamentales en Costa Rica.

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REPOSA es financiado por la UAW bajo su Programa del Uso Sostenible de la Tierra en los Areas Trópicos. La sede de REPOSA está ubicada en la Estación Experimental Los Diamantes del MAG en Guápiles.

Abstract

Current land use practices will have to be sustainable in order to guarantee a sufficient level of agricultural production for future generations. In this study a sub-regional multi-period linear optimization model of agricultural land use is developed in which land use decisions take their impact on future productivity into account. Given the time-lags associated with land degradation processes a long time horizon is required. However, the incorporation of the dynamics of investments in perennial crops simultaneously demands time periods of just a few years. To address these opposite requirements four periods of varying length are distinguished within a total planning period of 20 years. The first two periods comprise only one and two years, respectively, to capture the net investment period at the start of perennial cropping cycles. The last two periods cover six and eleven years to account for the long term effects of land degradation.

In the model land use practices affect production in following periods through inducing changes in soil fertility, which on their turn affect the production levels, as well as by a requirement to maintain productive perennials form previous periods. These relations between periods combined with an objective function maximizing economic surplus over all four periods forces land use decisions to incorporate their effect on future production possibilities.

Three versions of the model have been applied to the Neguev settlement, Costa Rica in order to assess the effect of land degradation on land use patterns as well as the effect of using an average slope instead of different slope classes. Inclusion of the effects of land degradation in the analysis results in almost thirty percent of the agricultural land being left fallow in the first three periods to avoid productivity losses in the last period. These fields are cultivated in case the effects of land degradation are excluded from the analysis. Use of an average slope instead of slope-classes resulted in an underestimation of the amount of erosion together with the use of degradation-prone soils in the early periods of the planning horizon. A comparison of the modeling results to the actual land use pattern indicates that several extensions will be needed before the model can be used to assess the long term effect of agricultural policies on the sustainability of agriculture.

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Preface and acknowledgments

During my stay in Costa Rica from October 1995 through June 1996 I started the work on this thesis. The major part of the time I spent at the REPOSA project in Guápiles was dedicated to a general farm survey of the Neguev settlement, which composed my internship for the department of Development Economics. In addition to executing the survey and processing its results I did most of the work on the calculation of the degradation and the erosion. In Costa Rica I also designed the general structure of the model, especially the way in which the effects on future productivity could be incorporated. After my return to the Netherlands I developed a test model and started the compilation of the data files for a more realistic model. After a couple of months debugging the model and the databases and I could finally run a real model, only to spend several more weeks on debugging that one.

Altogether the combination of my internship with this thesis gave me the opportunity to get hands-on experience with the whole process of building a land use model. From the collection of field data to designing a model structure, testing and adjusting this design, manipulating databases, debugging and finally writing the results in a form comprehensible to others. The successful completion of this process would not have been possible without the advice and support from a number of people.

In Guápiles Jetse Stoorvogel provided the data and literature which where needed for the calculations of the erosion and the effects of degradation. I would like to thank him for keeping degradation as simple as possible so that I could focus on the development of the model structure. Furthermore I would like to thank Hans Jansen for commenting on the early chapters of the thesis as well as for critically reviewing the final version. In Wageningen both my advisors, Ekko van Ierland and Rob Schipper, worked through all the earlier versions of the thesis. Next to pointing out lacks in the contents their comments greatly improved the readability of the thesis. I want to thank them for reading through those numerous pages and with their comments forcing me to step back from all the programming and data files and to put the work in a broader perspective. Finally, I would like to thank Jaap for patiently listening to incomprehensible explanations of matrices, data files and equations in the middle of the night and being able to ask some basic questions which put me back on track.

Chapter I

INTRODUCTION

The global importance of agriculture as a source of food for the human population and its dependence on land has led to an explicit concern of economists with land use. (Schipper, 1996:1) Considering the impact land degradation can have on agricultural production, it should be an explicit component of any attempt to analyze and optimize the use of land. Two features of land degradation processes are important with respect to their incorporation in economic land use models. In the first place the existence of long time-lags between land use activities which cause degradation and the appearance of their effects. A multi-period approach is needed in order to capture this characteristic of degradation processes.

A second aspect of land degradation processes which has to be accounted for is that their effects are not restricted to the plot on which degrading activities have taken place, but occur on a much more aggregate level. Erosion on agricultural lands can cause the siltation of water reservoirs used for hydroelectric power, disruption of stream ecology, flooding and increased water treatment costs. (Lal, 1985; Midmore et al., in print; Lal, 1985; de Groot, 1994; Pimentel et al., 1995) The analysis should thus not be restricted to the plot or farm level, but rather a regional approach to land use should be taken, preferably also including non-agricultural land uses.

The aim of the present study is to develop a framework to analyze the interactions between land use activities and land degradation processes. This framework has to account for the fact that effects might occur only after an extended period of time, while also allowing for an analysis at a higher level than the field or farm. In order to reach this objective a regional, multi-period linear programming model has been developed. This model has been denominated MERALM, a Multi-period Economic Regional Land use Model.

MERALM has its roots in a model which has been developed within the Research Program on Sustainability in Agriculture (REPOSA), in the context of which the present study has been executed. REPOSA is a continuation of the Atlantic Zone Program. The latter research program was initiated in the Atlantic Zone of Cost Rica in 1987 and involves a cooperation of CATIE (*Centro Agronómico Tropical de Investigación y Enseñanza*), WAU (*Wageningen Agricultural University*) and MAG (*Ministerio de Agricultura y Ganaderia*). The main focus of REPOSA is "development of an interdisciplinary methodology for the analysis and evaluation of ecologically and economically sustainable land use" (Jansen et al., 1996:1).

The study has been divided in four parts. The first part provides the theoretical background of soil erosion and land degradation processes and reviews land use models which incorporate land degradation. Chapter 2 presents a summary of the theory on land degradation and especially erosion. It also provides the background of the Universal Soil loss Equation (USLE) which has been used to calculate the amount of erosion resulting from land use activities in the study area. After this presentation of the basic issues of land degradation Chapter 3 reviews the literature on economic land use models which include the effects of land degradation. The models are compared with respect to five attributes: level of analysis, modeling methods, treatment of time, economic behavior and conditions and finally, biophysical details.

The second part of the study is devoted to a more detailed definition of the objectives of the study, as well as a describing the case study area and the data used in the modeling exercises. Chapter 4 specifies the objectives of the study in relation to the theory of the first part, as well as to the model which functioned as the point of departure for the development of MERALM. Chapter 5 then describes the study area, the Neguev settlement situated in the Atlantic Zone of Costa Rica. This area has been selected because of the availability of a large data-set, the result of nearly ten years of studies performed within the context of REPOSA. Chapter 6 then presents the assumptions and data which are used in the model runs. First the way in which soil types are defined is discussed, followed by a presentation of the land use activities which have been included in the modeling exercises. The next part of this chapter is devoted the three sustainability indicators included in MERALM: a biocide index, nutrient balance and erosion. The final part explains the way in which the effect of land degradation on land use has been made operational.

The third part of the study deals with the mathematical structure of MERALM and the results of its application to the Neguev settlement. Chapter 7 discusses the details of the mathematical structure of MERALM. The objective of the model is to optimize the economic surplus for the study area as a whole. The optimization of the objective function is subjected to restrictions on production and inputs, labor use and availability and land use and availability. The latter restrictions depend on past land use activities. Chapter 8 then presents the results of three versions of MERALM which have been developed for the Neguev settlement. The first model functions as the point of reference for the other 2 models. It contains 8 different soil types and land use decisions take their effect on future production possibilities into account. The second model assesses the need for the detailed differentiation of soil types by including only three soil types. Finally, the last model version is used to analyze the effect which the incorporation of land degradation has on the optimal land use pattern. This model again distinguishes eight different soil types, but this time land degradation does not affect future production.

The last part of the study contains the conclusions. Chapter 9 first reviews the way in which the objectives set out in Chapter 4 have been met. The next part analyzes the structure of MERALM with respect to the five attributes which have been derived from the literature in Chapter 3. The last part of the conclusions is devoted to an evaluation of MERALM in the light of a further improvement of its performance. Several ways in which the structure of the model could be modified are pointed out, as well as its significance with respect to existing land use models.

Chapter II

SOIL EROSION AND LAND DEGRADATION

2.1 Introduction

The aim of this study is the development of a framework to assess the long term effects of land degradation on agricultural production. In order to develop such a framework first an understanding of the physical processes of land degradation has to be obtained. On the human time-scale soil can be considered a non-renewable resource. The process of soil accumulation is so slow that a substantial amount of soil can only be formed over a geological time scale. Soil has certain abilities for self-regulation but misuses or extreme conditions can upset or destroy its regulating capacities, resulting in a less productive soil. (Lal et al., 1989:51) This non-renewable character of soils causes land degradation to be irreversible. This irreversibility may account in large part for the considerable focus in the literature on the effects of soil degradation and erosion on production now as well as in the future. Erosion tends to affect the poor part of populations in particular; often they live on the most fragile soils which they have to use most intensively, lacking other ways of satisfying their needs (de Groot, 1994:7). Poverty is also a cause of a recent increase in erosion, since both poverty and population pressure lead to intensive cultivation of marginal, possibly steep and fragile lands. In certain instances pricing policies also encourage intensive cultivation of previously extensively managed lands, thus increasing the risk of erosion. (Cárcamo et al., 1994:257)

Land degradation as well as erosion are complex, multifaceted problems, involving a great number of interrelated variables, externalities, and time lags. (Parton, 1996:376) Single physical measures, as for example the often used topsoil depth, do not take into account the total impact of soil degradation on soil quality and productivity. (Orazem & Miranowski, 1994:385) Within the range of variables determining land degradation, land management is considered to be the main controllable variable. (Parton, 1996:376) However, the great complexity of degradation processes hampers research and leads to a lack of reliable data. At present no evidence exists for catastrophic predictions about the effects of erosion, it could just as well be that erosion rates have a limited effect on agricultural productivity, even if these rates are high. (Lutz et al., 1994:4)

This chapter has been divided in four sections and starts with defining land degradation and soil erosion. Section 2.3 then discusses the factors promoting the occurrence of erosion. The next part examines the on- and off-site effects of erosion and the factors determining the adoption of soil conservation measures. The last part of this chapter is devoted to the Universal Soil Loss Equation (USLE) which has been used in this study to determine the amount of soil lost through erosion. The components of the USLE are reviewed as well as its use and limitations.

2.2 Soil degradation and erosion

Theoretically a distinction can be made between *soil degradation* and *land degradation*, with the latter encompassing soil degradation as well as a reduction of the vegetative cover (de Groot, 1994:1). Most authors however define soil degradation as such that a reduction in vegetation is implied. For example Lutz et al. (1994:3) define soil degradation as "....a reduction in the land's actual or potential uses", implying both a degradation of soil as well as vegetation. Another, more extended, definition of soil degradation is "..(a) diminution of soil quality (and thereby its current and potential productivity), and/or a reduction in its ability to be a multi-purpose resource due to both natural and man-induced causes.....The effects of degradation might be local or global." (Lal, et al., 1989:52). Both definitions of soil degradation are rather vague. In order to establish a clearly specified definition the critical limit which defines a soil as degraded has to be known. Given the lack of knowledge on susceptibility of soils to erosion and on growth of crops and animals in relation to soil degradation, this limit is hard to determine. (Lal, et al., 1989:53) In general the critical limit can be said to consist of the point at which a soil becomes economically unsuitable for any purpose. In the case of agriculture, the limit is reached when no economically viable or subsistence agriculture is possible. (Lal et al., 1989:52) This approach implies that the critical degradation limit is a dynamic concept, depending on economic conditions at a specific point in time.

In the analysis of soil degradation a distinction can be made between *processes* and *factors* of soil degradation. *Soil degradation processes* consist of physical, chemical, and biological processes, affecting the self-regulating capacity and productivity of the soil. These processes result in for example a deterioration of soil structure, leaching, toxification, and decline in organic matter. *Factors of soil degradation* on the other hand, are man-induced as well as natural agents and catalysts, bringing about the processes of degradation. Man-induced factors include among others, intensive row-cropping, ploughing and contamination. (Lal et al., 1989:53) Most studies on land degradation focus on soil erosion which encompasses all three mentioned processes of soil degradation. In extreme cases erosion can lead to irreversible degradation by exposing infertile subsoils. (Lal et al., 1989:58) Despite the voluminous literature on erosion, few reliable quantitative data are available on its magnitude. Data on other forms of degradation, like depletion of nutrients, reduction in physical and chemical properties, or reduction in the capacity to retain moisture are even scarcer. (Lutz et al., 1994:4) This lack of reliable data results from an absence of standardized methods to measure erosion, making results difficult to compare, as well as from the unreliability of methods presently used. (Lal et al., 1989:58) Another factor which limits the availability of data is the strongly site-specific character of erosion, limiting transferability of data, therefore necessitating a large effort at data collection.

An example of the lack of data and problems of transferability of results is the discussion on the tolerable amount of soil loss. Based on research in the United States, a soil formation rate of ten ton per hectare per year is mentioned by several authors (see for example Miranowski, 1984:61, Bork, 1991a:9). If it is assumed that "soil erosion can be accepted to that extent for which soil formation compensates" (Bork, 1991a:9), a soil loss of 10 ton per hectare per year can be deemed acceptable. But while many cite this number, generally no information is given on either parental material or climatic conditions. (Bork, 1991a:9) Pimentel et al. (1995) cite a number of 1 ton per hectare, per year, but again data on parental material and climatic conditions are lacking. The site-specific character of erosion which causes problems of transferability of results is clearly indicated by a German study. In this study soil erosion and formation only appeared at the same site in the case of grazed permanent grassland. Forests showed soil formation but no erosion, whereas on arable lands only erosion occurred. Therefore in the last situation the level of tolerable soil loss would be zero instead of the generally used 10 ton per hectare per year. (Bork, 1991a:9)

Erosion can occur through either ice, snow, water or wind, with the latter two constituting the most important forms of erosion. (Eppink, 1984:14) The present study of erosion is limited to the occurrence of water erosion of which several forms can be distinguished. *Splash erosion* can be defined as detachment and transport of soil particles, resulting from the impact of raindrops. The most important effect of splash erosion is destruction of soil aggregates and particles. Destruction of soil structure can reduce the infiltration capacity, increase overland flow, thus promoting soil erosion. With *sheet erosion,* also related to as laminar erosion, soil is removed in more or less uniform layers. Sheet erosion tends to change into *rill erosion,* defined as removal of soil particles by concentrations of flowing water, leading to rills which can reach a depth of 30 cm. Rill erosion is beginning *gully erosion,* which consists of large concentrations of water causing deep gullies and even gorges. (Eppink, 1984:17) The final step in this sequence is *streambank erosion,* consisting of rivers or streams cutting into their banks. (Hudson, 1973:38) Sometimes splash, sheet and rill erosion are referred to as horizontal erosion, opposite of the vertical gully and streambank erosion. The form of water which erosion occurs, strongly depends on the landscape. Splash and sheet erosion tend to occur on uncultivated slopes, whereas on cultivated lands sheet and rill erosion tend to dominate. Gully erosion mainly occurs on overgrazed slopes with a stepped profile. (Lal, 1985:243) Studies from Africa and the United States indicate that gully erosion only accounts for a small part of the sediments lost in the erosion process. The most important causes of sediment creation are sheet and rill erosion. (Vahrson, 1991:33)

2.3 Factors influencing erosion

Despite the differences in scale at which the effects of the various types of erosion occur they are all mainly induced by the following factors: *precipitation*, *soil*, *relief* and *vegetation*. The factors are interrelated in practice which hampers a quantification of the erosion process. (Eppink, 1984:51) The first factor, precipitation, has a direct effect on erosion through the *erosivity of rain,* defined as the ability of the rain to detach and transport soil particles. This erosivity is determined by the kinetic energy of raindrops, the intensity and the amount of rain. (Eppink, 1984:52) Rainfall also affects erosion indirectly by being an important determinant of the possibilities of agriculture, and therefore of the occurrence of erosion. (Eppink, 1984:62) An important factor in the spread of erosion in tropical regions is the high erosivity of rain in these regions, which is especially damaging if combined with poor vegetative cover. (Lal, 1985:241)

Just like precipitation soil also has a direct and an indirect effect on erosion. The *erodibility of the soil* is defined as the amount to which soil-material can be detached and transported by the impact of raindrops and run off water. This sensitivity to erosion is supposed to be a function of measurable physical, physical-chemical, and mineralogical characteristics of the soil. (Eppink, 1984:51) In practice no universal index for erodibility of soils exists, since it proves to be hard to determine. (Eppink, 1984:66) Indirectly soil characteristics affect erosion by influencing the type of crops which can be grown, as well as their growing speed and density, all of which affect the occurrence of erosion. (Eppink, 1984:62)

As far as relief is concerned, three components are important with respect to erosion; gradient, length and shape of the slope. Various studies report a exponential relationship between slope and erosion losses. (Lal, 1976:364) Most formulas used for the calculation of erosion ignore the variability in shape of slopes and therefore tend to overestimate erosion, since decreased erosion as a result of more convex parts is ignored. (Eppink, 1984:69)

Finally, the last important factor determining the occurrence and extent of erosion is vegetation. A vegetative cover can have important protective effects against erosion by intercepting precipitation, reducing overland flow, retaining of soil-particles by roots, increasing soil-porosity and biological activity, improving soil structure by increasing the amount of organic matter, and finally by increasing the water storage capacity of the soil. (Eppink, 1984:74)

These natural factors which induce erosion can be strongly influenced by human interventions. For example clearing of the natural vegetative cover can lead to a rapid increase in erosion, especially in the case of mechanical clearing. (Lal, 1985:247) The land use after clearing also has strong effects on erosion; soil loss from pastures and perennial crops is about the same whereas under annual crops the soil loss is about eight times as high. (de Groot, 1994:3) Crops which provide a continuous ground cover lead to less erosion than crops which demand annual seedbed preparation. Crop rotations and sequences also greatly influence the amount of erosion. Generally it can be stated that the way in which crops are grown is more important than which crop is grown. Providing a continuous vegetative cover is an important management measure to reduce erosion, as is the application of mulch. (Lal, 1985:248) Next to cropping patterns, the character of land tillage is the most important human intervention with respect to inducing erosion. Furthermore, cultivation on terraces, construction of sediment catchers and drainage all can aid in the prevention or reduction of erosion. (Eppink, 1984:75)

2.4 Effects of erosion and conservation measures

Erosion can be seen as a transportation of soil particles from their original location to another site. This transportation process affects all the places the particles pass through, from their original location until their final destination. Section 2.4.1 discusses the effect of erosion on the site where the erosion occurs, while the next section indicates some effects on the environment around the actual erosion site. Section 2.4.3 then discusses factors which affect the adoption of measures to reduce the occurrence of erosion.

2.4.1 On-site effects

The on-site effects of erosion on agricultural land consists of decreased productivity and increased production costs, both related to a loss of soil and soil structure. Yield losses are caused directly as well as indirectly by erosion, even before less fertile sub soils are exposed. Erosion reduces yields directly via poor seedling establishment, waterlogging and crop burial.

Indirectly erosion affects crops through a loss of essential nutrients and organic matter, moisture deficiency and a general deterioration of the structure of the soil, as well as by reducing the efficiency of inputs. (Lal, 1985:248, Walker, 1982:690) Yield loss is the most often mentioned on-site effect of erosion, but other damages also occur. Examples are higher fertilizer application-rates, since parts are washed away by run off water and accumulation of stones at the field which have to be collected, thus increasing production costs. (Lutz, et al., 1994:9)

The wide-spread occurrence of erosion has led to a general assumption that productivity is declining in major crop-producing areas. A number of reservations has to be made with respect to this postulate. In the first place the rate of soil generation is not known for most areas, the often cited number of ten tons per hectare, per year is not very reliable, as indicated before. Secondly, the use of average rates of soil loss ignores the concentrated character of the problem. Thirdly, there is no empirical established relation between productivity and topsoil loss. Finally, technical change might be able to compensate for the losses of productivity by soil loss. Statements about the impact of erosion on productivity can therefore only be made with a certain degree of uncertainty. (Miranowski, 1984:61) The principal problem with establishing a relation between erosion and productivity is the great number of interrelated factors determining agricultural yields. In order to assess the effect of erosion, its effects have to be separated from other factors influencing yield, like for example climate. Several studies found that soil loss only accounts for a limited part in yield variation. (Easter, 1975) The effects of erosion can also be masked by other factors, like technological changes and more efficient input use. Next to this, the indirect effects are particularly hard to measure since they are cumulative, with effects sometimes showing only after an extended period of time. (Lal et al., 1989:61)

2.4.2 *Off-site effects*

Erosion also leads to damages in the environment surrounding the erosion-site. Off-site effects of erosion include water pollution and eutrophication, siltation of reservoirs, waterways and harbors, disruption of stream ecology, flooding and increased water treatment costs. (Lal, 1985; Midmore et al., in print; Lal, 1985; de Groot, 1994; Pimentel et al., 1995) Finally, erosion also produces an externality for future generations by reducing the capacity for agricultural production. (McConnell, 1983:83)

2.4.3 *Conservation measures*

For the prevention and offsetting of erosion-effects both biological as well as mechanical measures can be used. In general biological measures are more effective and economic than engineering techniques of land forming. (Lal, 1985:248) A number of factors influence the adoption of conservation measures. (see Ervin and Ervin, 1982; Walker and Young, 1986; McConnell, 1983; Barbier, 1990; Cárcamo et al., 1994; Walker, 1982; de Groot, 1994)

An often mentioned factor influencing the adoption of conservation measures is the cost of investment. In the short term the financial possibilities of the farmer, like off-farm income or credit, are important determinants of the implementation of conservation measures. But, since it concerns a long term investment, discount rates, planning horizons and attitudes towards risk also play a role. Next to this, output and input prices affect the adoption decision. For example, subsidizing of inputs might encourage the substitution of lost soil by inputs like fertilizer. On the other hand, if conservation measure allows the farmer to shift to higher value crops, he might be more inclined to adopt them. Often farmers are unwilling to adopt conservation measures since investment costs make them seem more costly in the present than conventional practices. In other instances the savings which can be obtained with the shift to conservation practices are simply not worth the investment.

Technical improvements can discourage soil conservation if a decrease in soil fertility is masked by an increase in yields resulting from the technological changes. In fact however, a technological improvement increases the costs of erosion, if measured in forgone output and assuming that the technological change is exogenous, i.e. not induced by the erosion problem. (Walker and Young, 1986:84) Soil quality can also affect adoption of conservation measures; on fertile soils there are fewer incentives for conservation since production is less affected by erosion. Other factors that influence the adoption of conservation measures are insecurity of land tenure, and personal factors, like education or ethnicity.

Probably the most important factor for adoption of soil conservation measures is perception of soil loss and awareness of the consequences for production. Interesting in this respect is the result from a study by Midmore et al. (1996) which shows that farmers' perception of the seriousness of erosion increases with the distance from their farm. Empirical data on the incentives at the farm-level for soil conservation are scarce for developing countries, and no studies exist which incorporate risk in their analysis of soil conservation for these countries. (Cárcamo, 1994:258) It should be kept in mind that, given the uncertain effect of erosion on productivity as discussed before, conservation measures might not be desirable, neither from a farmer's, nor from society's point of view. (Lutz et al., 1994:4)

2.5 Measurement of erosion: the Universal Soil Loss Equation

The *Universal Soil Loss Equation* (USLE) was developed by Wischmeier and others in the early sixties, and belongs to the first generation of soil erosion models. It was designed to predict soil erosion on the basis of easily measured meteorological data and soil characteristics, independent of geographical location. The USLE is totally empirical, i.e. not based on an analysis of the processes of soil erosion. (Vahrson, 1991:43) The equation was developed on the basis of a statistical analysis of a large amount of empirical data, obtained from an area in the Midwest of the United States. Despite the limitations of the USLE and the availability of more sophisticated models, the USLE is still widely used. Its continued popularity can mainly be ascribed to the ease of its use. (Eppink, 1994:83) The USLE includes all four erosion-factors discussed in section 2.3: precipitation, soil, relief and vegetation. Figure 2.1 summarizes how the various erosion-factor enter the equation. In mathematical terms the USLE is stated as:

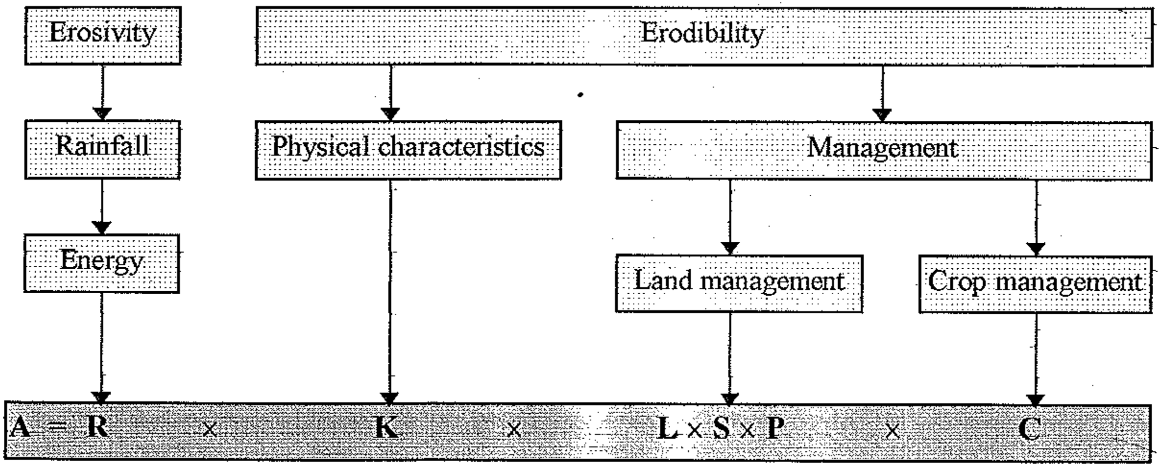
$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \tag{2.1}$$

with: A	=	estimated loss of soil	($t.ha^{-1}$; $Mg.ha^{-1}$)
R	=	rainfall factor	(erosion-index unit: $MJ.mm.ha^{-1}.h^{-1}$)
K	=	erosion sensitivity factor of the soil	($t.ha^{-1}$ per erosion index unit; $Mg.MJ^{-1}.h.mm^{-1}$)

L = length of slope factor (no dimension)
S = gradient of slope factor (no dimension)
C = crop and management factor (no dimension)
P = erosion control factor (no dimension)

The first four factors (R, K, L, S) are fixed in the short term and determine the potential loss of the soil. The last two factors (C, P) can change in the short run as a result of land use. In the long run all factors are variable, for example slope length can be influenced by building terraces. (Eppink, 1984:85) The variables of the equation can be arranged in a basic equation and subsidiary factors. The basic equation determines the soil loss under standard conditions on a specified reference field. The subsidiary factors adjust the outcome of the basis equation for the circumstances which differ from the standard situation.

Figure 2.1: Erosion-factors included in the USLE



Source: adapted from Hudson (1973)

2.5.2 *The basic equation*

The basic part of the equation consists of the first three elements of the USLE:

$$A = R \cdot K \tag{2.2}$$

After determining the soil loss (A) and erosivity of the rain (R) the erodibility of the soil (K) is defined. The soil loss is measured in tons per hectare (or an equivalent measure). (Hudson, 1978:182)

The *rainfall factor, R,* quantifies the erosive power of a shower. It consists of the sum of the erosion index over the period of the shower. The erosion index is defined as a product of the kinetic energy of the shower with the maximal precipitation intensity measured over a period of

30 minutes. The *R* factor reflects the combined effect of splash-erosion and turbulence of run-off on the transport of soil-particles. There are a number of alternative formulas to determine the *R* factor. Some are based on more easily measurable rainfall characteristics, while others consists of more extended formulas. (Eppink, 1984:86) The *erodibility factor, K*, is then defined as the increase in soil loss for each additional unit of the erosion index, under standard conditions, i.e. $L = S = C = P = 1$. By determining the soil loss during showers with different R values, an estimation of K can be obtained. (Eppink, 1984:91)

2.5.3 Subsidiary factors

The remaining four variables of the USLE can be considered subsidiary in the sense that they consist of ratios adjusting the basic equation for circumstances different from the standard conditions. (Hudson, 1978:182) The *length of slope factor* (*L*) is specified as the ratio between soil losses on the length of the slope under consideration and the standard slope length, keeping all other variables constant. The length of the slope is defined as the distance from the point where the run-off starts until the point where either the slope declines in such away that sedimentation occurs, or where the drainage reaches a well defined drainage system. The *slope gradient factor (S)* is defined as the ratio between soil loss of the gradient under consideration and the losses with a standard gradient of 9 percent. The USLE assumes that the slope has an uniform shape, irregular slopes therefore have to be divided into segments. The formula is only calibrated for slopes between 2 and 20 percent. Alternative ways of calculating *S* exist, especially for irregular slopes. (Eppink, 1984:95) Often a combined factor for the length and gradient of the slope (*LS*) is used. Especially in the case of mechanical conservation measures the length of the slope is determined by channel terraces, thus gradient and length are interrelated, making a single factor to account for both effects more convenient.

The last two variables in the formula can be influenced in the short run through the type of land use. The *crop and management* factor (*C*) is determined as the ratio of soil losses on the plot under consideration to a plot which has been fallow for at least two years, all other variables being equal. The standard value of *C* is 1 and is obtained by leaving the land fallow for an extended period, burning all humus, and keeping the ground clear from weeds by cultivation along the slope. The average *C* value for a cropping cycle is determined by averaging *C* factors of different growth stadia, using *R* values as a weight. (Eppink, 1984:99) In general it can be expected that *C* values will be fractions of 1, considering the extremely unfavorable reference point. (Hudson, 1987:182) The value of the crop factor varies most between the numerous applications of the USLE, due to distinct differences in agricultural practices. (Hudson, 1978:192)

The last variable of the USLE, the *erosion control* factor (*P*) is defined as the ratio of the soil loss on a cultivated land unit with supporting measures, to the loss on the standard unit under equal circumstances as far as the other variables are concerned. (Eppink, 1984:105) The expected value can again be expected to be a fraction of 1, since the reference situation leads to the highest possible rates of erosion. (Hudson, 1978:182)

2.5.4 *Use and limitations of the USLE*

The USLE can be used for estimation of yearly soil losses as a result of surface erosion, as a guideline for design of soil conservation measures and for estimation of the reduction of soil loss as a result of conservation measures. (Eppink, 1984:111) However, mainly due to its empirical character with lack of analysis of underlying processes, it can only be used with extreme caution outside the original area for which it was developed. Both overestimations as well as underestimations of the real amount of soil loss are reported in the literature. Vahrson and Cervantes (1991:116) conclude in a study of the Puriscal area, Costa Rica, that especially on slopes far out of the range of 2 to 20 percent, the USLE overestimates the amount of erosion. Cuesta (1994:42) also indicates on the basis of various sources that the USLE overestimates the amount of erosion. A German study on the other hand reports an underestimation of real erosion by the USLE. (Bork, 1991b:13)

The USLE has several limitations. Despite its simple appearance, in practice the determination of especially *R, K, C* and *P* proves to be hard. (Eppink, 1984:110) Due to its statistical base, the equation only calculates average erosion. Effects of single storms and changes in the surface between storms are ignored by the model, and therefore real erosion might be much higher than calculated. (Bork, 1991b:12) The USLE also does not include sedimentation, and thus has to be adjusted for watersheds where erosion as well as sedimentation take place. Furthermore, the effects of types of erosion other than rill, sheet and splash erosion have to be determined separately. (Eppink, 1984:111) Another problem with the use of the USLE is the lack of data necessary for an empirical estimation of the parameters. (Sanchez and Alvarez, 1991:146, Bork, 1991b:12) Finally, the factors in the formula might interact or change in time. (Lal, 1985:243)

Despite the fact that there are significant doubts about the applicability of the USLE, especially in humid tropical areas which differ in important respects from the area for which the formula was developed, the equation is still widely used. This can be accounted to the fact that at present no alternatives exists which are well adapted to the specific conditions in tropical areas. (Vahrson and Cervantes, 1991:116)

Chapter III

MODELING LAND USE AND LAND DEGRADATION

3.1 Introduction

The processes of land degradation and erosion have been discussed in the previous chapter from a technical, bio-physical point of view. Land and crop management can be considered the most important variables for controlling these processes; in the USLE these are the only factors which can be influenced in the short run. Considering this importance of land use with respect to land degradation, the analysis has to be extended beyond the physical processes to include the factors which determine land use patterns. Only then effective policies directed at reducing or preventing land degradation can be designed. In order to achieve this necessary broad understanding of degradation processes economic land use models should be combined with bio-physical models which quantify the effects of land use activities on land quality and productivity.

In response to the above considerations various efforts have been made to integrate bio-physical models with economic land use models. The result vary with respect to the details and structure of both the economic as well as the bio-physical components. First of all models analyzing land use from both an economic as well as a biophysical perspective are developed for a wide variety of reasons. Barbier (1996) uses a detailed land use model in order to distinguish the effects of population driven agricultural intensification form market driven intensification. This in order to test the validity of Boserup's theory that population growth leads to an intensification of production systems. Other models focus at assessing the attractiveness of adopting conservation measures, like Pagiola (1995), Walker and Young (1986), Cárcamo et al. (1994). More general oriented models directed at an analysis of the effects of land degradation on cropping patterns have also been developed (see for example Miranowski, 1984; Parton, 1996; McConnell, 1983; Orazem and Miranowski, 1994). And finally, large models have been developed to support land use decisions by organizing the massive amounts of relevant data. An example is NELUP[1], which includes extensive modeling of biophysical as well as economic relations and their interactions.

Next to their goals a number of other characteristics can be used to describe land use models. In the first place models differ with respect to the *level of analysis* which is used, varying form analysis at the field level to nationwide modeling. Then the adopted *modeling method* differs between models, with various mixtures of approaches occurring. Furthermore, the treatment of *time* is important due to the presence of time-lags in processes of land degradation and erosion. Finally, a wide diversity exists with respect to the amount of details on *economic behavior and conditions* as well as with regard to *bio-physical details.* The following sections of this chapter discuss the approaches found in the literature with respect to all the above characteristics of land use models which use both an economic as well as a biophysical perspective.

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[1] NELUP is the acronym of the Natural environment research council-Economic and social research council Land Use Programme, a modeling system of the River Tyne catchment in Nothern England.

3.2 Level of analysis

Various *levels of analysis* are adopted in land use models. Factors determining the chosen level are the objectives of the study, institutional arrangements, and biophysical conditions. Most studies focus their analysis on the farm-level (see for example Orazem and Miranowski, 1994; Miranowski, 1984; McConnell, 1983; Cárcamo et al., 1994; Walker and Young, 1986; Kramer et al., 1983). The prevalence of farm-level analysis is a result of the fact that land use decisions are not taken by governments or planning agencies, but by the direct users of the land, the farmers. These decisions are based on the objectives, production possibilities and constraints faced by the farmers, all of which can only be influenced indirectly through agricultural policies. However, if resources are not managed at the farm level but at the community level, like for example in parts of West Africa, the village level is a more appropriate level of analysis than the individual farmer (Barbier, 1996).

Other studies derive their unit of analysis not from the decision-making level but from the goal of their modeling exercise. The study of Campbell et al. (1992) is directed at optimizing agricultural land use in the island nation of Antigua, and therefore takes the whole country as their unit of analysis. Furthermore, instead of the socioeconomic organization of an area, biophysical considerations can also be the point of departure for the selection of the level of analysis. This can vary from using land types as the unit of analysis (Pagiola, 1995) to modeling a river catchment area (O'Callaghan, 1995), which is a natural unit of analysis for hydrology, but often does not coincide with administrative units. The latter characteristic might complicate the execution of policy recommendations.

Considering the fact that in most cases decisions about land use are taken at the farm level, the (dis)incentives faced at this level should be incorporated in the analysis in order to grasp the dynamics of land use patterns and formulate effective policies. At the same time however, the off-site effects of erosion and land degradation, like siltation of water reservoirs, call for a more aggregate unit of analysis. If it is also taken into account that policies are easiest to implement if the research area corresponds with an administrative unit, an intermediate level of institutional organization, like a county, seems the most appropriate level of analysis. In order to capture the incentives at the decision-making level, representative farms will have to be modeled within this larger framework. Such an approach enables the study of the incentives at the farm level, while at the same time providing a way to analyze the interactions between farms as well as the off-site effects of land degradation processes.

3.3 Modeling methods

After having selected the level at which the analysis takes place a modeling tool has to be chosen. A wide range of methodologies for the analysis of land use patterns can be found in the literature. Four often used approaches are *cost benefit analysis*, *linear programming*, *econometric models* and use of *optimal control* theory. Several models include more than one approach, for example relations used in linear programming are estimated econometrically.

All modeling approaches include an assessment of the cost and benefits of the alternative land uses, however cost benefit analysis refers to a specific tool to decide between various alternatives. The selection is based on an evaluation of the costs and benefits associated with each alternative. In order to be able to compare costs and benefits occurring at different points in time, the stream of net revenues is discounted towards the present, resulting in the net present value of the income stream. The alternative with the highest net present value is then selected. The study of Pagiola (1995) focuses at the net present value of the incremental return which can be obtained from a soil conserving practice compared to a currently used land use activity. In case the net present value of these incremental returns are positive farmers could be willing to replace currently used techniques with the soil conserving practices.

Linear programming is an often used method to find an optimal land use pattern. It can be defined as being concerned with finding the "optimal allocation of scarce resources among competing activities, under a set of constraints" (Beyers and Partners, 1993:331) A linear programming model consists of a linear objective function which either has to be maximized or minimized, subject to a number of linear constraints. Only continuous decision variables are allowed in the constraints and objective function[2]. The constraints consist of available production technologies, restrictions with regard to the availability of resources and restrictions representing additional production-aims, like for example the need for a minimal amount of food. (Campbell et al., 1992:540) The result of linear programming land use models is limited to indicating the theoretically optimal allocation of land, it does not indicate how this should be reached. In order to analyze the way in which the allocation of land can be improved, the links between farm household decisions, policies, markets and services have to be studied. (Schipper, 1996:115) Inclusion of these links will necessitate the use of non-linear relationships and thus the use of non-linear study methods. As a result linear programming models are not fit for explaining actual decision-making processes, although they are useful tools for exploring potential attractive land use patterns. Through the analysis of various scenarios, i.e. allocations under different sets of assumptions, an insight in possible effects of policies can be obtained.

Linear programming models allocate resources on the basis of one single objective function. In practice however, decision-makers simultaneously pursue different, often conflicting, goals. For example a farmer can strive for food security, cash-income, and long term viability at the same time. Linear programming cannot be used to address these issues and other methods should be used. Multiple criteria analysis calculates the contribution of each option the decision-maker faces to each goal and also provides an insight into trade-off between the different goals. Examples are goal programming, multi-objective programming and compromise programming. (Schipper, 1996:112) Next to a single objective function linear programming models also require fixed coefficients. However, at high levels of aggregation, like the national level, the quantity of inputs and outputs demanded and produced will affect their prices. Unless non-linear relations can be linearly approximated, linear programming is not suited in these situations. (Schipper, 1996: 114) Models based on econometric estimates or optimal control theory do not require linearity of all relations included in the model.

Econometrics involves the use of statistical and mathematical methods to estimate the parameters of the land use model (Maddala, 1992:1) Reliable estimates however require a large and detailed

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[2] In case variables have to be included which allow integer values. mixed integer programming has to be used.

database, often not available at the farm level. Next to the data requirements, econometric estimates are by definition based on historical data and therefore cannot include new production technologies. (Schipper, 1996:115) An example of the use of econometrics in land use modeling is the study of Orazem and Miranowski (1994). In this study the observed acreage allocations are assumed to reflect the beliefs farmers hold with regard to their soil capital and the effect of crops now and in the future on this soil capital. Using a cross-sectional time series database the structural parameters of a model for acreage allocations is estimated. Econometric methods can also be used in combination with linear programming. For example in NELUP some of the input-output coefficients are econometrically estimated (Moxey et al., 1995:22).

A fourth approach to modeling land use in relation to land degradation processes which can be distinguished in the literature is optimal control, or dynamic programming. As with linear programming these approaches also optimize an objective function but the solution method is entirely different. Linear programming consists of a systematic search among the input-output relations for a combination of activities which optimizes the objective function, subject to a number of constraints. Optimal control models on the other hand, aim at the optimal time path of each control, or choice, variable in order to maximize the objective function. (Chiang, 1992:3) The optimal time paths are determined with the use of the Hamiltonian function associated with the optimization problem at hand. (Chiang, 1992:169) In contrast to linear programming the optimal control approach does not require linearity of all model-relations. However, optimal control models require continuos functions because the first order conditions of the optimization are derived through differentiation of the Hamiltonian. An example of an optimal control model is the study of McConnell (1983). He focuses on the intertemporal path of the utilization of the soils from a private as well as a social perspective, i.e. to what extent the soil will be exhausted or conservation measures will be adopted.

3.4 Time

One of the fundamental characteristics of land degradation is the occurrence of time-lags. First of all the effects of degradation do not appear until long after damaging activities have taken place. (Parton, 1996:376) Furthermore, (large) time-lags also exist between the moment at which conservation measures are taken and the time at which their effects become apparent. The concept of time should thus be dealt with explicitly in the modeling exercise in order to capture the dynamic aspects of land degradation issues. Many studies use the net present value at the start of the planning horizon as a way to compare costs and revenues occurring at different points in time. In this way the attractiveness of conservation measures is assessed (Pagiola, 1995), or the effects of land use on erosion are determined (Cárcamo et al., 1994). This type of modeling results in a single optimal cropping pattern for the whole planning period.

Another approach to the incorporation of time is the use of multi-period models. These can either be recursive, i.e. solved for one year at a time with the results of period t affecting the available resources in period $t+1$. or they optimize over the whole planning period in a single model run. Considering the intertemporal productivity impacts of soil degradation, multi-period models seem more appropriate than comparison of the net present value over the whole period. The way in which the effects of erosion are dealt with varies considerably. The recursive models determine the effects of land use during period *t* on soil quality, after which the production functions in period *t+1* are adapted to reflect these effects (Barbier, 1996; Parton, 1996; Kramer et al., 1983).Each year the optimal land use pattern is selected which optimizes the income for that single year, *given* the available soil quality in that year. After this selection its effect on erosion is determined which is then used to calculate the resources available for production in the next period. Due to an absence of a link between the optimization in a single year and its effects on future productivity this type of model is only able to counteract land degradation which has already occurred, but cannot prevent it from occurring.

In order to have current production decisions influenced by their effect on future productivity a multi-period planning horizon has to be optimized in a single model run. Miranowski (1984) uses a multi-period model of fifty years with a penalty function which "reflects the productivity foregone after fifty years resulting from soil loss during the first fifty years. Because a penalty is incurred at the end of the first fifty years, changes are induced in crop management practices during the first fifty years" (Miranowski, 1984:62). Although this approach allows for an adjustment in present cropping patterns in response to effects on productivity after the planning period, the consequences of land degradation in the first fifty years are not taken into account. Furthermore, as a result of discounting, the productivity losses occurring beyond the fiftieth year have to be considerable in order to affect the decisions in the planning period. The last difficulty relates to the valuation of the productivity losses after the end of the planning horizon. The costs of erosion are closely related to the cultivated crops, assumptions about the cropping pattern from the fiftieth year into perpetuity are thus necessary.

An alternative approach to the incorporation of the effects of land use on future productivity is offered by the model developed by Barbier (1996), which combines a recursive approach with the multi-period method. The planning period of this model comprises three years. Within this period the effects of land use activities on land degradation are accounted for through equations which calculate the total effect of the land use in that year on three indicators of land degradation. The soil quality in the following year is then adapted for these effects. The objective of the model is to maximize the net income and leisure over all three years. Through the adaptation of soil quality within the planning period, land use decisions in the early years take their effect on productivity in later years into account. The results of this three year optimization is then used as input for the recursive part of the model. On the basis of the land use pattern for the first year as well as stochastic components included in the model, the availability of resources in the second year are determined. Given these resources land use is again optimized over a period of three years. In this way the model can be solved for any number of years, while looking three years ahead when land use patterns are determined. In contrast to the fully recursive approaches this model incorporates the effects of land use on a maximum of two future years. However, given the time-lags associated with land degradation a planning period of three years is probably insufficient to prevent degradation from occurring.

3.5 Economic behavior and conditions

A fourth attribute which can be used to distinguish land use models is the amount of detail with regard to economic behavior and conditions. The level of analysis to a large extent determines the economic relations included in the model. For example, the exchange of labor between farms cannot be included in a farm-level model, since this type of model by definition includes only a single farm. Land use decisions are taken at the farm level. In order to capture the dynamic aspects of land use patterns the relations in a model should to a reasonable extent reflect the responses at this level.

Most economic land use models assume that farm households are concerned with maximization of income. This assumption is reflected in linear programming models by maximization of an objective function consisting of the net revenue of agricultural production. Cost-benefit approaches reflect this presumption by selecting the option with the highest net revenue. However, a focus on land use patterns which render the highest income stream does not adequately reflect the environment in which land use decisions are taken by households. Other factors also have to be considered, like considerations of risk, availability of capital and land tenure arrangements.

Despite the importance of risk for production decisions most studies ignore its effect on land use decisions. Exceptions are for example the studies of Cárcamo et al. (1994), Kramer et al. (1983) and Barbier (1996). Ignoring the attitude of farmers towards risk by assuming that farmers simply maximize profits implies the assumption that farmers are risk neutral. Yet, substantial evidence exists that farmers are risk averse (see for example Kramer et al., 1983; Ellis, 1988). This is even more so for farm households in developing countries. A large part of peasant households are barely living above subsistence levels, any fluctuation in their income can result in a change form survival to starvation. Greater variation in climatic conditions in tropical zones with all its repercussions on production, imperfections in infrastructure causing an increased instability of markets, and poverty all contribute to an avoidance of risk. (Ellis, 1988:80)

In the light of the previous considerations minimization of the variance in income instead of maximization of profit can be considered a primary objective of farm households. In order to capture the importance of a stable income (adaptations of) the MOTAD (Minimization Of Total Absolute Deviation) procedure is often used. In the case of Target MOTAD selection of land use activities is directed at achieving a relatively secure level of income. In this approach the level of income, while taking into account variability in yields and prices, has to exceed a specified target income level. (Barbier, 1996:15) Research by Cárcamo et al. (1994) indicates that inclusion of risk consideration can have a considerable impact on the optimal land use pattern. Their findings in the first place suggest that higher levels of income are accompanied by increased variations in income. In the light of the risk-aversion of farmers, maximization of income without taking this increased variability into account does not adequately reflect the decision-making at the farm level. In the second place, Cárcamo et al. found that soil conserving measures are associated with higher levels of risk. Adoption of soil conserving measures might thus be hampered by risk-aversion of farmers.

Next to income maximization and risk considerations two other economic factors with regard to the decision-making at the farm level have to be distinguished: capital and land tenure. Capital, both in terms of cash as well as capital goods, affects land use decisions. Cash constraints hamper the investment possibilities of farmers. Examples of models which include restrictions to the availability of capital are Cárcamo et al. (1994) and Barbier (1996). Associated with limits on cash availability the possibilities for credit and the conditions on which it can be obtained, like interest and repayment period, should be included in the analysis. Another important aspect of capital is the existence of specialized capital goods in relation to shifting between land use activities. Almost all land use models assume that no costs are associated with the transition between different land uses. If land use activities are very similar this assumption of costless shifts is valid. However, in the case of very dissimilar land use activities adjustment costs compose an important part of the decision-making process. In order to take adjustment costs into account the following elements should be incorporated: specificity of on-farm capital goods, investment requirements for new capital goods, possibilities for disposing of the redundant capital stock and the decreased value of the existing capital stock in relation to its vintage. (Norton and Santaniello, 1996:5) In case these adjustment costs are ignored the flexibility of the farms with respect to land uses will be overestimated.

Land tenure arrangements are another important element in the land use decisions of farm households. The type of land tenure arrangements affects the productivity as well as the incentives for soil conserving measures. In general it is assumed that private ownership of land is to be preferred to sharecropping, state or communal ownership. In the first place because with private property the farmer will fully benefit from efforts to increase productivity or to maintain soil quality. With sharecropping part or even all of the benefits might accrue to the landowner, reducing the incentives to invest in productivity increasing measures. A second issue is the problem of supervision of labor. In case the worker of the land is not the owner some form of supervision has to be imposed in order to guarantee that the work is done properly. Especially in agriculture with its multitude of tasks of which the results often are not visible until after at least a couple of months, supervision hardly ever constitutes a good substitute for the incentives resulting from private property. (Gillis et al., 1987:486)

Next to the income and supervision arguments entitlement to the land also affects the possibilities of farmers to obtain credit. Official ownership of the land is often needed as collateral in the formal lending sector. Absence of a title to the land can force a farmer to borrow on the informal market with high interest rates or to refrain from borrowing, which can have serious consequences for the opportunities to invest in the farm, including investments in soil conserving measures. However, an absence of private rights to land does not imply that no system of secure entitlements to land exists. Well functioning communal property systems are able to effectively sanction the use of land by community members. Furthermore, private property does not guarantee a sustainable use of the land, nor does it solve the problem of external effects of land use activities. (Pearce and Warford, 1993:249)

Most often the issue of the type of ownership of agricultural land is ignored by land use models. Examples of exceptions are the studies of McConnell (1983) and Barbier (1996). McConnell translates three types of land tenure arrangements into differences in planning horizon. Using this as the only distinction between the tenure arrangements he finds no difference in the rate at which the soil will be exhausted. In the study of Barbier the village level is used as the unit of analysis. First of all to incorporate the fact that in West Africa communities manage many natural resources. Furthermore, constraints like labor, capital and risk are exchanged between farmers and should therefore not be imposed at the farm level. Finally, land degradation occurs at a more aggregate level than the individual farm, thus calling for a higher level of aggregation.

The majority of the concepts discussed above refer to economic issues at the farm level. At higher aggregation levels the interaction between farms also has to be incorporated in the modeling exercise. For example in regional models a labor market should be defined. Farm households not only compete for available labor, especially during peak periods, but can also supply labor to a local labor market. Furthermore, at higher aggregation levels it can no longer be assumed that production will not affect prices. Supply and demand conditions will have to modeled for inputs as well as outputs of the farms.

3.6 Bio-physical details

The last component of agricultural land use models which has to be discussed is the bio-physical part. In general it can be stated that the bio-physical components are related to the economic part of the models through their effect on the production levels. This relation is formalized by the production function. Aspects included in the production function are the number of different crops, crop rotations, technologies, requirements in terms of inputs and soil quality.

The number of crops included in the various models varies from just one to a wide rang of possible land uses. For example NELUP offers cropping activities, livestock systems and forestry as potential activities to a linear programming model. Not only the land cover type for the product produced is used to distinguish activities, but also the intensity with which production takes place; grazing of sheep with 1 ewe per hectare is thus distinguished form 2 ewes per hectare. (Moxey et al., 1995:27) Generalizing it can be stated that the approaches using linear programming include a larger number of land use activities than the other modeling approaches. This is a result of the fact that linear programming models can only select land uses from the range of activities with which it is presented. Thus if only a small number of activities is offered, the possibilities of forecasting land use patterns will be limited.

Despite theoretical advantages of including a large number of land use options the number of activities is limited by model size restrictions. In order to be able to include crops with a range of different intensities Barbier (1996) uses a type of linearized production function instead of defining the input-output coefficients for all possible crop-technology combinations. Total production of a crop in a given year and on a specific soil is determined by the number of hectares the crop with a specified amount of chemical fertilizer, the use of organic fertilizer, use of mechanical or manual cultivation, the organic matter deficit and the soil depth. This approach allows for the inclusion of larger number of potential land uses than would have been possible if they all would have been defined separately. As far as crop rotations are concerned different approaches are taken. Some models explicitly define all possible crop rotations as different land use activities, see for example Miranowski (1984). Other models define land use per period, sometimes in combination with the maximum area which can be occupied by certain crops (see Barbier, 1996).

Soil quality is an important part of all models which integrate economical with bio-physical approaches to land use. The effects of land degradation processes are translated into a soil of reduced productivity, causing a declining agricultural production. The characteristics used to assess the effects of degradation vary widely between the studies. The USLE is an often used measures of the effects of land use activities which only accounts for the soil loss as a result of sheet and rill erosion. (Miranowski, 1984; Cárcamo et al., 1994; Kramer, 1983) Most models translate the amount of soil loss into a change in top-soil depth. A production function is then defined in which top-soil depth is related to agricultural yields, thus quantifying the effect of land degradation to productivity. As has become clear of the discussion of land degradation in Chapter 2 degradation processes entail more than just top-soil-loss. EPIC is a model which describes crop yields in relation to water supply, temperature, soil compaction, soil depth, nutrient availability, aluminum toxicity and acidity. Barbier (1996) uses both an adapted version of the USLE as well as EPIC in order to quantify the effect of land use activities on land quality. Three indicators are included in the analysis: soil depth, soil organic matter and organic nitrogen. The NELUP model also uses EPIC to assess the effects of land use activities. The consequences of land use activities are furthermore determined in terms of changes in the hydrological balance, using the Système Hydrologique Européen (SHE). Finally the ecological effects of land use activities are captured through a sub-model which relates a change in land use activities to a change in species composition on each land class. (O'Callaghan, 1995:11)

Despite the dependence of agriculture on the weather conditions few models include this stochastic component. An exception is the model developed by Barbier. In this recursive model 'actual' outcomes of the land use decisions for each year are determined through a simulation of weather outcomes. The results in terms of total production and erosion are then used as the input for the next year. The stochastic character of agricultural yields is especially important in relation to the risk aversion of farmers.

Chapter IV

OBJECTIVES AND METHODOLOGY

4.1 Introduction

Land degradation due to unsustainable land use practices can cause significant losses of agricultural productivity. In the case of Costa Rica it has been estimated for the period from 1979 to 1989 that the annual productivity loss as a result of land degradation was somewhere between 6 and 13 percent of agricultural GDP. These rates of productivity losses can be assumed to affect the development of the economy. (de Groot, 1994:8) The preceding chapter has outlined the need for incorporating land degradation processes in economic land use models in order to capture the interaction between land use and soil degradation, and has discussed several ways in which this interaction can be modeled. The focus of this study is the development of a framework of analysis in which land use decisions are made while taking their effect on future agricultural productivity into account. Such a framework is needed for the assessment of the sustainability of potential and actual land use decisions.

The research has been carried out within the context of the Research Program on Sustainability in Agriculture (REPOSA). This research program has resulted in the development of the USTED (*Uso Sostenible de Tierras En el Desarollo*) methodology. USTED "integrates different simulation models (for example crop growth and farming systems) for a geo-referenced analysis (using a GIS) of land use scenarios" (Stoorvogel et al., 1995:6). Linear programming models of land use have been developed within this context to "evaluate the effects of external factors (e.g. labor availability and market prices) on land use at the sub-regional level." (Stoorvogel et aL, 1995:7) The land use model developed in the present study is based upon the Regional Economic Agricultural Land use Model (REALM), which forms a component of USTED.

This chapter starts with an overview of the structure of REALM, since many assumptions and constructions of this model have been adopted. Section 4.3 then discusses the objectives of the present study, in relation to the model structure of REALM. The next section gives a short outline of the model developed in this study. The chapter ends with a presentation of the methodology used for the analysis.

4.2 A Regional Economic Agricultural Land use Model

The objective function of REALM consists of maximization of economic surplus: "the difference between the value and the cost of production, including household and hired labor, plus off-farm earnings" (Schipper, 1996:124). A range of cropping and livestock LUSTs (Land Use System Technologies) is available for agricultural production. Each LUST describes a specific combination of a land unit with a land use type and a technology. These three elements specify the in- and output coefficients of each LUST. (Stoorvogel et al., 1995:6) The LUSTs comprise annual crops as well as perennial crops, with cropping cycles varying form just half a year to more than thirty years. Next to agricultural production within a sub-region, income can also be derived from off-farm work on banana plantations outside of the sub-region. Within the sub-region farm types are distinguished, in order to reflect the differences in terms of resource endowments which exist between farms .

REALM is a one period model with the months of the year as 12 sub-periods. In order to be able to compare the net revenues of cropping systems with different lengths, annuities are used to make the in- and outputs of crops commensurable. The model allows analysis at three levels; the level of individual land use activities (LUSTs), the farm type level and the sub-regional level. Optimization takes place at the sub-regional level through maximization of the economic surplus of the sub-region as a whole. The sub-region is defined so small compared to the rest of the country that it can be assumed that production will not affect prices. Constant prices can thus be assumed to exist in the modeling exercises. A drawback of optimization at the sub-regional level is the possibility of reduction of net income at one farm type in order to increase the income at the other farms and to obtain a higher regional income. The fact that farms aim at maximizing their own net income instead of regional net income is not incorporated in the model. Furthermore, the restriction towards maximization of net income is a gross simplification of the multitude of objectives and preferences of farmers and land owners. For example, risk aversion is not included, nor the effect of land tenure arrangements on agricultural production decisions. (Schipper, 1996)

The definition of REALM includes two measures of sustainability: a nutrient balance and a biocide index. The nutrient balance measures the effects of each LUST on the balance of nitrogen, phosphate and potassium in the soil. The second environmental indicator is a measurement of the toxicity of biocides used in agricultural production. It accounts for the toxicity of biocides used in the LUSTs, the quantity of toxic ingredients, as well as for the duration of the toxic components in the system.

4.3 Objectives of the study

The overall goal of the study is to develop a multi-period linear optimization model, which takes the effects of land use on future production possibilities into account: MERALM (Multi-period Economic Regional Agricultural Land use Model). To this end the following objectives have been formulated:

- incorporation of erosion
- formulation of a multi-period model
- endogenous determination of soil fertility
- assessing the need for a detailed differentiation between soil types

In addition to the two sustainability indicators included in REALM, erosion has been added as a third indicator. An assessment of the sustainability of agricultural practices has to include erosion, as it poses a wide spread environmental as well as agricultural problem; of the world's agricultural lands 80 percent is moderately to severely affected by erosion, while slight to moderate erosion is threatening another 10 percent of the agricultural land. (Pimentel et al., 1995:1117) The soil types in REALM are distinguished on the basis of fertility and drainage. Since the occurrence of erosion is to a large extent determined by the slope of the cultivated plot, a redefinition of soil types is needed in order to include erosion.

An important characteristic of land degradation processes is the existence of time-lags. Between damaging land use activities and the appearance of the effects of land degradation a long time can have lapsed. In order to adequately incorporate the consequences of degrading activities the time-span of the model thus has to cover several years. Furthermore, the existence of perennial crops also calls for a multi-year approach. These crops require a sacrifice of income in the first two to three years of their lifetime. The possibilities of bridging this period in which no returns are received influences the decisions to invest in perennial crops. These two concerns, time aspects with regard to the effects of land degradation and the investment period of perennial crops, are the rationale behind the second objective: formulation of a multi-period model.

Within the context of a multi-period model the relationship between periods in terms of land degradation should be considered. Land use in the early years can affect the fertility of the soil, and thus the production levels, in the remaining years of the planning horizon. Therefore, the effect of present land use decisions on future production possibilities has to be accounted for. These considerations are the motive for the third objective: endogenous determination of soil fertility. Only if the effects of land use activities can be determined within a single model run, these decisions can take their consequences for future productivity into account.

As stated before, to include erosion the slope of the land units has to be known. Theoretically a detailed subdivision in different slope classes is preferable to the use of an average slope, to increase the differentiation in terms of erosion. However such an elaborate distinction between soils requires extensive and expensive data collection. Next to this, increasing the number of soils leads to an 'explosion' of the number of variables in the model, which is an undesirable development in the light of model management and computer software limitations. In order to assess the necessity of specifying soils on the basis of various slope classes a model with six different classes is compared with a model with one (average) slope class for a major soil type. It can be hypothesized that an enumerated distinction of soils on the basis of slopes will lead to a more differentiated land use pattern. On strongly sloping soils erosion, and therefore loss of fertility will be extensive, promoting soil conserving land use at these sites in order to maintain productivity. If one average slope is used this distinctions between sites are not made and therefore a more uniform and erosive land use pattern will emerge.

4.4 A Multi-period Economic Regional Agricultural Land use Model

In order to achieve the objectives mentioned above MERALM has been developed. The planning horizon of MERALM spans 20 years, divided into 4 periods of 1, 2, 6 and 11 years. Each period is subdivided in 4 quarters in order to take the seasonal character of agricultural production into account. For each period the annuity of the net returns for each LUST are calculated in order to make crops with different production periods commensurable. The LUSTs are defined for 8 different soil types which are distinguished on the basis of fertility, drainage and slope-class. This definition of soil types allows for the incorporation of erosion as a third sustainability indicator, next to a nutrient balance and a biocide index.

The objective function consists of the maximization of the economic surplus at the sub-regional level over all four periods. Agricultural production within the region and off-farm work on banana plantations outside of the region provide sources of income. Within the sub-region farms can hire labor from other farms.

Production possibilities are affected by land use in earlier periods through the definition of soil fertility classes. Land use activities can cause a transition to a different fertility class in the following period by changing the nutrient balance as well as causing erosion. Since the optimization takes place over all four periods, land use decisions in earlier periods take the effect on production in later periods into account.

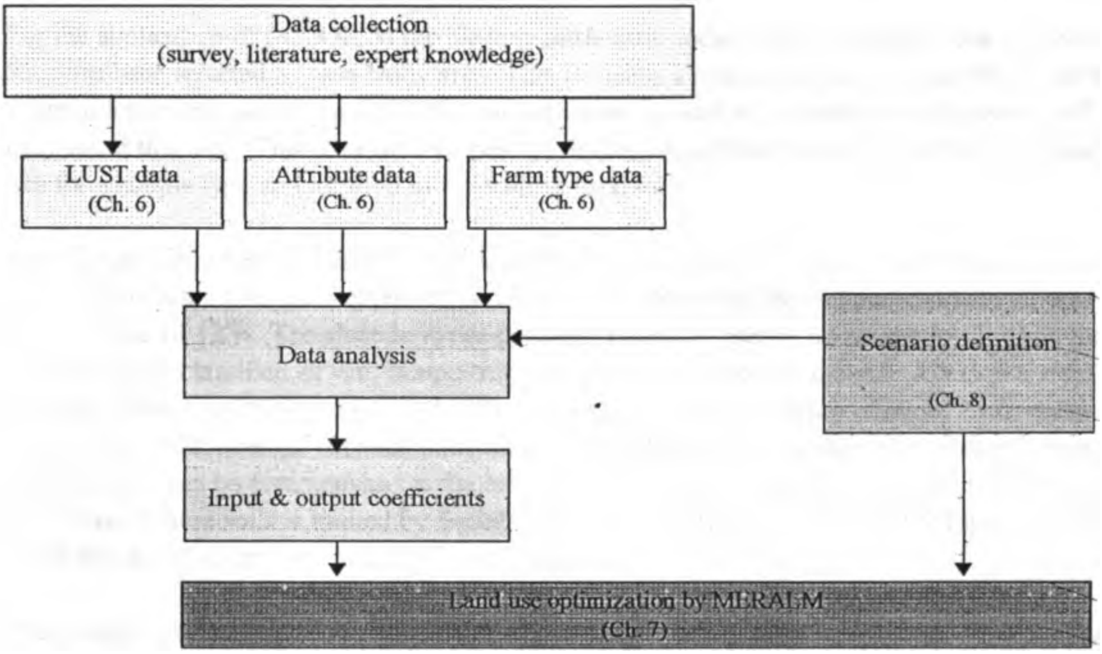
4.5 Methodology

The methodology adopted in this study is summarized in Figure 4.1. The land use activities or LUSTs stand at the basis of MERALM. From these LUSTs an optimal combination of activities is chosen in accordance with the objective of maximization of the economic surplus of the sub-region as a whole. Three types of databases are used: data of the LUSTs, attribute data and farm type data (Stoorvogel et al., 1995). These databases are constructed on the basis of surveys, literature and expert knowledge.

The LUST database contains information of land use systems with their technologies. For each LUST reference is made to a specific land unit and the operation sequences are described in quantitative terms (for a detailed discussion of the LUST database see Jansen and Schipper, 1995). Next to actual activities as observed in the field, the database also includes alternative land use systems which are constructed on the basis of expert knowledge. In- and output information in the LUST database is restricted to quantities used and produced. Additional information, like for example prices, are stored in the attribute database. This separation of quantities from their attributes facilitates the formulation of for example price scenarios, since only the attribute data files have to be manipulated. The combination of the LUST data with the attribute data result in the technical coefficients required by MERALM. In order to determine the optimal land use pattern the available resources have to be defined. The third data set contains data on labor availability for each farm type, as well as the size of available land units. Next to the information on the resources of the farm types the opportunities for plantation labor are specified in this data set.

The three data sets are analyzed with programs written in SPSS 6.1 for Windows and Dbase 5.0 for Windows. With Excel 5.0 the results are translated into the in- and output coefficients required for optimization with the linear programming software OMP (Beyers & Partners, 1993) These coefficients define for each period the necessary parameters for each LUST, as well as the availability of resources per farm type. The in- and output data files contain for example amounts of inputs needed per period; labor requirements per land use type, quarter and period; labor availability per farm type; and prices of products. Not all versions of MERALM use the same data set. The definition of scenario's determines the selection which is made out of the available data. At the same time the definition of scenario's also affects the structure of the linear programming model. That is to say that the various models can differ in used data, model structure or both.

Figure 4.1: Overview of the steps in the model optimization



Source: adapted from Schipper, 1996

Finally, the linear programming software OMP (Beyers & Partners, 1993) compiles the model on the basis of the scenario definition and the data files, executes the optimization and generates reports on variables and constraints. The result is an optimal land use pattern for each of the four periods included in the planning horizon.

The following chapter presents the case study area, the Neguev settlement in the Atlantic Zone of Costa Rica. The contents of the three databases as well as the assumptions on which they are constructed are described in Chapter 6. The next chapter discusses the mathematical details of the linear programming model MERALM. Finally, the results of three scenario's or model versions are described and compared in Chapter 8.

Chapter V

THE NEGUEV SETTLEMENT

5.1 The research area

For the application of MERALM the Neguev settlement, located in the Atlantic zone of Costa Rica has been selected as case study area. This choice is a pragmatic one: as a result of nearly ten years of intensive research by REPOSA an extensive data-set is available regarding soils and land use in this area. This data-set includes the figures needed for the incorporation of erosion, like for example type and location of the soils at each farm.

The Neguev settlement is located in the Atlantic Zone of Costa Rica, at the North-East side of the country (see Map 5.1). The settlement comprises 5340 ha and is located approximately between 83°33'E and 10°12'N. The altitude varies between 50 and 10 meters above sea level, while the climate can be classified as very humid tropical, without distinct dry months. Average annual rainfall amounts to 3630 mm (1972-1988) and the daily air temperature of about 25°C varies little (1976-1988: average between daily maximum and minimum temperature). Roughly two types of soils can be distinguished in the Neguev: low or non-fertile hilly soils and flat fertile soils. Use of these soils is limited by fertility and drainage. (Kuiper, 1996 and Schipper, 1996) More detailed description of the soils in the Neguev is given in Chapter 6.

The origin of the settlement is formed by the squatting of a *hacienda* called Neguev by landless agricultural laborers in September 1979. The *hacienda* was bought by the government and managed by the IDA (*Instituto de Desarollo Agropecuario*), who divided the area in farms of 10, 15 or 17 ha, with some further subdivisions being made later on. Officially farmers were not allowed to sell or rent their land until 1991. However, as a result of difficult farming conditions farmers did rent their land or sold the 'improvements'. The shifts in ownership since the start of the settlement have led to a much less homogeneous division of land nowadays, with an average farm size of 20 ha in 1996 compared to 13 ha in 1987. In 1996 about half of the farms is between 10 and 20 ha, a sixth is between 3 and 8 ha and sixth is larger than 30 ha, indicating that a process of concentration of land is taking place. (Kuiper, 1996) As a result of lack of data on the exact size and location of the farms[1] in the case study it has been assumed that the Neguev is divided into 307 farms, encompassing an area of 4236 ha of agricultural land. (Schipper, 1996:127)

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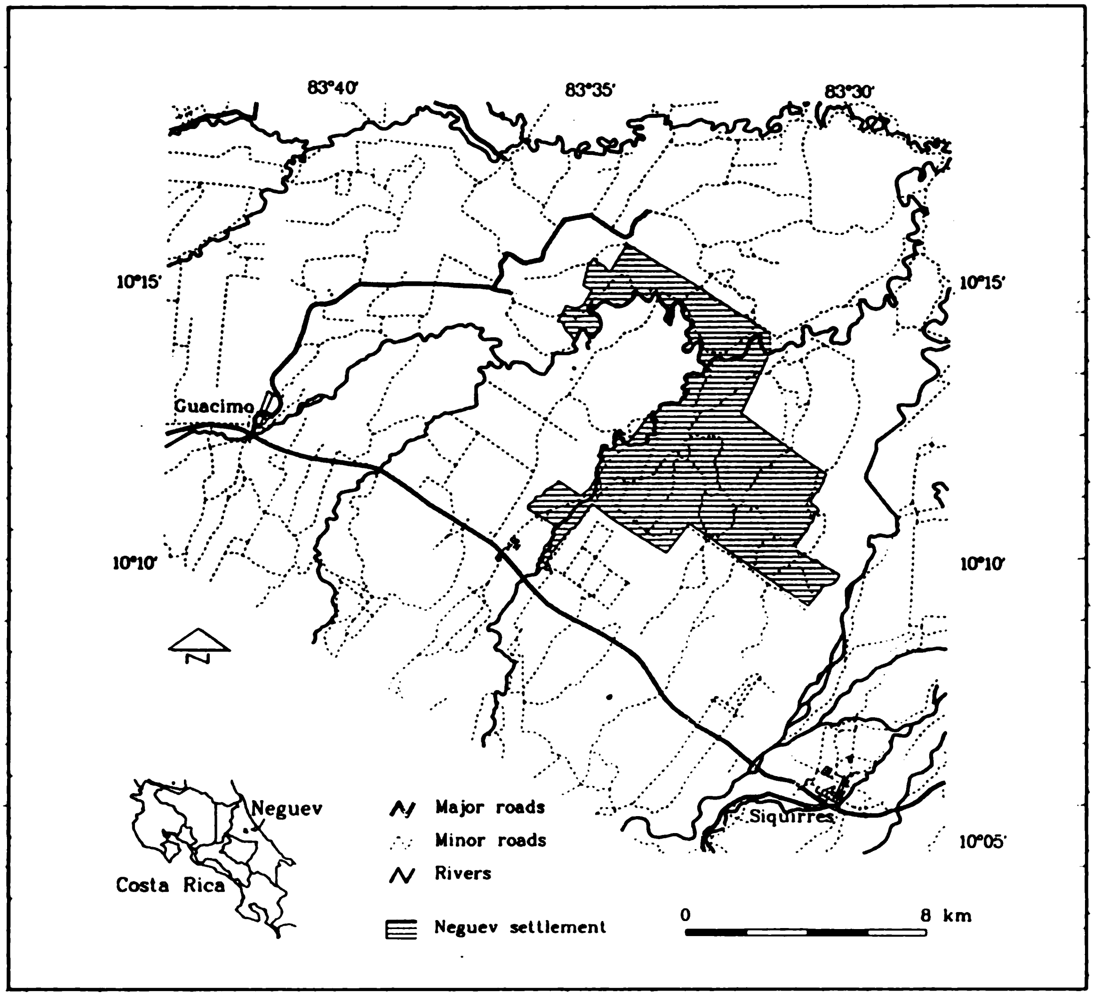
[1] According to IDA regulations farmers cannot own more than two parcels, whereas in practice various farmers own more. Next to this several (large) farmers do not fulfill other requirements for allocation of an IDA parcel, like for example lack of other means of obtaining an income than small farming. The official records thus do not correspond to the actual ownership situation in the settlement and cannot be used in the analysis.

Map 5.1: Location of the Neguev settlement in the Atlantic Zone of Costa Rica



Source: Schipper, 1996

The settlement is divided in two parts by the Parismina river. The Southern part is more isolated, only since 1992 bus services are available. At present all but the most remote parts of the settlement are provided with electricity, but still only the main center of Milano has telephone service. IDA has been actively involved in development of the settlement in the past: they provided land-titles, extension, credit and marketing assistance as well as a simple infrastructure of rural roads and small villages. At present their activities in the Neguev are mainly limited to assigning parcels and administrating ownership. (Schipper et al., 1995:92 and Kuiper, 1996)

5.2 Farming and land use

As a result of a structural adjustment program the price support policy for basic food crops, including maize, was abolished in 1988. This change in policy has had a considerable impact on the agriculture in the Neguev. Table 5.1 present land use in the Neguev for the 1985-1996 period.

The most important land uses in all years are forests, wastelands and pastures, with the latter increasing with almost 50 percent in 1996 compared to 1985. The area under crops has been steadily decreasing since the peak year of 1987.

If the areas of the most important crops are examined the declined importance of crops becomes even more clear (see Table 5.2). As a result of the abolishment of price support for maize, its area in 1996 is only a fraction of the area in earlier periods. Palm heart on the other hand, is the coming crop, showing a steady increase in area. The shift from maize to palm heart is also expressed by the fact that palm heart has taken the place of maize as the most important crop as indicated by the farmers. (Kuiper, 1996:34) The area under cassava has been fluctuating, in response to market and price conditions to which it has been proven to be very susceptible.[2]

Table 5.1: Major land use types in the Neguev for the 1987-1996 period (area in ha)

Land use types	1985	1987	1989	1991	1996
Annuals	460	998	282	356	168
Perennials	238	364	335	383	231
Pasture	2346	1745	2519	2407	3448
Forest & wasteland	1194	1073	1101	1090	390
Total	4236	4236	4236	4236	4236

Source: Schipper, 1996 and Kuiper, 1996

Table 5.2: Major crops in the Neguev for the 1987-1996 period (area in ha)

Crops	1985	1987	1989	1991	1996
Maize	414	589	181	154	29
Cassava	30	118	76	187	65
Pineapple	-	90	13	18	0
Plantain	-	23	25	44	34
Palm heart	-	-	90	138	151

Source: Schipper, 1996 and Kuiper, 1996

In the 1996 farm survey reasons for not having annual or perennial crops have been identified. Preference for other activities (most often livestock), unsuitability of the soil, commercialization problems, lack of investment finance for perennial corps, and unstable prices of annual crops are most frequently mentioned. (Kuiper, 1996:35) Especially the large fluctuations in the cassava price and commercialization problems have made farmers cautious with regard to investments in crops.

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[2] Readers interested in obtaining a more complete insight in the land use and farm types in the Neguev settlement are referred to van de Berg and Droog (1992), Finnema (1991), Kuiper (1996), Mucher (1992), de Oñoro (1990) and Schipper (1993).

Agricultural production in the Neguev takes place with a limited amount of capital goods. To a large extent this can be ascribed to the increased predominance of extensive livestock systems. Knapsack sprayers are the most widespread form of equipment, used by about 93 percent of the farmers. They can be used for the application of herbicides, fungicides etc. at pastures as well as for crops. The limited area of crops prohibits extensive use of specialized capital goods for crop production. The investments costs associated with shifting to another crop can thus be assumed to be limited.

5.3 Land degradation in the Neguev

As stated before, the Neguev has been selected as the case study area for reasons of data availability, not because of the incidence of land degradation. However, the abundant rainfall in the area could cause the leaching of nutrients as well as erosion (de Bruin, 1991:2-4). In the 1996 general farm survey an investigation of the occurrence of land degradation has been made. Of the 47 respondents 6 only recently obtained a farm in the Neguev and could therefore not indicate if any land degradation had taken place. Of the remaining respondents 56 percent indicated that degradation had occurred on their own farm and about the same percentage observed some form of degradation in the Neguev settlement. (Kuiper, 1996:25)

The respondents describe land degradation in terms of decreased fertility, necessity of fertilizers, decreased production, increased occurrence of plagues and pests and unsuitability for growing annual crops. The latter mainly relates to growing maize which in most places requires high fertilizer application rates. After the abolishment of a guaranteed price for maize, cultivation of this crop has become unprofitable in most places. Agro-chemicals and deforestation are the most often mentioned causes of degradation. (Kuiper, 1996:25) Deforestation not only leads to a loss of soil quality, it might also have caused a change in the climate of the Neguev. According to several farmers the last couple of years there have been distinct dry periods during the summer[3], causing a decreased production of palm heart and slower recuperation of pastures. The high deforestation rates in the Atlantic Zone and Costa Rica in general[4] might have disturbed the hydrological balance in the area, fostering the emergence of dry months.

Farmers describe soils in terms of color (colored, dark), material (sandy, clayey), location (high, low, close to a river), drainage (dry, swampy) and quality (fertile, acid, cultivable). The presence of slopes was never mentioned by any of the respondents, even if their farm obviously contained several steep hills. Erosion was also never referred to as a form of land degradation. This is a logical consequence of the absence of slopes, its major determinant, from the soil attributes identified by the farmers. Apparently, in spite of the abundant rainfall in the area, the physical characteristics of the area and the vegetative cover of pastures prevents the occurrence of erosion. However, on the area used for the cultivation of crops degradation in terms of loss of fertility,

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[3] In Costa Rica 'summer' refers to the period December to April which for the country as a whole is the dry period.

[4] From 1970 to 1989 the rate of deforestation in Costa Rica has been extremely high, varying between 1.2 and 1.8 percent of existing area annually, whereas the average for the tropical areas is 0.5 percent. (WRI, 1991:14)

need for fertilizers and increase in plagues and pests is observed by the farmers, indicating that degradation processes do occur.

Despite the fact of a present absence of erosion and the limited occurrence of other land degradation processes, the development of a multi-period land use model for the Neguev is still of more relevance than only the development of a methodology. The absence of land degradation with the present land use pattern concentrated at pastures for livestock does not guarantee that if land use patterns change no degradation will occur either. Observations by the farmers of a loss of fertility of fields used for the cultivation of crops indicate that land degradation does occur in the settlement.

Development of an instrument to assess the long term effects of land use on soil quality can be useful to evaluate the sustainability of possible changes in land use. If, for example, self sufficiency for staple food would become a goal of future agricultural policy, maize production could be supported once again. Widespread growing of maize which requires regular preparing of the soil and provides limited ground cover could cause a significant increase in land degradation.

Chapter VI

ASSUMPTIONS AND DATA USED IN MERALM

6.1 Introduction

This chapter reviews the databases presented in the top part of Figure 4.1. Next to a discussion of the data used, the way in which land degradation is defined in the case study is described. In order to incorporate erosion soils had to be distinguished on the basis of slopes, next to fertility and drainage. The resulting classification of soils is presented in Section 6.2. The following section is dedicated to the various uses which can be made of the soils. The remaining part of the chapter is devoted to the sustainability indicators of MERALM. First the biocide index is outlined in Section 6.4, followed by a description of the nutrient model which assesses the effect of land use on the nutrient balance of the soil. The third sustainability indicator included in MERALM is erosion, which is discussed in Section 6.6. Finally, the last part of the chapter presents the way in which erosion and the nutrient balance are used to quantify land degradation and how this affects future production possibilities.

Table 6.1: Classification of soils on the basis of fertility and drainage

	Relatively high fertility	**Relatively low Fertility**
Well drained	*Fertile Well drained (SFW)* Young alluvial volcanic soils, relatively fertile and well drained. (Inceptisols and Andisols)	*Infertile Well drained (SIW)* Relatively old soils, developed on fluvio-laharic sediments, relatively low fertility but well drained. (Oxisols and Inceptisols)
Poorly drained	*Fertile Poorly drained (SFP)* Young volcanic soils, relatively high fertility but poorly drained. (Entisols and Inceptisols)	-

Adapted from Stoorvogel et al. (1995)

6.2 Soil types

Based on photo-interpretations and field work a soil map of the Neguev settlement has been developed (scale 1:20,000), distinguishing 11 different soils. (de Bruin, 1992:8) A number of these soil types are further subdivided, resulting in 37 different mapping units. This great detail is not necessary for the present modeling exercise and also leads to an unmanageable size of the model. Therefore the soils are reclassified into 8 main soil types, based on slope, fertility, and drainage[1]. Slopes play an important role with erosion, whereas fertility and drainage are both important determinants of agriculture and also influence erosion indirectly.

Using fertility and drainage as classification-parameters, three broad groups of soils can be distinguished in the Neguev (see Table 6.1). These three soil classes will hereafter be referred to as *Soil Fertile Well drained* (SFW), *Soil Infertile Well drained* (SIW), and *Soil Fertile Poorly drained* (SFP). The SFW category is found along rivers, whereas the SFP category mainly occurs in the north of the settlement. The SIW category dominates the center part of the settlement.

Table 6.2: Classes of slopes

Class	Description	Gradient (%)
a	Flat to almost flat	0 - 1
b	Undulated	1 - 3
c	Strongly undulated to inclined	5 - 8
d	Hilly to moderately steep	10 - 16
e	Steep	20 - 30
f	Very steep	45 - 65

Source: de Bruin (1992)

Since the incorporation of erosion in a linear programming model forms the primary interest of this study, the slope of the soils is used as a third classification category, being an important determinant of the amount of erosion. Only the SIW category contains significant slopes, therefore this category is subdivided in accordance with the six classes which can be distinguished within the Neguev settlement (Table 6.2). The resulting soil types are denominated SIWa, SIWb through SIWf. Since the SFP and SFW soils are not subdivided according to slope a total of eight different soil types is distinguished. A further sub-division of the SFW and SIW soils in three fertility classes has been made to incorporate the effect of present land use on future

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[1] Annex A gives the soil type to which each of the original 37 soil mapping units belongs.

production possibilities. This sub-division of the soil types in fertility classes is described in Section 6.7.

6.3 LUSTs

The soil types presented above can be used for a variety of crops, as well as for forestry and livestock systems. The activities offered to the linear programming model are shaped as Land Use System Technologies (LUSTs), each of which consists of a specific Land Unit (LU) combined with a specific Land Use Type (LUT) and a specific technology. For each LUST the database contains a complete operational sequence, described in terms of four groups of biophysical in- and outputs: labor, traction, equipment and materials. The LUST-description does not include data on socio-economic and environmental aspects, like prices, nutrient contents, and toxicity, as these are stored in the attribute database. This separation leads to a greater flexibility of the model since optimal land use can easily be calculated with varying technologies and socio-economic conditions. Based on the description of activities and the related attribute data, the technical coefficients needed by the linear programming model are calculated. (Jansen and Schipper, 1995:33)

On the basis of distinctions in fertility, drainage, slope and fertility class a total of twenty-two different land units have been included in the model. Furthermore, seven different land use types which can be applied to the land units are distinguished. Four of these consists of annual and perennial crops: maize, plantain, cassava, pineapple, palm heart. The remaining two land use systems are tree plantations and pastures with an extensive livestock fattening system. For all activities an actually used technology as observed in the field is included, as well as up to 3 alternative technologies, differing in use of biocides, fertilizer and labor. Next to a variety of technologies a distinction is also made between different types of products which can be produced by the LUSTs. Generally three types of products are distinguished, high quality products for export, products for local consumption and refuse. In several cases further sub-distinctions are being made within these categories on the basis of quality differences. Finally, for each LUST the time period at which the crop is planted is specified since this affects the flow of in- and outputs in time. Distinguishing LUSTs on the basis of soil type, crop, technology and planting time results in a total of 924 different LUSTs and 24 different products which at most can be included in the linear programming model.

For each of the LUSTs the following input and output coefficients are determined: land use, costs of current inputs (sum of input quantities times prices), labor requirement in hours and production specified per type of product. Furthermore, the coefficients for three sustainability indicators are determined for each LUST: soil nutrient depletion with regard to nitrogen, phosphorus and potassium, a biocide use index value, and erosion. Finally, the effect each LUST has on soil fertility is determined for each period. The quantification of these sustainability indicators is described in the following sections.

6.4 Biocide index

The first sustainability indicator included in MERALM is a biocide index, specified for each LUST. The development of a deterministic model of the flow of the wide variety of biocides used into ground and surface water is impeded by the large amount of data needed for such a modeling exercise. Furthermore, no data are available on the effects of biocides on humans and ecosystems. It can however be assumed that the effect of biocides will largely be determined by the amount of active ingredients, the duration of their activity in the ecosystem and their toxicity. (Jansen et al., 1995:68) In order to make relative comparisons of biocide use across LUSTs the following biocide index is calculated for each LUST (Jansen et al., 1995:69):

$$BILU_L = \frac{1}{Y}\sum_{a=1}^{n}\sum_{b=1}^{m} A_{L,a,b} \cdot AI_b \cdot TOX_b \cdot DUR_b \qquad (6.1)$$

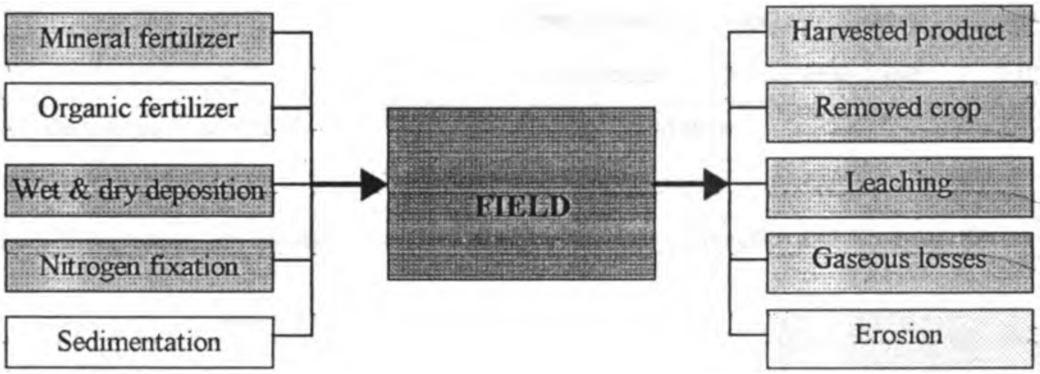
with: $BILU_L$ = biocide index of LUST L
Y = duration of LUST L in years
n,*a* = total and a^{th} number of biocide application *a* in LUST L
m,*b* = total and b^{th} number of biocide used at application *a* in LUST L
A = amount of commercial formulation of biocide *b* at application *a*
AI = fraction active ingredient in the commercial formulation of biocide b
TOX = indication of toxicity of biocide *b*
DUR = indication of duration of existence of toxin of biocide *b* in the system

The toxicity and duration indicators are derived from World Health Organization (WHO) codes which are subjectively transformed into numbers. Given the latter transformation and the fact that the durations are determined under different conditions than prevailing in the Atlantic Zone of Costa Rica, the resulting values can only be interpreted as reflecting the different behavior of the biocides. (Jansen et al., 1995:71) The tentative nature of the biocide index combined with the lack of knowledge on the effects of biocides on ecosystems prohibits the imposing of objective limits on biocide use in the linear programming model. Furthermore, the lack of data on the effects of the biocides on humans and ecosystems prevents the inclusion of biocide concentrations in the quantification of land degradation.

6.5 Nutrient balances

Despite the lack of an univocal definition of sustainability consensus exists about the cardinal importance of balancing nutrients. The nutrient balance is determined by ten basic in- and outputs (see Figure 6.1). (Guiking et al., 1994:248, Stoorvogel, 1995:86) A nutrient balance model (NUTBAL) quantifies for nitrogen (N), phosphate (P), and potassium (K) the in- and outputs per LUST. Nutrient inputs as a result of mineral fertilizer are quantified for each LUST. Due to the lack of use of organic fertilizer or manure this input is not included in the analysis. The second source of inputs quantified for each LUST is wet deposition. Although the amount of nutrients in rainfall are very low, the large quantity of rainfall leads to a considerable input of nutrients. The last source of inputs included in the analysis is biological nitrogen fixation by leguminous trees in living fences. (Stoorvogel, 1995:87) Sedimentation as a source of nutrients was not included since this requires a further distinction of soils based on proximity to rivers and streams.

Figure 6.1: Basic in- and outputs of the nutrient balance



The second part of the NUTBAL model consists of the various ways in which nutrients leave the system. Nutrients are removed from the field with the harvested product and with crop residues if taken from the field. A third source of extraction of nutrients quantified for all LUSTs is leaching. Finally, for nitrogen the loss as a result of denitrification has also been quantified. The loss of nutrients as a result of erosion is quantified separately from the NUTBAL model. The quantification of the effects of LUSTs on the nutrient balance allows for the determination of the change in nitrogen, phosphate and potassium after each period.

6.6 Erosion

For each soil type and crop combination erosion per hectare has been calculated with the Universal Soil Loss Equation. The estimated soil loss is expressed in ton per hectare and depends on erosivity of the rain (R-factor), erodibility of the soil (K-factor), slope gradient and length (LS-factor), crop cover (C) and conservation measures (P-factor). Vahrson (1991) calculated the R-factor for 115 weather-stations in Costa Rica, including *El Carmen*. The latter is a weather station located six kilometers east of the Neguev settlement, with a R-factor of 800.5. It is assumed this R-factor applies to the whole settlement, thus implicitly assuming that within the settlement no differences in the R-factor exist. The K-factors were derived from a nomograph[2], after calculating the percentage silt, sand and organic matter, as well as determining the structural class and permeability class for the soils[3]. These values are presented in Table 6.3.

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[2] The used nomograph can be found in Appendix B.

[3] The percentages are determined on basis of the profile description of the soil mapping units constituting each of the three types. First the average percentages for each unit were calculated using the length of the specific profile descriptions as weights for averaging the

Table 6.3: The K-factor

Soil type	Silt (%)	Sand (%)	Organic matter (%)	Soil structure	Permeability	K-factor
SFP	30.1	31.8	3.1	Fine granular	Moderate to rapid	0.08
SFW	30.1	31.8	3.1	Fine granular	Moderate to rapid	0.20
SIW[1]	24.2	12.2	2.9	Fine granular	Moderate to rapid	0.05

Note: [1] The K-factor is the same for all SIW soils since they only vary in slope

The LS-factors were calculated using the following formulas (Sanchez and Alvarez, 1991:150):

$$LS = \left(\frac{L}{22.1}\right)^{0.3} \cdot \left(\frac{0.43 + 0.30 \cdot S + 0.043 \cdot S^2}{6.613}\right) \qquad (6.2)$$

$$LS = \left(\frac{L}{22.1}\right)^{0.3} \cdot \left(\frac{S}{9}\right)^{1.3} \qquad (6.3)$$

with: LS = LS-factor
L = length of the slope (ft.)
S = gradient of the slope (%)

Formula 6.2 is used for slopes with a gradient of less than 9%, whereas the second formula is used for slopes of more than 9 %. The gradients used for each soil type[4] can be found in Table 6.4. For each slope a length of 150 m or 492 ft. has been assumed. The SIW soil refers to the case in which no distinction between slope sub-classes is made, the slope of this soil is an average using the areas of the various slope-classes as weights.

Finally the crop factors are presented in Table 6.5, they are taken from the literature. No distinction could be made between possible effects of the various technologies on crop coverage. Also, none of the technologies can be considered soil conserving, therefore the P-factor is fixed at 1 for all LUSTs.

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various values. On the basis of these values the average percentages for each soil type are then calculated using the areas of each mapping unit as weights.

[4] The soil types SIWb, SIWc and SIWd contain soils which are classified as both BC, CD and DE, respectively. Therefore the gradient used for these classes is based on weighted average of the average gradient of the single class and combined class, using the areas as weights. For example the SIWd soil type exists for 69 percent of soil with a slope classified as DE (average slope of 20%) with the other 31 percent classified as D (average slope of 13%). The slope of the SIWd soil is therefore calculated as 0.69*20+0.31*13=18%.

Table 6.4: K-factors, slopes and LS-factors per soil type

Soil type	**Slope** (%)	**LS-factor**
SFP	0	0
SFW	0	0
SIWa	1	0.2
SIWb	2	0.5
SIWc	8	2.2
SIWd	18	6.2
SIWe	25	9.6
SIWf	55	26.7
SIW[1]	12	3.7

Note: [1] SIW soil refers to the soil type without slope sub-classes, using an average slope

Table 6.5: C-factors for the land use types

Crops	**C-factor**
Maize	0.5
Cassava	0.3
Plantain	0.2
Pineapple	0.2
Palm heart	0.2
Wood	0.04
Pasture	0.01

Note: All factors are taken from Stoorvogel (1995), with exception of the C-factor for wood which is taken from Sanchez and Alvarez (1991).

Based on the preceding the soil loss per crop and soil type can be calculated with the USLE (see Table 6.6). The resulting values are low compared to the values found in the literature for Costa Rica (see for example Sanchez and Alvarez, 1991; Vahrson and Cervantes, 1991). This reflects the fact that erosion is generally considered to be tolerable in the Atlantic Zone of Costa Rica. (Stoorvogel, 1995:91)

Table 6.6: Soil loss per land use type and soil type (ton/hectare, year)

Soil	Maize	Cassava	Plantain	Pineapple	Palm heart	Wood	Pasture
SFP	0	0	0	-	0	0	0
SFW	-	0	-	-	-	-	0
SIWa	-	3	-	1	1	-	0
SIWb	-	6	-	2	2	-	0
SIWc	-	27	-	8	8	-	1
SIWd	-	74	-	21	21	-	2
SIWe	-	115	-	33	33	-	4
SIWf	-	320	-	92	92	-	11
SIW	-	44	-	13	13	-	1

Note: '-' indicates that the crop-soil combination does not exist

6.7 Relating soil degradation to future production

The three sustainability indicators discussed above cannot be readily transformed into a soil degradation measure. As stated before, the tentative character of the biocide index prohibits the incorporation of this indicator in the quantification of land degradation. Of the two remaining indicators, the nutrient balance and erosion, only their effect on the potential nitrogen supply by the soil is considered. In the case the effects of LUSTs on the nutrient balance, the supply of phosphate can be excluded since, due to the soil characteristics, it is not limiting production. Furthermore, the Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model has not yet been calibrated for potassium, thus this nutrient has to be excluded from the analysis as well. (Stoorvogel, 1995:89; Guiking et al., 1994:255) With respect to erosion, a restriction of its effects to loss of nitrogen implies that all other on-site effects as discussed in Section 2.4.1 are omitted from the analysis. Next to the fact that the lack of data necessitates such a limited definition of soil degradation, a restriction to one nutrient simplifies the analysis.

The effect of the supply of N on production is quantified in three steps. First the potential supply of N by the soil is quantified. Then the loss of organic C as a result of land use is derived from the N-balance of the NUTBAL model and the amounts of soil lost through erosion. Finally, the percentual change in potential supply of N induced by each LUST is calculated and related to a change in production through the definition of fertility classes.

6.7.1 Potential supply of N by the soil

The potential supply of N is quantified with QUEFTS, which has been calibrated for the Neguev settlement for SFW and SIW soils. SFP soils require special treatment in calibration and are therefore excluded[5]. (Guiking et al., 1994:251) The potential supply of N (SN) is related to organic C and pH in the first 20 cm of the soil in the following way (Guiking et al., 1994:255):

$$SN = 0.25 \cdot (pH - 3) \cdot 2.9 \cdot organic\ \mathrm{C} \qquad (6.4)$$

On the basis of the profile descriptions of the soils which constitute the SFW and SIW soils (de Bruin, 1992) the data presented in Table 6.7 have been calculated.[6] The associated potential supply of N is 73.6 and 37.9 kg per hectare for the SFW and SIW soil, respectively. This potential supply serves as the base level, representing the highest fertility class.

Table 6.7: Characteristics of SFW and SIW soil types

	Soil depth of 20 cm			Soil depth of 5 cm	
	OM ($g \times kg^{-1}$)	*Organic C* ($g \times kg^{-1}$)	*pH*	*OM* ($g \times kg^{-1}$)	*Organic C* ($g \times kg^{-1}$)
SFW	54.5	31.6	6.2	68.4	39.7
SIW	58.2	33.8	4.6	90.3	52.4

6.7.2 Change in potential supply of N by the soil

In order to determine the effect of land use on land degradation the change in potential N supply from the base level has to be determined. To obtain the change in potential N supply first the loss in organic C from the NUTBAL N-balance and from erosion have to be calculated. It has been assumed that 75% of the change in the N model takes place in the top 20 cm of the soil. Using a ratio between organic C and N of 10:1 this means that the change in organic C as a result of the N-balance can be calculated as:

$$\Delta\,\mathrm{organic\ C_n} = \mathrm{BAL_N} \cdot 0.75 \cdot 10 \qquad (6.5)$$

with: $\mathrm{BAL_N}$ = N-balance from the NUTBAL model

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[5] Given the fact that erosion is the primary cause of nutrient loss and that effectively no erosion takes place on the flat SFP soils, this omission can be assumed not to seriously affect the results.

[6] First for all mapping units an average value has been calculated for the first 5 and 20 cm. Subsequently the values for the soil types are calculated using the area of the constituting units as weights.

To calculate the loss of organic C due to erosion the following formula is applied:

$$\Delta \text{ organic } C_e = \frac{LSD}{TSD_5} \cdot \text{organic } C_5 \cdot E \qquad (6.6)$$

with: LSD = lost soil depth (cm)
TSD$_5$ = top soil depth of 5 cm
organic C$_5$ = organic C in the top 5 cm (g×kg^{-1})
E = enrichment factor

The top 5 cm values are used in the calculation of the nutrient loss from erosion since this layer contains relatively more organic matter (OM) and organic C. Use of the values for the top 20 cm layer would underestimate the nutrient loss. Furthermore, an enrichment factor of 2 is applied to account for the fact that the sediment contains about twice as much nutrients than the remaining soil.[7] Finally, the first term on the right hand side converts the soil loss in ton per hectare from the USLE into a fraction of the top 5 cm using the fact that a loss of 10 ton soil per hectare implies a loss of 1 mm topsoil.

Now that both the change in organic C from the N-balance as well as from erosion are known, the change in potential N supply can be determined for each LUST. The change in potential supply of N by the soil is related to a change in organic C in the following way:

$$SN = 0.25 \cdot (pH - 3) \cdot 2.9 \cdot (\Delta \text{ organic } C_n + \Delta \text{ organic } C_e) \qquad (6.7)$$

6.7.3 Change in production as a result of N loss

In the previous sections the base level supply of N and the changes induced by LUSTs have been determined. The last step which has to be taken in the quantification of land degradation is relating the change in potential supply of N to changes in yields. No data are available relating land degradation to production levels. Therefore it has been assumed that a reasonable approximation is a linear relationship, with the level of production changing with the same percentage as the change in N supply. (J. Stoorvogel, 1996, personal communication)

In order to include the effect of land degradation in the soil type definition, three fertility classes are defined for the SFW and SIW soil types. Class I has the highest fertility and a production which is similar to the production level of the LUSTs as derived from surveys, literature and expert knowledge. Class II contains soils which supply 25 % less N than the class I soils and therefore have a 25% lower production level. The last class contains soils with a 50% lower N supply and production than the first class. As stated earlier, land use on the SFP soils is assumed not to affect soil-fertility. Then, for all activities on SFW and SIW soils two additional LUSTs

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[7] This is caused by the fact that clay particles are removed more easily by the water than sand particles due to the larger size and higher weight of the latter.

can be defined for the II and III fertility classes. These only differ from the original LUSTs on class I soil in production levels.

After each period the effect of a LUST in terms of a loss in potential supply of N by the soil can be determined. This effect can then be translated in a change in fertility class of the used soil and the availability of land types in the following period can be adjusted in accordance with these changes. As a result of the definition of additional LUSTs for the lower fertility classes, the change in fertility is reflected in lower production levels.

Chapter VII

THE MATHEMATICAL STRUCTURE OF MERALM

7.1 Introduction

This chapter discusses the general structure of MERALM which forms the basis of the linear programming exercises in Chapter 8. MERALM is an economic multi-period model in which land use decisions in preceding periods influence land quality in the remaining periods. Figure 7.1 gives a schematic representation of the structure of MERALM. The model has one objective function which maximizes the economic surplus of four periods. For each period MERALM includes a sub-model which determines the optimal land use in that period. This land use pattern is selected under restrictions on production and inputs, land and labor. The selected land use influences the levels of the three environmental indicators, biocide index, nutrient balance and erosion. These indicators do pose any direct restrictions on the production, however part of the effects of the nutrient balance and erosion are captured by changes in fertility classes induced by land use.

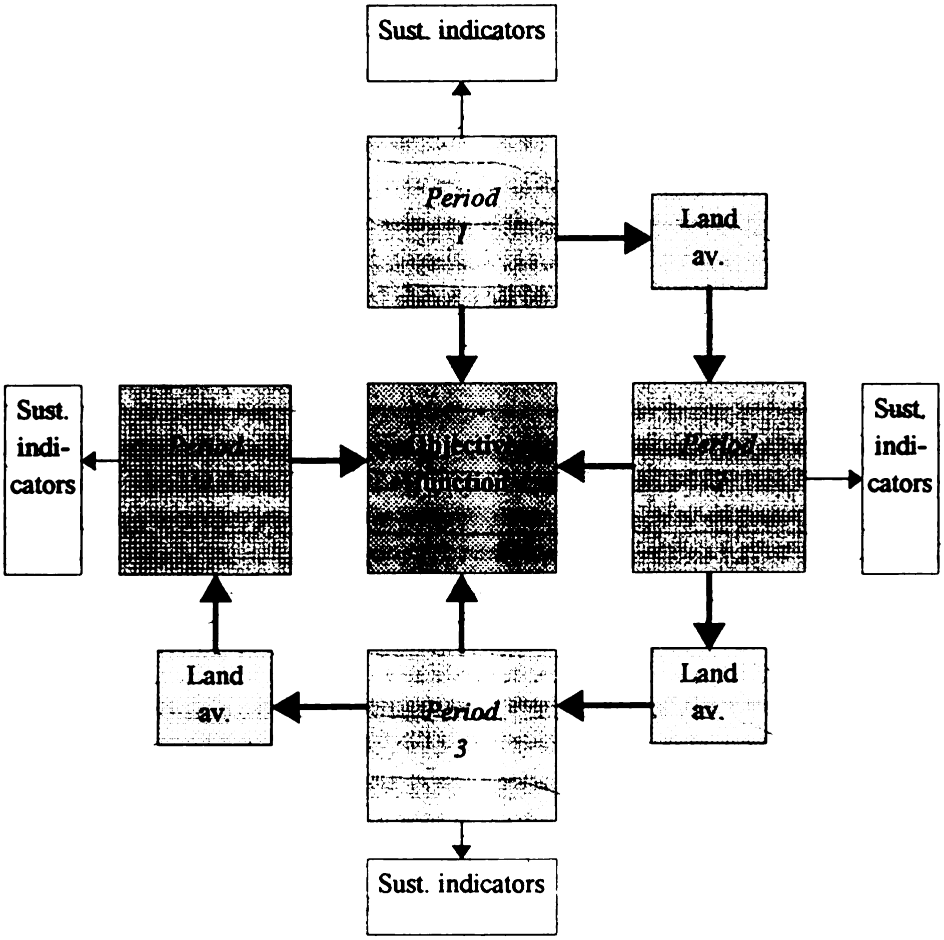
The selected land use pattern can affect the land availability the following period by causing a shift in fertility classes. A second way in which land use in the following period is restricted is by the maintaining of still productive perennial crops. The four periods in the model are thus related by the objective function and by changes in land availability, as a result of shifts in fertility classes and perennial crops.

Section 7.2 discusses the ideas on which the structure of the model is based. Then the model is spelled out in mathematical terms, starting with the objective function in Section 7.3. Subsequently the restrictions and balances regarding the production and input use are discussed in Section 7.4. Land and labor have pivotal roles in the model and are therefore treated separately in Section 7.5 and 7.6, respectively. The last part of this chapter discusses the biocide, nutrient and erosion balances of the model.

7.2 Background of the model

The core of MERALM consists of an array of possible land use activities (LUSTs), as discussed in Chapter 6. At most, the various versions of the model contain 22 different land units (distinguished in terms of fertility, drainage slope and fertility class), 7 land uses (cassava, maize, pineapple, plantain, palm heart, pastures with cattle and tree plantations), and a maximum of 4 different actual and potential technologies for each activity. For all activities the technology as observed in the field has been included. Potential technologies have been selected in such a way as to reflect a wide diversity of fertilizer, biocide and labor uses. The fourth attribute used for distinguishing the LUSTs is the period in which the crop is planted. This is especially necessary in the case of perennial crops, for which distinct differences exist in the flow of costs and benefits between the starting and later years. The maximum number of LUSTs which can be included is 924, since for several activities less than 4 different technologies are distinguished and not all activities occur on all soil types.

Figure 7.1: The structure of MERALM



Of the 7 land use activities only 2, maize and cassava, are annual LUSTs. The remaining activities occupy the land for more than a year, varying from 1.25 year for cassava to 33 years for a tree plantation. In the case of perennial crops, costs exceed benefits in the first years after planting, whereas the opposite is true in the later years of their lifetime. In order to capture this essential characteristic the model contains four periods, of 1, 2, 6 and 11 years respectively[1]. This

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[1] Theoretically it would be preferable to model all 20 year separately, i.e. to develop a model with 20 periods. This would however result in an unmanageable size of the model due to an 'explosion' of the number of variables. For example, since all LUSTs have to be distinguished on the basis of their planting period, as a result of differences in the flow of costs and benefits, 18,480 land use activities would then have to be included in the model.

variation in length of the periods is assumed to account for the main dynamic aspects of choices pertaining to perennial crops, since these involve a sacrifice of income in the first 2-3 years. (Norton, 1995:5)

In order to be able to select activities the costs and revenues of the crops have to be compared. Costs and revenues of each LUST occur at different points within a period, with costs and benefits occurring at a later point valuing less than those occurring at the beginning of the period. Therefore all values are discounted towards the starting year of the period, resulting in a net present value for each LUST and period combination. Discounting is a normal procedure for values occurring at different points in time, but is a less obvious procedure for quantities, like amounts of labor. However, values can be reduced to a multiplication of quantities with prices. Thus, if constant prices are assumed[2] quantities can be discounted and afterwards multiplied with the price to obtain the present value. (Schipper, 1996:131)

Activities could then be selected on the present value of their costs and revenues, but this necessitates the assumption that land uses selected at the beginning of the period will continue for the full period. For example, in the case of a specific maize LUST which occupies the land from January through May, it has to be assumed that it will be planted again in January of each year of the period. The total net present value will then consist of the discounted value of maize in all these years. This assumption of repeated growing of crops has one major disadvantage. In practice it is possible to grow more than one crop on the same plot in the same year. A specific palm heart LUST starts in June. First the maize mentioned before could be planted, after which palm heart is started, thus making use of the plot for the full length of the first year. This possibility can only be incorporated in a net present value approach if all possible crop combinations are explicitly modeled as new LUSTs. Given the fact that LUSTs are specified for 22 soil types and 4 starting periods this approach would lead to an unmanageable number of LUSTs.

Therefore another approach is chosen in which crops are selected on the basis of a comparison of annuities. The net present value for each LUSTs is converted into an annuity[3] for each period. This procedure makes the net present values of time periods with different length commensurable. In this way for each period a representative year is constructed, on the basis of which activities

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[2] Constant prices, just as constant input- output ratios are a basic assumption underlying the linear programming model, at least within one period. One could model different prices, and input/output ratios for each period.

[3] The net present value (NPV) of a stream of future net benefits (B_n) occurring at the end of a total of N periods, using an interest rate of i is:

$$NPV = \sum_{1}^{N} \frac{B_n}{(1+i)^n}$$

The annuity (A) of the total net present value of all future net benefits (NPV) for the total of N years can then be calculated through:

$$A = NPV \cdot \frac{i(1+i)^N}{(1+i)^N - 1}$$

(Gittinger, 1982:433)

Following Schipper (1996) a discount rate of 10 percent is assumed to reasonably reflect the opportunity costs of capital in Costa Rica, since a study of the appropriate level of the discount rate is not within the scope of this study.

are selected by MERALM. Restrictions on labor and land use are modeled for each quarter to take the seasonal aspects of agricultural production into account. Construction of a representative year also enables the modeling of the growing of two or more crops on the same plot in the same year through calculation of average use of the land by a crop for each quarter.[4]

Restrictions on the availability of labor are identical for all quarters and years, and thus do not have to be converted into annuities. The amount of labor required for production in each quarter is calculated through an annuity instead of an average as with the use of land. Annuities, being based on the net present value, can be interpreted as weighed averages which attach greater value to quantities occurring at the beginning of the planning horizon then those occurring later. If the planning horizon comprises a large number of years with high labor requirements at the beginning compared to later years, an annuity of the labor quantities will be higher than an unweighted average. However, in case identical quantities of labor are needed in each year an unweigthed average will yield the same result as calculation of an annuity.

Perennial crops are characterized by investments at the beginning of their lifetime, in terms of capital as well as labor requirements. Of the 21 perennial crops included in the analysis only one has higher labor requirements at the end of its lifetime. The remaining 20 perennial crops either have a high labor need at the beginning of their lifetime or they have an nearly constant labor requirement over time. In the latter case an annuity will yield the same result as an unweighted average. For perennial crops with higher labor requirements at the start of their lifetime an unweighed average will underestimate the need for labor during the first investment years. An annuity approximates the need for labor more closely, by weighing the investment in terms of labor-time at the beginning stronger than the lesser requirements later on. Considering that especially the investment-requirements may hamper the production of perennial crops, an annuity approach to the need for labor is more appropriate than an unweigthed average.

A final question which has to be tackled concerns returns which occur beyond the end of the last period. These returns are not captured in the objective function through any of the periods. Therefore the discounted value of these returns are included directly into the objective function. (Hazell and Norton, 1986:59)

7.3 The objective function

The objective of all versions of MERALM is maximization of economic surplus at the sub-regional level. The objective function consists of two parts: net benefits of each period and returns which occur beyond the end of the fourth period (Equation 7.1).The returns of each period (Y_p) are calculated, as discussed above, in terms of annuities. However the different length of the periods has to be accounted for, as well as their occurrence in time. Therefore the net benefits of each period are multiplied with a discounting factor (d_p) which incorporates the number of years

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[4] For example, 1 ha palm heart which starts in April and ends in May, 15 years later, occupies on average 0.93 ha (14/15*1) in the first quarter, 0.96 ha (14.33/15*1) in the second quarter, and 1 ha (15/15*1) on average in the third quarter of the year.

of the period as well as the timing of the benefits. The result of this multiplication is the net present value in the starting year of the planning horizon of the benefits occurring in all years of period p. The second part of the objective function consists of the discounted value of the returns occurring beyond the end of the last period (R).

$$Max \quad Z = \sum_{p} d_p Y_p + R \tag{7.1}$$

with:

$$-\sum_{f}\sum_{s}\sum_{l}\sum_{t}\sum_{i} m_{fslti} X_{fslti,p=4} + R \leq 0 \tag{7.2}$$

Equation 7.2 calculates for all LUSTs the discounted value of returns occurring beyond the end of the last period. To this end the area of the LUSTs which are present in period 4 are multiplied with the discounted value of their returns per hectare occurring beyond the end of the fourth period (m_{fslti}). The net return of each period consists of the value of production and the income derived from working off-farm, minus the costs of production in terms of used inputs and labor costs (Equation 7.3). The first term on the left consists of the total value of the annuity production ($p_{jp}\ Q_{jp}$) derived from all j products. From this value of production first the annuity costs of inputs (I_p) are deducted. The last three terms refer to costs and income of labor. First the total amount of household labor used for production is valued against the reservation wage ($w_{rfqp}F_{fqp}$, ¢/hour[5]). Household labor used on-farm is valued against a reservation wage because it is reasonable to assume that a minimum return is required to have people work at their own farm. At the same time household members often have a preference for working on their own farm instead of performing off-farm work. A reservation wage greater than zero and less than the off-farm wage rate will employ household labor before hiring labor while at the same time assure that no activities are selected which yield less than the minimum return. (Schipper, 1996:117)

$$-\sum_{j} p_{jp} Q_{jp} + I_p + \sum_{f}\sum_{q} w_{rfqp} F_{fqp} + \sum_{f}\sum_{q} t_{fqp} H_{fqp} - \sum_{f}\sum_{q} w_{afqp} P_{fqp} + Y_p \leq 0 \quad \text{all p} \tag{7.3}$$

Next the costs of hired labor should be added. However, the objective function is maximized at the sub-regional level. As expressed in Equation 7.16 the total amount of hired on-farm labor (H_{fqp}) equals the total amount of labor of household-members on other farms (O_{fqp}) for the Neguev as a whole. At the sub-regional level the amount of hired labor represents a cost whereas the labor worked on other farms represents a source of income. In case both are valued the same way they will neutralize each other at the regional level. However, the hiring of labor can be assumed to involve transaction costs, reflected in the costs of hired on-farm labor being higher than the wage obtained by working on other farms. The third term on the left deducts only the transaction costs of hired labor ($t_{fqp}H_{fqp}$), since the remaining costs of hiring labor are canceled by the income from working on other farms. Finally, the last term consists of the income derived from work on plantations outside the Neguev ($w_{afqp}P_{fqp}$).

Maximization of the objective function takes place under various constraints, for example limited supply of land and labor. Next to these constraints which, if binding, limit the value of the

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[5] The currency unit of Costs Rica, the *Colón* (¢), is used to measure all monetary values

objective function, the model also includes a number of balances. These balances are merely included for calculation variables for the objective function or to compute aggregates, and do not constrain the objective function in any way. The constraints and balances are discussed below. First the production and input use will be reviewed, followed by land use, labor, biocide use, nutrient balances and finally erosion.

7.4 Production and inputs

The production is determined at farm type level as well as for the settlement as a whole (see Equations 7.4 and 7.5). First the annuity of the production for each period (*p*), product (*j*) and farm type (*f*) is calculated by multiplying the annuity yield ($y_{jfsltip}$, kg or 'units'/ha) with each LUST (X_{fsltip}, ha/year) and summing over all attributes of the LUSTs: soil types (*s*), land use types (*l*), technologies (*t*) and starting periods (*i*). Subsequently the production for the Neguev as a whole (Q_{jp}, kg or 'units'/year) is found for each product-period combination by summation of production, Q_{jfp}, over all farm types.

$$\sum_{s}\sum_{l}\sum_{t}\sum_{i} -y_{jfsltip}X_{fsltip} + Q_{jfp} \leq 0 \qquad \text{all j, f, p} \tag{7.4}$$

$$-\sum_{f} Q_{jfp} + Q_{jp} \leq 0 \qquad \text{all j, p} \tag{7.5}$$

Both land and labor have pivotal roles in the model by linking the four periods and farm types within one period, respectively. They are therefore dealt with in separate sections. All other inputs used in production, like fertilizer, herbicides etc., are converted into a single monetary value for each LUST. The amount spend on inputs is determined analogue to the production equations (compare Equations 7.6 and 7.7 with Equations 7.4 and 7.5).

$$\sum_{s}\sum_{l}\sum_{t}\sum_{i} c_{fsltip}X_{fsltip} - I_{fp} \leq 0 \qquad \text{all f, p} \tag{7.6}$$

$$\sum_{f} I_{fp} - I_{p} \leq 0 \qquad \text{all p} \tag{7.7}$$

The input use per farm type (I_{fp}, ¢/ha) is found by multiplying the annuity costs of inputs (c_{fsltip}, ¢/ha) with the area of each LUST. The amount used in the settlement as a whole is again found by summing over all farm types.

7.5 Land use and availability

As has been outlined in Chapter 6, the effects of erosion and alterations in the nutrient balance are incorporated through their effect on the potential nitrogen supply of the soil in later periods. This effect is translated into changes in fertility classes of the available soil types. The use of land by LUSTs in period p is limited by the available area of each soil-type in period p, which on its turn is determined by the initial supply of soil types over the farm types, as well as land use in previous periods. A second limitation on land availability by land use in previous periods is brought about by perennial crops. It has been assumed that a decision about the investment in perennial crops is taken with a long-term perspective. This implies that once perennial crops are planted the use of this land is fixed for the whole productive lifetime of the perennial crop.

In contrast to the production and input equations discussed above, land use is not determined for the year as a whole but instead per quarter, this in order to take seasonal fluctuations of land use into account. As has been discussed in Section 7.2, land use is calculated in terms of average amount of land occupied by the crop in a period, to allow for several crops using the same plot within a single period. Multiplying this average land use per quarter ($a_{fsltiqp}$, ha/year) with the area of each LUST provides the total need for land per quarter, which can never exceed the available amount of land for each farm type (Equation 7.8). The availability of land (A_{fsp}, ha/year) is determined on a yearly basis (see Equations 7.9 and 7.10), and therefore has to be multiplied by an unity matrix (q_{qp}) to arrive at the quarterly availability of land.

$$\sum_{l}\sum_{t}\sum_{i} a_{fsltiqp} X_{fsltip} \le q_{qp} A_{fsp} \qquad \text{all f,s,q,p} \qquad (7.8)$$

The average land use construction allows for the selected area of a crop to exceed the available land in a period. This means that a crop is grown more than once. For example if a crop occupies 0.5 hectare in each quarter of a two-year period and 10 hectare of land is available, the model can select 20 hectare of the crop. The crop is then grown twice, once in each year of the period. In the case of crops with a cropping cycle less than the length of the period this construction works since the start of the crop can be moved within the period.

However, problems can arise with perennial crops. For example, assume that a two-year cassava is planted in the first period. Since the first period contains only one year the cassava is still present in the first year of the second, two-year period. On average the crop occupies thus 1 hectare in the first period and 0.5 hectare in the second. Assume furthermore that 10 hectare of land is available of which 5 hectare is used in period 2 for planting palm heart, a perennial crop. Given the average occupation of land by cassava in the second period and the fact that no other crops are present in the first period, 10 hectare of cassava could be selected by the model without violating the restrictions on the availability of land in any of the two periods. This would imply that 10 hectare of cassava planted in the first period changes in 5 hectare cultivated twice during the two years of the second period. To avoid this type of impossibilities an additional restriction on land use is needed.

$$\sum_{l}\sum_{t}\sum_{i} o_{fsltip} X_{fsltip} \le A_{fsp} \qquad \text{all f,s and p} \ge 2 \qquad (7.9)$$

In the case of perennial crops it has been assumed that these crops are always planted in the first year of a period[6]. In order to avoid that perennial crops occupy more land than available, a

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[6] In case this assumption is dropped for each perennial 20 LUSTs have to be determined, one for each possible starting year of the planning horizon. This is necessary to determine the exact flow of costs and revenues in each period, which is determined by the year in which each crop is started.

restriction with regard to the occupation of land in this first year of each period is thus sufficient. Equation 7.9 is similar to Equation 7.8 in that the area occupied by the crops cannot exceed the available land. However, in contrast to the latter, Equation 7.9 does not use average use of the soil but the use of the soil in the first year of a period. Furthermore Equation 7.9 is only effective for certain crops, depending on the value of o_{fsltip}. The coefficient o_{fsltip} has value 1 for still productive crops stemming from previous periods and perennial crops which start in the period under consideration and whose lifetime exceeds or equals the length of the period. In all other cases the coefficient o_{fsltip} has value 0, effectively excluding these crops from the restriction. The latter is possible for all crops which occupy the land for less years than the total number of years of the period. These crops do not exist in following periods and therefore their starting year can be shifted within the period under consideration without affecting the flow of costs and benefits in subsequent periods. As a result there is no need to require that these crops are present in the first year of each period.

With respect to the cassava example, Equation 7.9 assures that no more than 5 hectare of the two-year cassava is planted since the area palm heart and cassava in the first year of period 2 cannot exceed 10 hectare. At the same time Equation 7.8 allows for the cropping of 5 hectare of for example an annual maize LUST in the second year of the second period. After all, the average occupation of cassava in the second period stays 0.5 hectare so 2.5 hectare are still left in this restriction. At the same time an annual maize will not be included in Equation 7.9 and thus the 2.5 hectare can be used for this crop without violating the latter restriction. This means that after the cassava is harvested at the end of the first year of the second period the 5 hectare fallow land can be used for one-year maize.

Now that the use of land has been specified the availability of land has to be defined. In the first period the supply of land is determined exogenous. The availability of soil types for each farm (A_{fsp}, ha/year) in the first period is equal to the stock of land of each farm type as determined on the basis of a soil survey ($r_{fsp=1}$, ha/year), as shown in Equation 7.10. The supply of soil types in the remaining periods is determined endogenous through the land use in all previous periods (Equation 7.11).

$$A_{fs,p=1} = r_{fs,p=1} \qquad \text{all f,s} \tag{7.10}$$

$$A_{fs,p-1} + \sum_{l}\sum_{t}\sum_{i} k_{fslti,p-1} X_{fslti,p-1} = A_{fsp} \qquad \text{all f,s and p} \geq 2 \tag{7.11}$$

The availability of land types in period p is determined by the availability of soil types in the previous period ($A_{fs,p-1}$) adjusted for the effect of land use in that period which is given by the second term on the left hand side. The effects of land use on land quality are captured by the coefficient $k_{fslti,p-1}$. This coefficient indicates for each LUST if it causes a shift to a different fertility class. In case a shift in fertility classes occurs the increase in one fertility class is fully compensated by a decrease in the class the soil used to belong to. The total available area is thus constant but the available amount of various fertility classes varies as a result of land use. Summation of the changes in fertility caused by all LUSTs over the crops, technologies and starting period results in the total change of soils of each fertility class. Adding this change in soil types to the availability of soil types at $p-1$ results in the soil-availability in period p[7].

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[7] Appendix E illustrates the exact working of this mechanism with an extensive example.

The second constraint limiting the supply of land is the presence of perennial crops from previous periods. Considering the long term character of these crops it is reasonable to assume that still productive crops from earlier periods will not be replaced in later periods. The available land therefore has to be restrained by the area occupied by these perennials. Two complications arise with imposing this restriction. In the first place the restriction should only apply in the periods following the starting period of the crops, since before that the crop either does not exist or an optimal area has to be selected. Furthermore the dynamic aspects of soil fertility have to be incorporated since a perennial crop can cause a soil type to shift to another fertility class. The restriction thus has to take into account that the same crop in terms of land use activity, technology, and starting period, might be standing on soil of a different fertility class.

Three situations can be distinguished with regard to the maintaining of perennial crops. In the first place perennial crops which are not productive in the period under consideration or of which the optimal area is selected in this period. The second case refers to perennial crops which are still productive and therefore should be maintained, but which do not cause land degradation. The last situation refers to perennial crops which are still productive and which as a result of their effects on land quality are located on a soil of a different fertility class than the one on which they have started.

The first group of perennials has to be excluded from a restriction on the availability of land. Crops which are no longer productive or which start in later periods do not occupy any land in the period under consideration. Furthermore crops of which the optimal area is determined in the period under consideration should not be restricted beforehand. The restriction thus only has to be effective for the perennials in the two last groups distinguished above. The constraint is similar to the way in which the changes in fertility class are determined in Equation 7.11:

$$X_{fslti,p-1} + h_{slti,p-1} X_{fslti,p-1} = X_{fsltip} \qquad \text{all } s,l,t,i \in \alpha, f, p \geq 2 \qquad (7.12)$$

Equation 7.12 is only imposed on LUSTs which belong to a sub-group of LUSTs denominated α. This sub-groups consists of the perennials from earlier periods which are still productive and of which some have caused a change in soil fertility. Identical to the coefficient $k_{fslti,p-1}$ in Equation 7.11 the coefficient $h_{slti,p-1}$ adjusts for changes in soil fertility, if necessary. In the case of perennials which do not cause any change in soil fertility this coefficient has value zero, effectively removing the second term on the left hand side from the equation. Equation 7.12 then reduces to equating the area of the perennial in period p to the area occupied in period $p-1$.

In the case of perennials which do cause a shift in fertility class the situation is a little more complicated. The starting point is again the area of the perennial in period $p-1$ ($X_{fslti,p-1}$). However, now this area is adjusted for the change in the fertility class of the soil on which the crop is standing. The coefficient $h_{slti,p-1}$ assures that the area of the perennial on the soil fertility class from period $p-1$ is reduced to zero in period p, while at the same time creating the same perennial in terms of area occupied, land use activity, technology and starting period but on a soil of different fertility class in period p. As with the changes in land type availability, the total area of the perennial is thus maintained from period p to period $p-1$, only the soil fertility class on which it is standing has changed[8].

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[8] Appendix E contains an example of the transition of a perennial from one soil fertility class to another one.

7.6 Labor use and availability

While land quality links the different periods, labor connects farm types within a single period through the assumption of a closed labor market; for the settlement as a whole labor hired for on-farm work has to equal the amount of time worked off-farm on other farms within the Neguev.

First of all the total amount of labor needed for production has to be determined. The annuity labor use for each LUST ($v_{fsltqip}$, hours/ha) together with the number of hectares each LUST covers determine the total amount of labor needed by each farm type. As with the land constraints, the need for labor is determined per quarter in order to take seasonal fluctuations into account.

$$\sum_{s}\sum_{l}\sum_{t}\sum_{i} v_{fsltqip} X_{fsltip} - F_{fqp} - H_{fqp} \leq 0 \qquad \text{all f,q,p} \qquad (7.13)$$

As can be seen in Equation 7.13 the need for labor can be satisfied with own family labor (F_{fqp}, hours/year) as well as hired labor from other farms (H_{fqp}, hours/year). Together these two types of on-farm labor will have to satisfy the need for labor for each farm type, while at the same time being subjected to constraints in their supply.

Next to the two types of on-farm labor also two types of off-farm labor are being distinguished. Family members can either work on other farms within the Neguev (O_{fqp}, hours/year) or on banana plantations outsides of the Neguev (P_{fqp}, hours/year). The total amount of hours worked by family members, either on or off the farm, cannot exceed the total supply of family labor. This total supply of family labor is subjected to two constraints (Equations 7.14 and 7.15).

$$F_{fqp} + O_{fqp} + P_{fqp} \leq g_{fqp} \qquad \text{all f,q,p} \qquad (7.14)$$

$$\sum_{q} F_{fqp} + \sum_{q} O_{fqp} + \sum_{q} P_{fqp} \leq g_{fp} \qquad \text{all f,p} \qquad (7.15)$$

The total supply of family labor cannot exceed the supply per quarter and per year, with the supply per year (g_{fp}, hours/year) being less than the sum of the supply per quarter (g_{fqp}, hours/year). It has been assumed that at least fifteen days a quarter are unavailable for work, since farmers can be expected to rest at last five days a month. But at the same time it can be assumed that for the year as a whole more days are taken off. This construction of a double restriction on labor availability allows for some flexibility in labor use since full use of labor in one quarter can be compensated with less use of labor in other quarters.

$$\sum_{f} H_{fqp} - \sum_{f} O_{fqp} = 0 \qquad \text{all q,p} \qquad (7.16)$$

$$\sum_{f} P_{fqp} \leq p_{qp} \qquad \text{all q,p} \qquad (7.17)$$

The amount of time worked off-farm is subjected to constraints of the availability of work.
At the regional level no more hours can be worked off the farm than the total number of hours of hired on-farm labor (Equation 7.16). This constraint represents the assumption of a closed labor-

market for the Neguev as a whole. Furthermore, the number of hours worked on plantations outside the Neguev is limited by the available employment at the plantations, p_{qp} (Equation 7.17).

7.7 Environmental indicators

Three environmental indicators are included in the analyses: a biocide index, nutrient balances and erosion. The effects of the latter two processes on production in future periods is included in the Equation 7.11 trough the coefficient $k_{fsq,p-1}$. As a result of the provisional character of the biocide index, discussed in Chapter 6, the effects on production possibilities in later periods cannot be determined. In Equation 7.18 balance of biocide use (B_{fp}, index value/year) is calculated at the farm type level by multiplying the average biocide index value (b_{fsltp}, index value/year) with the area of the respective LUSTs.

$$\sum_{s}\sum_{l}\sum_{t}\sum_{i} b_{fsltip} X_{fsltip} - B_{fp} = 0 \qquad \text{all f,p} \tag{7.18}$$

For three major nutrients (n) balances are calculated using the NUTBAL-model (Stoorvogel, 1995), namely nitrogen, phosphate and potassium (see also Chapter 6). The nutrient balances (N_{nfsp}, kg) are determined per nutrient and farm type with the use of the average nutrient loss or gain for each LUST (u_{nfsltp}, kg/ha) as described in Equation 7.19.

$$\sum_{s}\sum_{l}\sum_{t}\sum_{i} -u_{nfsltip} X_{fsltip} - N_{nfp} = 0 \qquad \text{all n,f,p} \tag{7.19}$$

Finally the erosion per farm type (E_{fsp}, ton/year) is determined for each period through multiplication of the erosion coefficient (e_{fsltp}, ton/ha) with the LUSTs (Equation 7.20). This erosion coefficient is determined with the USLE on the basis of the data and assumptions presented in Chapter 6.

$$\sum_{s}\sum_{l}\sum_{t}\sum_{i} e_{fsltip} X_{fsltip} - E_{fp} = 0 \qquad \text{all f,p} \tag{7.20}$$

Chapter VIII

MODELING RESULTS

8.1 Introduction

The general model discussed in Chapter 7 has been applied to the Neguev settlement, Costa Rica. For this case study the structure of the model had to be adapted with respect to the distinction of farm types, a central feature of MERALM. As discussed in the preceding chapter almost all constraints are defined per farm type. In the objective function the data of all farms are joined in order to maximize the economic surplus at the sub-regional level. However, distinguishing farm types within the Neguev leads to an 'explosion' of the number of variables in the model. For example, all of the 924 LUSTs have to be specified per farm type, causing a swift increase in the number of variables. Considering the limits imposed by the computer software the merits of distinguishing farm types compared to modeling the Neguev as one single farm have to be reviewed. This boils down to examining the size of the aggregation bias of a model without farm types compared to one which does make this distinction.

Ignoring differences between farm types causes a significant aggregation bias in case there are differences between farm types with respect to objective function coefficients and/or constraints. In the case of MERALM all farm types have access to the same LUSTs. This implies that the farms face equal input-output coefficients. Furthermore, the objective function coefficients, i.e. the in- and output prices, are identical for all farms. Even though differences in for example location of the farms can be assumed to cause a variation in prices faced by the farmers, these are not accounted for in the model. As a result farm types only differ with respect to relative availability of land and labor. However, the possibility of exchanging labor between farms reduces the differences in land/labor ratios between the farms. (Schipper, 1996:161) Considering that at present the dissimilarity between farm types is restricted to land/labor ratios and the fact that these differences are diminished through labor exchange between the farms, the aggregation bias of ignoring farm types can be expected to be small. At the same time, a simplification of MERALM facilitates a focus on the assumptions regarding soil types and effects of erosion.

Given the limited aggregation bias and the need for a clear focus on the assumptions regarding soil types, only versions of MERALM without a distinction between farm types are analyzed in this chapter. The differences between the three versions of MERALM which have been developed for the Neguev settlement are summarized in Table 8.1. Two issues are being addressed by the case study. In the first place the necessity of a detailed soil differentiation. To this end two versions of MERALM have been developed. The first one, reviewed in Section 8.2, distinguishes the 8 different soil types as they have been presented in Chapter 6. The following section analyzes the results of MERALM in case the LUSTs are only specified on the basis of 3 soil types, i.e. without a subdivision of the SIW soil type according to slope-differences.

The second issue tackled in this chapter is the effect which land degradation has on the selected cropping pattern. In order to isolate the effect of land degradation from all other factors influencing land use a model has been developed in which land degradation does not affect productivity. Section 8.4 discusses the results of this model in relation to the eight soil type model of Section 8.2. Finally, the last part of the study compares the results of the models with respect to the need to diversify between soil types and the effect of land degradation on land use decisions.

Table 8.1: The three model versions of MERALM used in the case study

	Eight-soil type model	Three soil type model	No effects of land degradation
Soil types	• SFP, SFW, SIWa, SIWb, SIWc, SIWd, SIWe, SIWf	• SFP, SFW, SIW	• SFP, SFW, SIWa, SIWb, SIWc, SIWd, SIWe, SIWf
Degradation	• affects production	• affects production	• does not affect production
Goal	• point of reference	• assessment of the need for a diversification of the SIW soil type	• evaluation of the effect of land degradation on land use patterns

8.2 The Neguev as a single farm: eight soil types

In the model of the Neguev with eight soil types some adjustments have been made with respect to the model specification discussed in Chapter 7. In line with the considerations presented above only one farm is distinguished, the Neguev as a whole. The absence of a distinction of farms within the Neguev prohibits specification of labor exchange between farms. As a result working on other farms disappears as an income earning possibility and only own family labor is available for agricultural production[1]. Income can be derived from agricultural production in the Neguev, for which 924 different LUSTs are available, as well as from working on banana plantations outside the Neguev. Production levels are affected by land use in previous periods through the effect of land degradation on soil fertility classes.

8.2.1 *Economic aspects of production*

Table 8.2 presents the economics of production in the Neguev for each period. The numbers refer to the annuities of the costs and revenues occurring during each period. The low return in the first period is the result of investments in a 1.5 year cassava LUST and the perennial palm heart (see Table 8.4 for the crops in each period). The harvesting of cassava from the first period causes the

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[1] From Equations 7.14 through 7.16 hired on farm labor and labor worked on other farms are deleted, whereas Equation 7.17 as a whole is removed from the model.

relative high returns in the second period. In the third period the investments in palm heart from the first two periods are paying off, making this the most productive period of the whole planning horizon.

Table 8.2: The annuities of the returns in each period for the eight soil type model (¢ 10^6 per year)

	Period 1[1]	Period 2[1]	Period 3[1]	Period 4[1]
Value of production[2]	181	447	889	745
Input costs[3]	73	31	45	39
Gross margin[4]	108	416	843	706
Own labor[5]	60	48	75	69
Return to land, own capital and farm management[6]	48	367	768	637

Note: [1] The periods comprise 1, 2, 6 and 11 years, respectively
[2] Physical output valued at farm gate prices
[3] Costs of current inputs and capital services
[4] Value of production minus input costs
[5] Costs of own labor valued at a reservation wage
[6] Gross margin minus own labor

The investment character of the first period is also reflected by a high input use. The annuity of input costs in the first period is almost twice as high as in the other three periods. Despite these investments, the return to land, own capital and farm management is still positive, although low compared to the other periods. In order to get an insight in the total income available to the settlement, the income derived from plantation work also has to be taken into account. Table 8.3 presents the composition of the economic surplus of each period. Again as in Table 8.2, the annuities of the returns in each period are given.

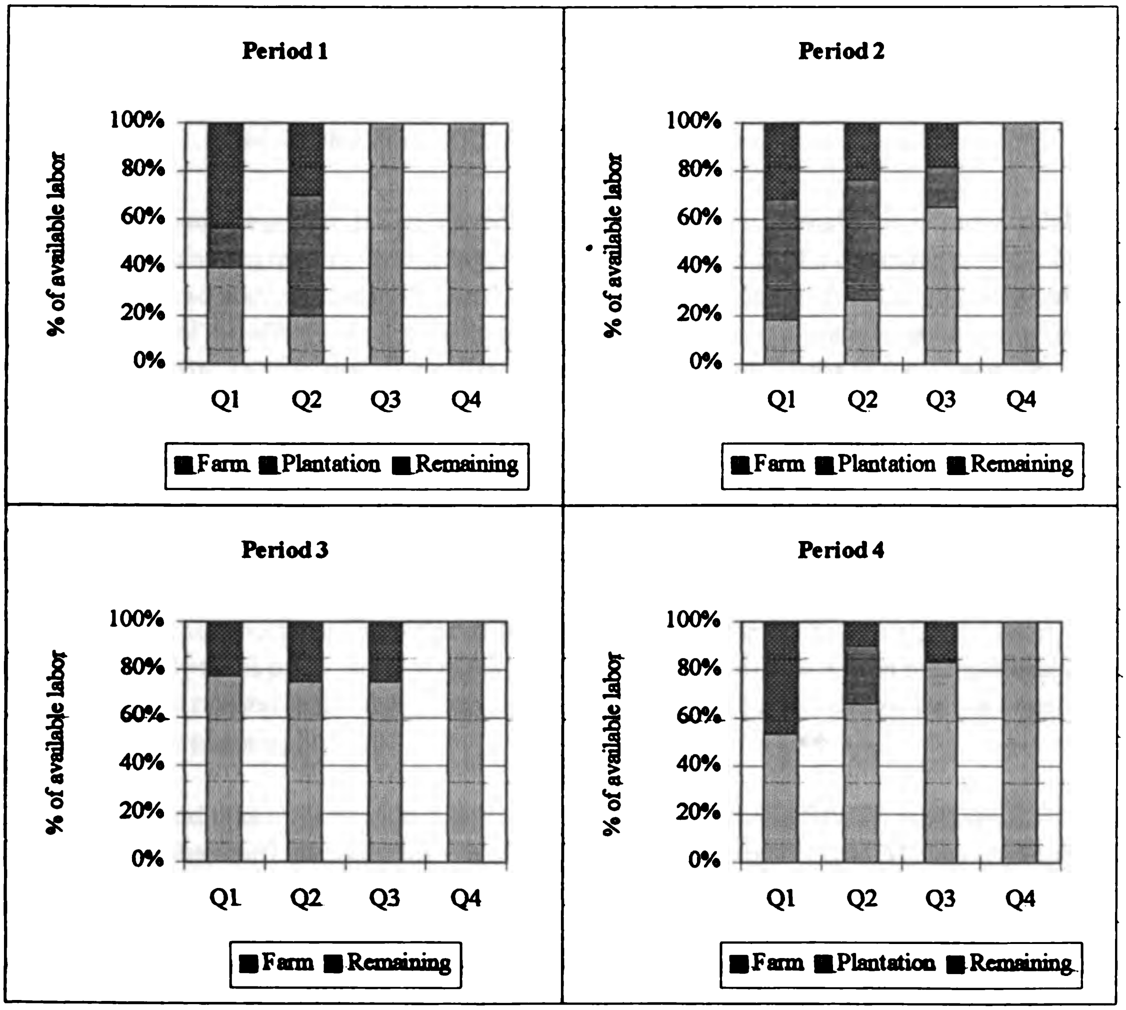
Table 8.3: Annuities of the economic surplus for each period (¢ 10^6 per year)

	Period 1[1]	Period 2[1]	Period 3[1]	Period 4[1]
Gross margin	108	416	843	706
Plantation work[2]	47	82	0	17
Total income[3]	154	498	843	723
Own labor	60	48	75	69
Economic surplus[4]	94	449	768	654

Note: [1] The periods comprise 1, 2, 6 and 11 years, respectively
[2] Remuneration of plantation work
[3] Gross margin plus plantation work
[4] Total income of the Neguev minus costs of own labor

Table 8.3 does not include the returns occurring beyond the last period. These returns from beyond the planning horizon sum up to ¢ 65 10^6 and are the result of the production of palm heart planted in the last period. The value of the objective function[2], comprising both the surpluses of each period as well as the present value of the returns after the fourth period, is ¢ 5686 10^6. The total income in the first period of ¢ 154 10^6 corresponds to 1.3 million US \$[3]. Considering that 307 farms are included in the analysis this would account for 4118 US \$ per family. In the following periods the yearly income per farm increases to 13,287 US \$, 22,512 US \$ and 19,314 US \$, respectively. The high contribution of plantation work to total income in the second period is a result of the 1.5 year cassava LUST selected in the first period. This cassava area is not used in the last year of the second period since plantation work renders more income than growing an annual crop during the remaining year of this second-year period.

Figure 8.1: Allocation of labor in the eight soil type model



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[2] In order to calculate the contribution of the periods to the objective function the economic surplus of each period has to be multiplied with the discount factor. This factor includes both the length of each period, as well as the timing of the annuity returns.

[3] On average 1 US \$ in 1991 could be exchanged for 122 *Colones* (¢) (Schipper, 1996:154)

8.2.2 Labor use

The restriction on labor is an important determinant of land use. In all periods the yearly availability of labor is limiting. Recall from the discussion of the mathematical structure of MERALM that two restrictions are imposed on labor. One restriction applies to the availability on a quarterly basis whereas a more stringent restriction is imposed on a yearly basis. In order to comply with the yearly labor restriction some labor available on a quarterly basis has to remain unused. In Figure 8.1 this is indicated by the category remaining labor. The first category of labor refers to family labor used in the Neguev for agricultural production. As can be seen in the Figure the last two quarters are peak periods for agricultural production, the fourth quarter is even exclusively dedicated to farm production in the whole planning period. The peaking labor demand in the fourth quarter is caused by cassava production which is harvested in the last months of the year. The third category of labor shown in Figure 8.1 gives the percentage of available time worked on plantations outside of the Neguev. The availability of plantation work is limiting in the second quarter of the first period and the first and second quarter of the second period.

8.2.3 Land use activities

The optimal land use pattern is determined by the restrictions on availability of land and labor, the effects of land degradation on future productivity levels and by the discounting of net returns. The latter characteristic of the model tends to favor annual crops which quickly yield income. The incorporation of the effects of land use in previous periods causes a preference for using first the soils less sensitive to degradation in order to prevent productivity losses in future periods.

Table 8.4 presents the area of the LUSTs selected in the model with eight soil types[4]. Land use in the first three periods is largely restricted to less degradation prone soils: SFW and the relatively flat SIWa, SIWb and SIWc soil types. As a result, degradation is restricted to the SIWc1 soil which, due to cassava growing in the third period, degrades to fertility class two. An exception to this avoidance of degradation is the use of 13 percent of SIWe1 soil for cassava growing in the third period. These hectares are excluded from production in the fourth period; palm heart production only takes place on the remaining 505 hectare SIWe1 soil. Given the model-relations it is apparently profitable to exhaust part of the SIWe soil and leave it fallow for the remaining 11 years of the planning horizon.

The steepest and thus most erosion-prone soils, SIWd1, SIWe1 and SIWf1, are taken into cultivation in the fourth period. This is a result of the structure of MERALM. The objective function is restricted to the 20 years of the planning horizon. Productivity losses as a result of land use in the fourth period are only accounted for by the returns beyond this last period. Considering that the fourth periods spans 11 years, 73 percent of revenues of palm heart planted in the fourth period and all of the revenues from palm heart planted in earlier periods are covered by the last period. Only a very limited number of years is thus included in the revenues beyond the last period and therefore exhaustion of the soil in the fourth period goes largely unpunished.

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[4] In order to increase readability of the tables a '-' indicates that the crops is not present in a period.

As a result of the land use in the fourth period all the steep SIW soils have degraded to the third fertility class at the end of the period.

Table 8.4: Land use activities in each period for the eight-soil type model

Land use activity		Percentage of available soil			
Crop	*Soil*	*Period 1*	*Period 2*	*Period 3*	*Period 4*
Cassava	SFP	79	-	-	-
	SFW1	24	24	56	102
	SIWa1	100	-	-	-
	SIWb1	100	11	-	-
	SIWc1	100	100	100	-
	SIWe1	-	-	13	-
	Total area (ha)	*2113*	*624*	*891*	*984*
Palm heart	SFW1	76	76	81	100
	SIWa1	-	100	100	100
	SIWb1	-	89	100	100
	SIWc2	-	-	-	100
	SIWd1	-	-	-	100
	SIWe1	-	-	-	87
	SIWf1	-	-	-	100
	Total area (ha)	*737*	*1768*	*1938*	*3597*
Livestock	SFP	-	-	100	100
	Total area (ha)	-	-	*581*	-
Pineapple	SIWc1	-	-	100	-
	Total area (ha)	-	-	*274*	-

Note: The percentages are calculated on the basis of the available area of all fertility classes of one soil type. If the use of a soil type exceeds the 100 percent this implies that in one period multiple crops are cultivated after each other.

SFP: fertile, poorly drained soil
SFW1: fertile well drained soil of fertility class 1
SIWa1: infertile well drained flat to almost flat soil of fertility class 1
SIWb1: infertile well drained undulated soil of fertility class 1
SIWc1, SIWc2: infertile well drained strongly undulated to inclined soil of fertility class 1 and 2
SIWd1: infertile well drained hilly to moderately steep soil of fertility class 1
SIWe1: infertile well drained steep soil of fertility class 1
SIWf1: infertile well drained very steep soil of fertility class 1

The optimal land use under the present model-assumptions consists mainly of a mix of investments in the perennial palm heart and cassava which yields return within 1.5 years. Both crops have a high gross margin per hour of labor input, making them attractive given the relative scarcity of labor. The cassava LUSTs vary in lifetime from 1 to 1.5 year whereas the palm heart occupies the soil during 15 years. The large area of cassava planted in the first period results in a high income stream in the beginning of the second period whereas the investments in palm heart during mainly the second period start yielding returns during the third period.

The palm heart area increases from 17 percent of the available land in the first period to 85 percent in the last period. The focus on palm heart is in line with the results of the annuity model of the Neguev (Schipper, 1996:157) and with the finding in other studies that palm heart is an attractive crop for small farmers (Jansen et al., 1996:23). From two farm-surveys in the Neguev it can be derived that a shift has taken place from a diversity of crops with maize and cassava as dominant crops in 1987 to production of a very limited number of crops with palm heart as the leading crop in 1996 (Kuiper, 1996:33). However, despite a significant change in cropping pattern towards palm heart the estimated total area under palm heart in 1996 is no more than 150 hectare. Factors not included in the model like limited availability of capital, risk aversion and preferences for livestock account for the divergence between the concentration on palm heart and cassava in the model solutions and the limited areas encountered in the field.

The selected palm heart LUST is a potential technology which uses no fertilizer nor biocides and as a result uses less labor than the other two available palm heart technologies. The limited use of labor causes the gross margin (value of output minus input costs) per unit of labor to be the highest of the available palm heart technologies, making it the most attractive LUST in the light of the relative scarcity of labor. In case of cassava two technologies are selected. On the SFP, SIWa1 and SIWb1 soils a one-year cassava LUST is planted using a technology as observed in the field. The other technology is a potential one which stands 1.5 year and for which both biocides and fertilizer are used..

In case of the cassava more than one crop can be grown in the third and fourth period since the length of these periods exceeds its cropping cycle. This is expressed by the total number of cropped hectares exceeding the available number of hectares on a yearly basis. For example in the case of the SIWc1 soil in the third period cassava and pineapple both use 100 percent of the available area. This is possible because the pineapple stands for 5 years and the selected cassava LUST for one year, together they thus occupy the available SIWc1 soil for all 6 years of the third period. The same goes for the use of the SFW1 soil in the third and fourth period; cassava is then used to fill the periods in which the palm heart area lays fallow.

Finally, the SFP area is used for an extensive livestock system on natural pasture in the third and fourth period. All of the SFW soil is already used in this period, just as the SIW areas not too sensitive land degradation. The remaining labor can then be allocated to either cultivation of the SFP soil or plantation labor. A potential livestock technology is selected which yields the highest net present value of the available LUSTs for SFP soil. Although the livestock system has a low gross margin on a hectare basis the gross margin per hour of labor is higher than the earnings with plantation labor in the third period.

8.3 The Neguev as a single farm: three soil types

In order to assess the necessity of a detailed differentiation between soil types a second version of MERALM has been developed, distinguishing only three different soil types. All SIW sub-groups classified on the basis of the slope categories *a* through *f* are combined in one SIW soil type with an average slope. In all other respects the three soil type model is identical to the one discussed above. No farm types are distinguished and thus no hiring of labor within the Neguev is possible. Plantation work and agricultural production are therefore the only sources of income. As a result of the decrease of soil types from 22 to just 7, the number of LUSTs has diminished to 324. As in the previous model land use can affect future production levels by causing a transition to another fertility class.

Table 8.5: The annuities of the return in each period for the three soil type model (¢ 10^6 per year)

	Period 1[1]	Period 2[1]	Period 3[1]	Period 4[1]
Value of production[2]	57	393	964	789
Input costs[3]	107	44	24	34
Gross margin[4]	-49	349	939	755
Own labor[5]	42	58	75	63
Return to land, own capital and farm management[6]	-91	291	864	692

Note:
[1] The periods comprise 1, 2, 6 and 11 years, respectively
[2] Physical output valued at farm gate prices (¢ 10^6 per year)
[3] Costs of current inputs and capital services (¢ 10^6 per year)
[4] Value of production minus input costs (¢ 10^6 per year)
[5] Costs of own labor valued at a reservation wage (¢ 10^6 per year)
[6] Gross margin minus own labor (¢ 10^6 per year)

8.3.2 Production economics

The economic production data of the three soil type model are shown in Table 8.5. Again the first period is characterized by investments in perennial crops. This time the investments result in a negative gross margin and return during the first year. In contrast to the eight soil type model mainly the 1.5 year cassava LUST is selected. As a result almost no harvesting takes place in the first period and therefore little income is derived from agricultural production in this year, resulting in the negative return.

Again the third period is the time at which investments in palm heart from the first two periods are yielding their benefits (see Table 8.7 for the cropping pattern). Furthermore the tree plantations from the first period do not require any inputs after the second period, while starting to be productive from the third period on. Together this results in the third period being the most profitable one of the planning horizon.

The total value of the objective function is ¢ 5945 10^6 for the planning period as a whole. Table 8.6 shows the economic surplus for each period. In addition to the returns from the periods the returns occurring beyond the last period have a present value of ¢ 20 10^6. Although the agricultural production in the first period requires a net investment instead of rendering income, the total income of the settlement is positive in this period. This is the result of the high number of hours worked at the plantations (see Figure 8.2). However, an income for the settlement as a whole of ¢ 51 10^6, circa 0.4 million US \$, can assumed not to be sufficient to support the families of the 307 farms in the area during the first year (it would provide roughly 1300 US \$ per farm). Again the income increases in the following periods; the yearly income per farm goes from 10,695 US to \$ 25,078 US \$ in the second period and 21,160 US \$ in the last period.

Table 8.6: Annuities of the economic surplus in each period for the three soil type model (¢ 10^6 per year)

	Period 1[1]	Period 2[1]	Period 3[1]	Period 4[1]
Gross margin	-49	349	939	755
Plantation work[2]	100	52	0	37
Total income[3]	51	401	939	793
Own labor	42	58	75	63
Economic surplus[3]	9	342	864	730

Note: [1] The periods comprise 1, 2, 6 and 11 years, respectively
[2] Remuneration of plantation work
[3] Gross margin plus plantation work
[4] Total income of the Neguev minus costs of own labor

8.3.3 Labor use

The allocation of the available labor to agricultural production, plantation work outside the Neguev and the remaining labor for each quarter is presented in Figure 8.2. As in the previous model the yearly labor availability is limiting in all periods. This time there is no single quarter exclusively devoted to farm labor, but in all periods most labor is used for agriculture during the last two quarters of the year. This labor-peak is the result of the cultivation of cassava which, in contrast to palm heart, has a distinct harvesting period at the end of the year.

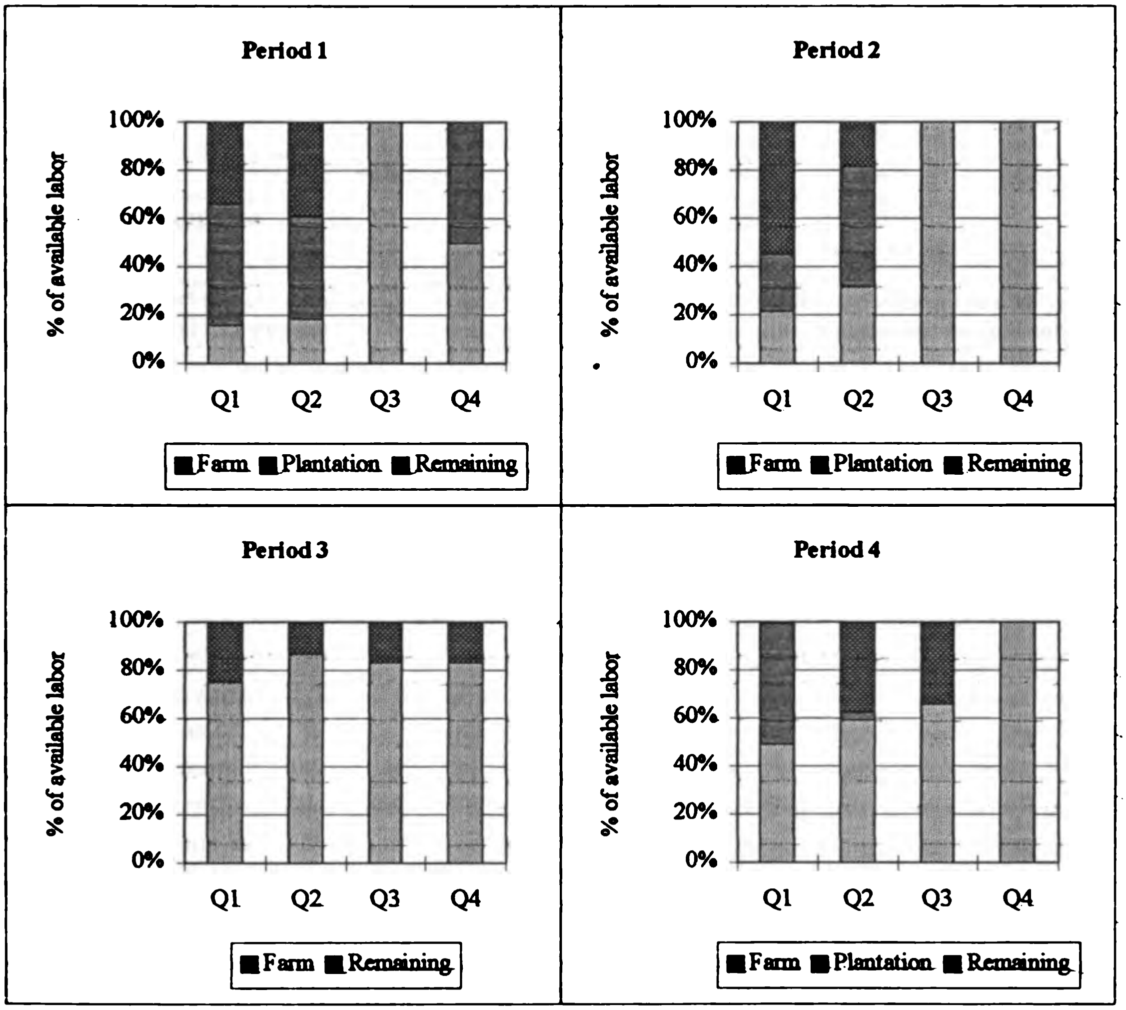
In the first and last quarter of the first period the full amount of available plantation work is used. Since almost no cassava with a cropping cycle of a year is grown the labor peak in the last quarter of the first period is lacking. The planted cassava is not harvested until the second period, therefore labor is available to work on plantations outside of the Neguev, while at the end of the second period all labor is needed for agricultural production. As in the previous model during the third period all labor is needed for agricultural production and thus no income is derived from plantation labor.

8.3.4 Land use activities

Table 8.7 presents the cropping pattern selected in the three soil type model. In contrast to the preceding model all the available SIW soil is degraded to the second fertility class as the result of land use in the third period. On the SFW soils no degradation takes place. The selected land use pattern consists of three crops with high revenues but distinct differences in productive lifetime. The selected cassava stands either 1 or 1.5 years, whereas tree plantations and palm heart are productive for 13 and 15 years, respectively. Palm heart again forms the core of the solution of the model, occupying 17, 59, 72 and 77 percent, respectively, of the total available land in each period.

Palm heart is primarily grown on SIW soil types. Planting on SFW soils does not occur until the third period when all available SIW soils have been used. This despite the fact that the yield per hectare is highest on the fertile SFW soils. Two factors cause the reservation of SIW soils for palm heart production. In the first place the SFW soils have better alternative land uses apart from palm heart, resulting in a comparative advantage of SIW soils with regard to palm heart, for which attractive alternative uses are lacking. (Schipper, 1996:172) However, probably more important in the light of the relative scarcity of labor is the fact that the gross margin per unit of labor is the highest on SIW soils for the selected palm heart technology. The selected technology uses no fertilizer nor biocides and therefore has a low labor input. Thus, despite the fact that the yield per hectare is highest on the SFW soils, the return per unit of labor is higher on SIW soils.

Figure 8.2: Allocation of labor in the three soil type model



Not only the attractiveness of palm heart causes the absence of any other crop from the SIW soils. Planting cassava on SIW soils causes soil degradation and thus a loss of productivity in the last periods. However, the palm heart LUSTs from the first three periods cease to exist at the end of the fourth period and since almost no penalty exists for soil degradation in the last period cassava could then be grown. But because growing cassava on the SFW soil yields more, the fallow SFW palm heart area form the third period, as well as fallow melina tree area is first cultivated with cassava, as can be seen in Table 8.7. The cultivation of the cassava is then limited by the availability of labor in the fourth quarter. As can be seen in Figure 8.2 all labor in the fourth quarter of the last period is dedicated to agricultural production and thus no more cassava can be planted, despite the fact that some SFW and SIW soils are still available.

Table 8.7: Land use activities in each period for the three soil type model

Land use activity		**Percentage of available soil**			
Crop	*Soil*	*Period 1*	*Period 2*	*Period 3*	*Period 4*
Cassava	SFP	100	-	-	-
	SFW1	60	60	66	113
	Total area (ha)	*1162*	*581*	*639*	*1093*
Palm heart	SFW1	-	-	38	60
	SIW1	26	92	100	-
	SIW2	-	-	-	100
	Total area (ha)	*710*	*2494*	*3075*	*3288*
Melina tree plantation	SFW1	40	40	40	40
	Total area (ha)	*387*	*387*	*387*	*387*

Note: The percentages are calculated on the basis of the available area of all fertility classes of one soil type. If the use of a soil type exceeds the 100 percent this implies that in one period multiple crops are cultivated after each other.

SFP: fertile, poorly drained soil
SFW1: fertile well drained soil of fertility class one
SIW1: infertile well drained soil of fertility class one
SIW2: infertile well drained soil of fertility class two

Cassava has a high gross margin accompanied by a high labor requirement in the last quarter of the cropping cycle when the tubers are harvested. Two cassava LUSTs are selected. On the SFP soils a technology as observed in the field is used, standing one full year and using only biocides as inputs. The selected LUST for the SFW soils stands for 1.5 years and use biocides as well as fertilizer. For this LUST multiple cropping is possible in the third and fourth period, since both of them comprise more than two years. The fact that the total SFW1 area occupied by cassava, trees and palm heart exceeds the 100 percent in period 3 and 4 implies that cassava is cropped several times with the land being fallow in the period between two cropping cycles. These fallow periods could be used to cultivate a 6-month maize LUST, but working on the banana plantations provides more income per unit of labor.

Tree plantations are also an attractive land use in terms of the gross margin per hectare and per unit of labor. However, in contrast to palm heart which starts rendering a positive gross margin form the second year on, the benefits of trees planted in the first period mostly take place in the fourth period. The long gestation period of the trees combined with the limited use of labor after the initial investment explains the planting of trees in the first year of the planning horizon. In this way the benefits from the investments are occurring as soon as possible which as a result of discounting is very attractive, while at the same time the limited labor use later on enables the substantial planting of palm heart in the third and fourth period.

8.4 The effect of land degradation on production

In the preceding sections two versions of MERALM have been analyzed in which land use affected productivity levels in later periods. The selected land use activities where thus partly based on avoiding a loss of future productivity. In this section the effect of degradation is separated from the other determinants of production: labor supply, land availability and discount rates. The most important constituent of the land degradation as included in the modeling exercises is erosion, while the disruption of the nutrient balance only accounts for a small part of the change in potential nitrogen supply. Erosion on its turn is mainly determined by the slope of the cultivated soil. Therefore, as a point of reference the eight soil type model as reviewed in Section 8.2 is used. This model with sub-groups of SIW soils based on slope-classes, allows for the most precise insight in the effect of land degradation on cropping patterns.

The model without effects of land degradation is identical to the eight soil type model from Section 8.2, except for the data on production and returns occurring beyond the last period. Land degradation affects the model solution through the fact that production levels on the second and third fertility classes are 75 percent and 50 percent of those on fertility class one. The use of inputs as well as labor are identical for all fertility classes. Therefore, in order to exclude the effects of erosion only the production levels have to be made identical for fertility classes of one soil type. In terms of the model specification of Chapter 7 the coefficient $y_{jfsltip}$ from Equation 7.4 indicating the production per LUST and the coefficient m_{fslti} defining the returns beyond the last period (Equation 7.2) have to be adapted. The changes in fertility classes are still recorded just as in the previous two models, but this time the transitions do not have any consequences for future production levels.

The Neguev is once again modeled as one single farm. Income can be derived from cultivating a selection from 924 LUSTs and from working on the plantations. All restrictions on land and labor availability and the discount rate are identical to the eight soil type model. Compared to the latter model it is expected that more transitions of soils will take place; no economic incentives for avoiding soil exhaustion exist while the models are identical in all other respects.

8.4.1 Land use activities

The selection of land use activities is the central aspect of each model solution. All other variables like allocation of labor, income streams and transition of soil types between fertility classes are determined by this selection. Therefore first the allocation of land of the model in which land use does not affect production levels is reviewed in relation to the land use pattern of the eight soil type model of Section 8.2. In the following part the transitions of soils between fertility classes are analyzed.

In the model of Section 8.2 the degradation-prone soils (SIWd, SIWe, SIWf soils) were not used until the last period to avoid punishment for the exhaustion of soils. As Table 8.8 shows, in the present model these soils are used from the first period on. And in contrast to Table 8.2 the SFP soil is now totally excluded from production. This is the result of the absence of a limitation in terms of lost future productivity to prevent the use of SIW soils. The production of cassava in the first period therefore takes place on these soils which yield a higher return then cultivation of the

SFP soil. In the first period the one-year cassava LUST is selected almost exclusively. This assures that the soils are available for palm heart in the second period. Since this cassava LUST renders the highest gross margin on the SIW soils the SFW soil is allocated to other uses.

Again the cropping pattern is biased strongly towards palm heart and cassava. The lack of incentives to postpone the use of degradation prone soils to the fourth period also prevents the selection of livestock. Instead melina tree plantations are selected which have a lower labor requirement than the livestock in the last two periods. This frees labor for increased cultivation of cassava and palm heart in the last two periods.

Table 8.8: Land use activities of the model without effects of degradation

Land use activity		**Percentage of available soil**			
Crop	*Soil*	*Period 1*	*Period 2*	*Period 3*	*Period 4*
Cassava	SFW1	-	-	-	116
	SIWa1	100	-	-	-
	SIWb1	56	-	-	-
	SIWc1	-	-	100	-
	SIWd1	100	-	-	-
	SIWd2	-	87	13	-
	SIWd3	-	-	85	-
	SIWe1	100	-	-	-
	SIWf1	101	-	-	-
	Total area (ha)	*1956*	*592*	*942*	*1120*
Palm heart	SFW1	39	39	39	39
	SIWa1	-	100	100	100
	SIWb1	26	100	100	100
	SIWc2	-	-	-	100
	SIWd3	-	-	59	100
	SIWe3	-	100	100	100
	SIWf3	-	101	101	101
	Total area (ha)	*655*	*2131*	*2530*	*3087*
Melina tree plantations	SFW1	61	61	61	61
	Total area (ha)	*587*	*587*	*587*	*587*

Note: The percentages are calculated on the basis of the available area of all fertility classes of one soil type. If the use of a soil type exceeds the 100 percent this implies that in one period multiple crops are cultivated after each other.

SFP : fertile, poorly drained soil
SFW1 : fertile well drained soil of fertility class 1
SIWa1 : infertile, well drained flat to almost flat soil of fertility class 1
SIWb1 : infertile, well drained undulated soil of fertility class 1
SIWc1, SIWc2 : infertile, well drained strongly undulated to inclined soil of fertility class 1 and 2
SIWd1, SIWd2, SIWd3 : infertile, well drained hilly to moderately steep soil of fertility class 1,2 and 3
SIWe1, SIWe3 : infertile, well drained steep soil of fertility class 1 and 3
SIWf1, SIWf3 : infertile, well drained very steep soil of fertility class 1 and 3

As expected, the value of the objective function is much higher in case land degradation is assumed not to affect future productivity. In the first place yields on fertility classes two and three are higher than in the model of Section 8.2. Furthermore, the absence of an effect of land use on future productivity allows for the cultivation of high yielding crops which cause land degradation, like cassava, during the whole planning horizon. The value of the objective function in the model without effects of land degradation on productivity is ¢ 6186 10^6. This is an increase of 9 percent compared to the total economic surplus of the model with eight soil types.

The allocation of labor is similar in both models. The fourth quarter of each period is exclusively dedicated to agricultural production, whereas the third period as a whole is dedicated to farm work. Plantation labor is especially high in the first two periods, availability of plantation work is limiting in the first quarter of the first period and the second quarter of the second period. More palm heart and less cassava is cultivated in the last model, causing total labor use to be slightly lower than in the model of Section 8.2. As a result more hours can be worked at the plantations. The availability of labor is again limiting in all periods, and especially in the third period the shadow price for labor is high.

8.4.2 *Transitions of soils to other fertility classes*

The differences in selection of crops causes significant differences in transitions of soils. Table 8.9 presents the availability of soils for the model with eight soil types, while Table 8.10 gives the data for the model without effects of land degradation. In the eight soil type model land degradation is limited to the SIWc1 and SIWe1 soil type. The 77 hectare SIWe1 soil degraded to fertility class 3 is excluded from production in the last period. The SIWc2 soil is used for palm heart production in the last period.

Table 8.9: Transitions of soil types in the eight soil type model

Soils		**Number of hectares**			
Soil type	*Fertility class*	*Period 1*	*Period 2*	*Period 3*	*Period 4*
SFP	-	581	581	581	581
SFW	1	968	968	968	968
SIWa	1	76	76	76	76
SIWb	1	1074	1074	1074	1074
SIWc	1	274	274	274	-
SIWc	2	-	-	-	274
SIWd	1	682	682	682	682
SIWe	1	582	582	582	505
SIWe	3	-	-	-	77
SIWf	1	18	18	18	18

Note: SFP : fertile, poorly drained soil
SFW : fertile well drained soil
SIWa : infertile, well drained flat to almost flat soil
SIWb : infertile, well drained undulated soil
SIWc : infertile, well drained strongly undulated to inclined soil
SIWd : infertile, well drained hilly to moderately steep soil
SIWe : infertile, well drained steep soil
SIWf : infertile, well drained very steep soil

In the model without any effects of land degradation on productivity many transitions between fertility classes take place, mainly caused by growing cassava. Table 8.10 clearly shows that the

SIW soils of fertility class *c* through *f* are most prone to erosion. The other soils do not show any transition, just as in the model with eight soil types their availability remains identical in all periods. The most steep soil types, SIWe and SIWf, already shift to the lowest fertility class after one year of use in the first period. Degradation of the SIWd soil takes place in a stepwise fashion. The SIWd soil degrades to fertility class two as a result of growing cassava in the first period. During the second period, 592 hectares of 1.5 year cassava planted in the first period cause a further degradation of the soil to the lowest fertility class. The 90 hectare which have been under the one-year cassava in the first period are fallow during the second period. Finally, after using all the 90 hectare SIWd2 soil for cassava in the third period, all SIWd soil has degraded to the lowest fertility class at the start of the fourth period.

Table 8.10: Transitions of soil types in the model without degradation

Soils		**Number of hectares**			
Soil type	*Fertility class*	*Period 1*	*Period 2*	*Period 3*	*Period 4*
SFP	-	581	581	581	581
SFW	1	968	968	968	968
SIWa	1	76	76	76	76
SIWb	1	1074	1074	1074	1074
SIWc	1	274	274	274	-
SIWc	2	-	-	-	274
SIWd	1	682	-	-	-
SIWd	2	-	682	90	-
SIWd	3	-	-	592	682
SIWe	1	582	-	-	-
SIWe	3	-	582	582	582
SIWf	1	18	-	-	-
SIWf	3	-	18	18	18

Note: SFP : fertile, poorly drained soil
SFW : fertile well drained soil
SIWa : infertile, well drained flat to almost flat soil
SIWb : infertile, well drained undulated soil
SIWc : infertile, well drained strongly undulated to inclined soil
SIWd : infertile, well drained hilly to moderately steep soil
SIWe : infertile, well drained steep soil
SIWf : infertile, well drained very steep soil

8.5 Comparison of the results of the three models

In order to facilitate the comparison of the models their results have been summarized in Table 8.11. The economic surplus corresponds with the value of the objective function of each model, i.e. the surplus of all years of the four periods as well as the returns beyond the last period. The cost of own labor and the income from the plantation work, palm heart and cassava production give an indication of the allocation of labor and optimal land use pattern of each model. Finally, the total amount of erosion indicates to what extent land degradation is avoided in each of the models.

8.5.1 Differentiation between soil types

The first goal of this chapter is to assess the need for a detailed differentiation between soil types. To that end two models have been developed, one with eight soil types and a second one with three soil types (SFP, SFW and SIW). The eight soil types are obtained by a subdivision of the SIW soil in six different slope classes, SIWa through SIWf. The principal difference between the two models is the cultivation of the SIW soils. In the eight soil type model use of the steep and thus degradation-prone soils is postponed until the fourth period to avoid land degradation. In the second model 92 percent of the SIW soil is already in use during the second period and all the SIW soil is used in the third and fourth period.

This early use of almost all the SIW soils compared to the first model is the result of using an average slope for the SIW soil type as a whole. The distinct differences between the SIW slope classes are obscured by this average slope and thus the steep soils, comprising 47 percent of the SIW soils, are used from the second period on. As a result the economic surplus is 5 percent higher than in the first model. This higher surplus is mainly caused by a larger palm heart area, as is indicated in by the higher value of the palm heart production.

Table 8.11: Summary of the model results

	Eight soils	Three soils	No degradation
Economic surplus (¢ 10^6)	5686	5945	6186
Total costs own labor[1] (¢ 10^6)	241	304	282
Total income plantation labor[2] (¢ 10^6)	623	603	610
Total value palm heart production (¢ 10^6)	3634	3961	3691
Total value cassava production (¢ 10^6)	2597	2264	2731
Total erosion (10^3 ton)	477	544	871

Note: [1] Net present value of own family labor valued at the reservation wage
[2] Net present value of the remuneration of plantation work

All optimal land use patterns are biased towards palm heart and cassava, but models differ in the soil types allocated to these crops. In the three soil type model all SIW soil is subjected to degradation as the result of an average slope for all SIW sub-classes. Therefore the cultivation of cassava, causing a relative strong degradation, is restricted to the SFW soil. In the eight soil type model on the other hand, cassava is also grown on relatively flat SIW soils which are not subjected to degradation. The model solutions further differ with respect to cultivated crops other than cassava and palm heart. In the eight soil type model livestock and pineapple are grown, whereas in the second model melina trees are planted. These differences are the result of the fact that in the eight soil type model use of the steep SIW soils has to be postponed to the last period. Compared to the three soil model this frees labor in the first three periods, which is used for the pineapple and livestock.

In the three soil type model erosion on the SIW soil type is calculated on the basis of the average slope. Given the early use of the steep SIW soils this underestimates the total erosion. In case the erosion as a result of the optimal land use pattern of the three soil type model would be specified for each SIW sub-class the total soil loss would be even higher. Even with this underestimation, the total erosion in the second model already exceeds the soil loss in the first model with 14 percent. This higher level of erosion is the result of using more of the SIW soil than in the eight soil type model in the first three periods of the planning horizon.

In the light of the use of SIW soils sensitive to degradation and the underestimation of erosion one can conclude that a more differentiated approach than just three soil types should be adopted. However, the specification of eight different soil types can be considered too much detail, especially in the light of the restrictions to model size imposed by computer software. Observing the use of the SIW soil types in the eight soil type model a dichotomy between two groups of SIW soils becomes apparent. On the one hand the relatively flat SIWa, SIWb and SIWc soils which either are not subjected to degradation or only after extended use. These soils are used from the first period on. On the other hand one finds the steep SIW soils almost totally excluded from cultivation until the last period. It can be assumed that the selected optimal land use pattern will differ little from the one presented in Table 8.4 in case the six different SIW soils are replaced with two groups: a flat soil type consisting of the SIWa, SIWb and SIWc soils and a steep degradation-prone group of soils, containing the remaining SIW soils. At the same time a restriction to four soil types will greatly reduce the number of variables in the model.

8.5.2 Absence of the effect of land degradation

The last model, in which land degradation does not affect future productivity, has the highest value of the objective function of all models discussed in this chapter. The economic surplus is 9 percent higher than derived from the first model in which productivity is affected by erosion. This percentage can be seen as an indication of the costs of land degradation as measured by MERALM since both models are identical in all aspects, except for the effect of land degradation on future production levels. The difference between the two objective function values can thus be interpreted as the amount of economic surplus which has to be sacrificed in order to bring the land degradation to an acceptable level in economic terms.

The difference in economic surplus is the result of differences in cropping patterns and of a higher production level on fertility classes two and three. In case the effect of degradation is not taken into account, the steep soils will be used from the first period on. Thus more land is available than in the first model which excludes the steep soils from production during the first three periods. This increased availability of land leads to an increased production of cassava and palm heart causing the higher value of the objective function. The use of the degradation-prone soils from the first period on has significant consequences for the transitions of the soils to lower fertility classes. The steep soils degrade to the lowest fertility class after just one year of use, whereas the less sensitive soils are fully degraded after the three periods. On the other hand, in the first model almost no degradation does occur; nearly all soils stay in fertility class one except for the SIWc area and a small part of the SIWe soil.

Concluding it can be stated that the inclusion of land degradation in the model has significant consequences for the cropping pattern. In case the effect of land degradation on future productivity levels is accounted for 45 percent of the SIW soil is left fallow during the first three periods of the planning horizon in order to avoid future productivity losses. In the second model in which three soil types are distinguished, these soils are used from the second period on whereas in the last model the steep soils are used from the first period on. Averaging or excluding the effect of land degradation thus causes an overestimation of the cultivation possibilities and economic surplus which can be derived form agricultural production.

Chapter IX

CONCLUSIONS

9.1 Introduction

The aim of this chapter is to evaluate the model developed in this study with respect to the goals of the study, other land use models as well as the actual land use observed in the Neguev. The review of the *Multi-period Economic Regional Land use Model* (MERALM) starts with the way in which it addresses the objectives of the study set out in Chapter 4, since these to a large extent determine the structure of MERALM. Section 9.3 then compares MERALM to the land use models which have been discussed in Chapter 3, in order to outline the similarities and differences with respect to other efforts at integrating land degradation in economic land use models.

After these mostly theoretical considerations Section 9.4 compares the results from MERALM to the actual land use pattern as it has been observed during the 1996 general farm survey. This comparison highlights some of the important factors which determine the land use in the Neguev settlement. Furthermore, it also provides and indication of the way in MERALM could be applied for the evaluation of different agricultural policies. Finally, on the basis of the results from the previous sections, the last part outlines possible directions for further development of MERALM and the way in which certain drawbacks of the present structure could be addressed.

9.2 The objectives reconsidered

The overall goal of this study is the development of a multi-period linear optimization model, which takes the effects of land use on future productivity into account. In relation to this aim the following objectives have been formulated in Chapter 4:

- incorporation of erosion
- formulation of a multi-period model
- endogenous determination of soil fertility
- assessing the need for a detailed differentiation between soil types

The first three objectives refer to requirements with respect to the structure of the model, whereas the last one is concerned with the amount of detail needed in the data-sets.

The inclusion of erosion has been motivated by the widespread agricultural and environmental problems caused by this form of land degradation. In order to assess the sustainability of agricultural practices their effect on erosion rates has to be accounted for. Because of the distinct differences between the soil mapping units which constitute the *Infertile Well-drained* (SIW) soil type it has been sub-divided in 6 slope classes. No data are available on the relation between the technologies and the occurrence of erosion. Soil loss thus has to be assumed not to be affected by differences in the technologies between *Land Use System Technologies* (LUSTs). This assumption also entails that no soil-conserving technologies are distinguished in the analysis. Based on the erosivity of the rain, erodibility of the soil, slope gradient, slope length and crop cover the soil lost by erosion has been calculated with the *Universal Soil Loss Equation* (USLE). On the basis of the resulting LUST-specific data the erosion brought about by the selected land use pattern can be calculated for each period.

The time aspect of land degradation processes and the investment period of perennials were the rationale behind the second objective: development of a multi-period model. In order to take the long run effects of land degradation into account a sufficient number of years has to be included in the analysis. At the same time, the investment period associated with perennials crops requires a significant amount of detail in order to distinguish the investment period from the productive period. Because of these two considerations a planning horizon of 20 year has been adopted, in which four periods have been constructed of 1, 2, 6 and 11 years, respectively.

Periods which cover 5 or more years obscure the sacrifice of income in the first two to three years of perennials, since part of the productive period is also included in the calculation of the annuities. To address this issue the first periods comprise only a few years. Use of a large number of short periods to cover the 20 year planning horizon is not possible since the number of variables increases rapidly with the number of periods. Therefore, later periods span a larger number of years to obtain a sufficiently long time horizon to account for the effects of land degradation. This need for a longer time horizon for the effects of land degradation is illustrated by the results of the first two models discussed in Chapter 8. In both models shifts in soil fertility classes do not occur until the fourth period. The use of time periods of different length and annuities to represent a period have some drawbacks, which are discussed in Section 9.5.1.

For all periods a representative year is constructed based on annuities for production, inputs and labor use. The use of land is calculated with averages to allow for the cultivation of multiple crops on the same plot of land. The objective function of the model maximizes the economic surplus of all four periods, taking into account their difference in length as well as their timing.

The existence of a relationship between periods in terms of the effects of land degradation is the rationale of including an endogenous determination of soil fertility. In order to incorporate the consequences of land use for future production in the decision processes these effects have to be determined within a model run and cannot be determined after the optimal land use pattern has been selected. For all LUSTs their effect on soil fertility is defined in terms changes in the potential nitrogen supply of the soil, induced by soil-loss due to erosion and through a disruption of the nutrient balance. Differences in fertility are translated into three fertility classes, each with a different production level which is directly related to the nitrogen supply. For each LUST the effect on the soil in terms of inducing a transition in fertility class is determined. Thus after each period parts of the cultivated area can be shifted to a different fertility class, depending on the selected of LUSTs.

The differences in production between fertility classes serve as punishment for land degradation, since they cause a reduced production in all following periods. As a result the degradation-prone soils are either cultivated with crops causing only limited degradation, or they are left fallow in the early periods of the planning horizon. The comparison of the eight soil type model with the model without degradation effects illustrates this mechanism. In the eight soil type model 45 percent of the SIW soil is left fallow in the first three periods, whereas in the model without degradation effects all SIW soil is used from the second period on. Furthermore, in the eight soil type model all SIW soils are used in the fourth period; this is the last period and thus no punishment in terms of less production in later periods can be imposed.

Finally, the last objective is to assess the need for a sub-division of the SIW soils in six slope-classes instead of using an average slope for the SIW soil type as a whole. Comparison of the land use in the eight soil type model with the results of the model distinguishing only three soil types shows that the latter model uses the degradation-prone soils from the second period on. In the first model these soils are left fallow in the first three periods in order to avoid a reduced production in the last period. Considering the fact that the degradation-prone soils constitute about a third of the available agricultural area, a sub-division of the SIW soil types according to slopes is necessary.

However, the land use in the eight soil type model shows a clear dichotomy between the relatively flat and the steep SIW soils. The first group is used during the whole planning horizon since they are hardly affected by erosion, whereas the latter group is excluded from production in all but the last period. Given the restrictions to model size it seems more appropriate to replace the six slope-classes with two SIW sub-groups, based on the previously mentioned dichotomy. This will greatly reduce model size and can be expected to have little consequences for the optimal land use pattern.

9.3 A comparison of MERALM with other land use models

Land use models have been described in Chapter 3 on the basis of the level of analysis, modeling method, treatment of time, economic relations and biophysical components. This section compares MERALM to other land use models in terms of these five attributes.

9.3.1 Level of analysis

In contrast to the majority of the land use models found in the literature MERALM uses a sub-region as the level of analysis instead of the farm-level. As a result the general formulation of the model allows for an analysis of land use patterns at the level of soil types, farm types and the sub-regional level. Selection of the sub-regional level also permits modeling of the interactions between the farms in terms of the exchange of labor. As has been discussed in Chapter 3, farmers take the decisions with respect to land use and they can only be indirectly influenced by agricultural policies. Ideally MERALM should thus focus at an optimization of the objective functions of the different farm types. However, within the context of a linear programming structure it is difficult to incorporate multiple objective functions and therefore the economic surplus is maximized at the sub-regional level.

A drawback of this approach is that some farms might be required to sacrifice part of their income in order to increase the economic surplus of the sub-region as a whole. This corresponds to a situation in which the land use in the sub-region is determined by a central planner, whereas in reality farmers base land use decision on their individual income and not that of the sub-region as a whole. Farmers will only be willing to give up part of their income to increase the sub-regional income if some mechanism exists which compensates for the sacrifice of income.

9.3.2 Modeling method

As most other models found in the literature, MERALM uses linear programming in order to determine the optimal land use pattern. The advantage of linear programming is that potential land use activities can be included in the analysis, next to land use practices as they are observed in the field. This means that the analysis is not restricted to past land use patterns but that scenarios describing future land use patterns can also be explored.

The use of linear programming requires a linear specification of the relations included in the model. Furthermore, linear programming models can only deal with one single objective function. In addition to the above mentioned issue of the need for including the objective functions of the individual farmers, an individual farmer might pursue a variety of (conflicting) goals. A third drawback of linear programming is that the results indicate the optimal land use given the conditions included in the model, but do not provide the way in which this allocation of land can be achieved. Nevertheless, scenarios based on model-runs with different assumptions can provide an insight in the effects of policy measures on land use patterns.

9.3.3 Time

The total planning horizon of twenty years of MERALM does allow for the long term effects of land use to be taken into account. In contrast to the models discussed in Chapter 3 MERALM optimizes land use over four periods in one model run, while allowing for endogenous adjustments in soil fertility after each period in response to the selected land use activities. In the case of the recursive models soil fertility is adjusted for the effects of land use activities after these activities are selected.
The land use decisions thus do not incorporate their effect on future production possibilities. It is however likely that farmers will take the effects of their decisions on land quality into account, using their past experiences with the crops.

MERALM makes the differences in the timing of revenues from production commensurable in two steps. For each period annuities are determined on the basis of the net present value of the revenues of each crop in that period. This allows for a comparison of the land use activities within a single period. In the second step the revenues from the periods are compared by discounting them to the start of the planning horizon, while taking their different timing and length into account.

9.3.4 Economic behavior and conditions

Due to the sub-regional level of analysis the interactions between the farms can be modeled within MERALM. In the present version the farms can exchange labor, but no competition for the available labor exists between farms. This is reflected by an identical wage in all quarters of all periods.

The focus on a maximization of economic surplus does not adequately reflect the environment in which land use decisions are taken. The exclusion of risk considerations implies that farmers are assumed to be indifferent with respect to different levels of risk. However, especially in developing countries farmers can be assumed to be risk-averse, and therefore oriented towards a minimization in the variation of their income rather than maximizing their income. A second factor which is not taken into account in the present version of MERALM are restrictions on the availability of capital, as a result of a lack of data. The availability of capital can be expected to especially affect the cultivation of perennial crops. Furthermore the results of periods in terms of stocks of cash or produce are not transferred to the next period. Finally, adjustment costs of shifting to different crops are not included in MERALM. However, the main capital good used in the Neguev settlement is the knapsack sprayer which is used for almost all crops as well as for the pastures. (Kuiper, 1996) Given this limited use of capital goods the adjustment costs of shifting to a different cropping pattern can be assumed to be negligible.

Another aspect of decision-making at the farm level is the effect of land tenure arrangements on land use decisions. In MERALM it has been assumed that all farmers are the owners of their land. Formally this assumption is correct since the Neguev is a settlement in which parcels are assigned to farmers without other means of subsistence. Nevertheless, in practice an increasing number of parcels is owned by people who live in the capital and employ an *adminstrador* to look after their livestock. Their focus on livestock is not caused by a higher net revenue but is a result of the easiness of its production compared to cultivating crops; there is no distinct harvesting period and thus much less problems with supervision of laborers exist. Furthermore, the presence of resourceful absentee landowners combined with the low fertility of the soil has led to an increased concentration of the ownership of land in the Neguev. The general formulation of MERALM, as all land use models discussed in Chapter 3, assumes that the number and size of farms is constant during the whole planning horizon of twenty years.

9.3.5 Bio-physical details

The land use activities are distinguished on the basis of soil type, crop, technology and starting period. This approach implies that a new LUST has to be defined for each different level of input which is being considered. The possibilities of crop rotations within a period are not defined by separate LUSTs, but multiple cropping is allowed through using average land uses per quarter in the land availability constraints. The effect of weather on production levels is not included in MERALM, although the stochastic character of agricultural yields is important in relation to risk-averse behavior of farmers.

MERALM includes three sustainability indicators: the biocide index, the nutrient balance and the level of erosion. However, these indicators do not affect production and thus cannot affect land use decisions. The interaction between the effects of land degradation on production decisions is provided by the transition of soils between the fertility classes. Since the fertility classes are associated with different production levels they affect the economic components of the model. This endogenous determination of land quality combined with the optimization over the planning period as a whole allows land use decisions in early periods to be affected by their consequences for soil fertility in later periods.

Soil fertility is adapted in a location specific way: if 50 hectare of a degrading crop are cultivated these 50 hectare will be of a lower fertility class in later periods but the remaining agricultural area is left unaffected. This in contrast to the model developed by Barbier (1996). In this model the effects of crops on soil quality parameters are translated into deficits which are allocated to all crops in the following period, although the degradation might have only occurred in a small area. This averaging of the effects of land degradation over all the available area of a soil type reduces the incentives for conservation measures: considerable erosion in a small part of the area will lead to a low average deficit and thus no measures will be taken. This effect is comparable to the use of degradation-prone soils in the model without a sub-division of SIW slope-classes: areas which are left fallow in case the differences in slope are accounted for are used from the first period on. In both cases the use of an average obscures the erosion which occurs on degradation sensitive soil types.

MERALM defines land degradation as a change in the potential supply of nitrogen and assumes a linear relation between this supply and production levels. This is a rather crude approximation the complex effects of land use activities on the quality of the soil. For example, the EPIC model which is used in various models discussed in Chapter 3 describes crop yields in relation to water supply, temperature, soil compaction, soil depth, nutrient availability, aluminum toxicity and acidity. In addition to this the NELUP model also includes changes in the hydrological balance and species composition as a result of land use activities.

The USLE has been used to calculate the amount of erosion, despite the fact that there are considerable doubts about is applicability in humid tropical areas. At present no alternatives exist which are well adapted to the humid tropical conditions. Furthermore, the data needed to apply more sophisticated models of land degradation, like the EPIC model, are not available. According to the study of Vahrson and Cervantes (1991) the USLE overestimates the amount erosion, especially on slopes far out of the range of 2 to 20 percent for which the USLE has been calibrated originally. Of the soils included in the study 14 percent has a slope exceeding 20 percent. It can thus be assumed that the USLE overestimated the erosion occurring on these soils. Given reports of both underestimations as well as overestimations of the amounts of erosion in the literature the accuracy of the erosion estimates on the remaining part of the soils is cannot be assessed without actual erosion measurements in the Neguev settlement.

9.4 Comparing the model solution to actual land use

The aim of this section is to highlight some of the reasons why the actual land use pattern as observed in the Neguev settlement differs distinctly from the land use pattern selected by MERALM. Such a comparison of land use patterns allows for a focus on the factors which determine the actual land use and thus provides the background for the following section which addresses possible directions for future developments of MERALM. Furthermore, this comparison allows for a discussion of the possible use of MERALM in terms of supporting agricultural policy-making.

Table 9.1: Actual and optimal major land uses (percentage of available land)

Land use type	**1996 survey**[1]	**Eight soil types**[2]
Annuals	4	23
Perennials	5	67
Pasture	81	12
Forest & wasteland	9	-
Total	100	102[3]

Note: [1] Source: Kuiper (1996)

[2] The average percentage for MERALM are calculated through a weighed average of the areas occupied by the crops in each period, using the number of years of the period as a weight.

[3] Due to multiple cropping of cassava the total area occupied by the crops exceeds the available area

Table 9.1 presents the major land uses as they were encountered during the 1996 survey, next to the results of the eight soil type model of Chapter 8. The land use patterns of the four periods have been converted into an average land use pattern for the planning period as a whole, to allow a focus on the major differences between the two land use patterns. The starting year of the planning period in the case study is 1990, therefore the land use pattern in 1996 has been selected as the point of reference. Table 9.1 shows that actual land use pattern is dominated by pastures, whereas in the case of MERALM more than half of the available area is used for perennial crops.

Table 9.2: Actual and optimal major crops (percentage of available land)

Crops	**1996 survey**[1]	**Eight soil types**[2]
Maize	1	-
Cassava	2	23
Pineapple	-	2
Plantain	1	-
Palm heart	4	65

Note: [1] Source: Kuiper (1996)

[2] The average percentage for MERALM are calculated through a weighed average of the areas occupied by the crops in each period, using the number of years of the period as a weight.

As can be seen in Table 9.2 palm heart is the major land use suggested by MERALM, but although at present it is the most important crop in the Neguev, it occupies only a fraction of the available area. The focus of MERALM on palm heart thus corresponds with the empirical finding that palm heart has become the most important crop (see Table 5.2 for the developments in the areas of the most important crops in the Neguev from 1985 to 1996). However, in contrast to the solution proposed by MERALM the area actually dedicated to crops is only a fraction of the total available agricultural land. The great majority of the settlement is used for extensive livestock systems.

The focus of farmers on extensive livestock systems can be attributed to a number of factors. An important advantage of livestock is the low level of risk compared to crops. Livestock does not have a specific harvesting period, after which it becomes worthless if not harvested. Next to that it can serve as a secure and accessible way of accumulating capital. Furthermore, the extensive way in which livestock is kept allows farmers to work on plantations outside of the settlement. A fourth factor contributing to the expansion of the pasture-area is the presence of absentee land owners. As discussed in Section 9.3 they prefer livestock because of the easiness of the supervision of laborers compared to cultivation of crops. Finally, a last factor contributing to the popularity of livestock is the preferences of farmers based on their experience and cultural background. A number of farmers has migrated to the Neguev settlement from the Guanacaste area, located in the Northwest of Costa Rica, where livestock is the main land use. Due to a familiarity with livestock several farmers prefer it over the cultivation of crops.

The area used for cassava shows large fluctuations during the past decade (see Table 5.2). The crop has proven to be very susceptible to market and price conditions and most farmers have become reluctant to growing it as a result of negative experiences in the past. Palm heart shows a steady increase in area, but not as fast as one would expect on the basis of the potential it has to generate revenues. Some farmers are reluctant to invest in this perennial crop because of sudden price decreases in the past, like with cassava. Other farmers do not have access to marketing channels, which are essential in the case of palm heart since it is mainly produced for the export. A third factor inhibiting a rapid increase in palm heart are investment costs, especially with respect to obtaining planting material. The supply of planting material has not kept pace with the increased demand and as a result the prices have increased. Finally, given the past failures of credit projects most farmers in the Neguev are unwilling to take out credit for palm heart investments, but instead slowly increase its area in pace with their own financial resources.

The objective of MERALM is to maximize economic surplus, and thus the crops with the highest gross margin are selected, resulting in a focus on cassava and palm heart. The high risk levels associated with the cultivation of cassava, nor the capital constraints important for palm heart are incorporated in the decision-making. The restriction of land use decisions to achieving the highest economic surplus also underestimates the advantages of working on plantations outside of the Neguev. Although the return per unit of labor might be lower than for on-farm activities, the income is more secure because it does not depend on the weather nor on the prices at time of harvesting. Furthermore, in the case of plantation work the payment is received in the short term, instead of being delayed until the harvesting period.

Another source of the divergence between the land use patterns is the fact that in MERALM potential land use activities are included. The majority of the LUSTs selected by MERALM are potential LUSTs which at present, by definition, cannot be selected by the farmers. A model which only allows for actually used activities would therefore provide a better basis for the comparison. Finally, the aim of MERALM is to optimize land use over a period of twenty years, whereas the farmers use a much shorter time horizon.

From the discussion of the reasons for the divergence between the solution derived by MERALM and the actual land use pattern two main factors can be derived which limit the use of the present version of MERALM for the derivation of policy measures. In the first place the absence of risk and capital considerations, next to the absence of other goals that the farmers might be aiming at. In the second place the time horizon of twenty years does not correspond to the time frame used by the actual decision-makers. Therefore other models will be needed for assessing more precisely the responses to different policies.

Despite the need for short run models to predict actual responses to policies, MERALM can be useful as a tool to asses the long term sustainability effects of agricultural policies. Its long term perspective is needed to take the extensive time-lags of land degradation processes into account.

The optimal direction of land use patterns with respect to minimizing the effects of land degradation on production can be derived from MERALM, after which short run models could be used to fine-tune the policies. The use of linear programming for MERALM results in a transparent, straightforward model structure. Due to its transparency and the widespread availability of solving algorithms the model can be adapted relatively easy to different regions or circumstances. However, several extensions will have to be made in order to be able to actually use MERALM for the evaluation of the long run sustainability of agricultural land use practices.

9.5 Possible directions for future research

The preceding three sections have evaluated the structure and results of MERALM with respect to the objectives of the study, land use models found in the literature and the actual land use pattern as it was observed during the 1996 general farm survey. In order to serve as a tool to assess the long run sustainability of agricultural land use several extensions of the model are needed. The following parts identify possible research topics in three broad areas: the treatment of time, economic relations and biophysical indicators.

9.5.1 The incorporation of time

In order to include the investment aspects of the cultivation of perennials as well as the long run aspects of land degradation, periods of different length are used in MERALM. The costs and revenues of perennial and annual crops grown in these periods are made commensurable through the construction of annuities. Although this approach permits a detailed focus on the initial years of perennial crops as well as allowing an extended time-horizon within the limits imposed on model size, it has some drawbacks.

In the first place the periods of different length in combination with the use of annuities to represent the flow of revenues in the individual periods, favors the postponement of perennial crops to later periods. In the calculation of the annuities for the last two periods a substantial part of the benefits is included, which obscures the investments needed at the start of the cropping cycle. This results in more favorable annuities for perennial crops compared to the first two short periods. At the same time, the limited number of years included in the first two periods implies that the postponement of investments in perennial crops is not restrained by the discounting of the net revenues. An illustration of this effect is provided by the selection of livestock in the eight soil type model at the expense of plantation work. As a result of the different amount of years used for the annuity calculations, livestock becomes an attractive option in the last two periods compared to working on plantations. Nonetheless this side-effect does not dominate the selected land use pattern. In the discussion of the results in Chapter 8 palm heart and melina tree production is still initiated in the first period.

A second drawback of the present structure of MERALM results from decision-taking for a whole period at once instead of on a yearly basis. This necessitates the assumption that perennial crops always start in the first year of a period, since the exact stream of costs and benefits in the following periods has to be known for the calculation of the annuities. As a result, land which becomes fallow after a perennial crop has ceased to exist cannot be replanted with another perennial crop until the start of the following period. For example, the land which becomes available in the fourth period after palm heart from the beginning periods has ceased to exist, cannot be replanted with palm heart. A second consequence of the analysis per period is the possibility of overestimation of the benefits of the returns of crops which are allowed to be cultivated more than once in a period. Their annuity is based on the net present value of a crop which is planted in the first year of the period. An assumption with respect to their starting period is needed since their starting year is not known beforehand. However, a crop planted later in a period has a lower annuity than a crop planted in the first year, due to the discounting of the net revenues.

Two possibilities exist to address part of the above drawbacks of the way in which the issue of time is handled in the present version of MERALM. In the first place a version of MERALM could be constructed which uses time periods of the same length, in order to eliminate the effect of the differences in years on the modeling results. If the number of soil types is reduced by dividing the SIW soil type in a flat sub-type and a steep sub-type a larger number of periods can be included. However, limits to model size result in a trade-off between the amount of detail needed for the investment decision in perennials and the number of years needed to incorporate the long term-effects of land degradation.

A second option is to develop a model version with a large number of short early periods, followed by several longer ones. The length of the periods will still affect the calculation of the annuities but postponing the investment in perennials to the longer periods will now be discouraged since these periods are further away in time and thus affected more by discounting. Such a model type allows a better study of the effect of the investment period on the planting of perennials, while still permitting a sufficient number of years to address the long run effects of land degradation. The effects of the assumptions with respect to the planting periods of crops are also reduced by including less years in the periods. Again the amount of detail which can be achieved is restricted by the limits to model size.

Although the optimization over a time period of twenty years allows for the land use decisions to take their effect on land degradation into account, farmers use a much shorter time frame while taking the land use decisions. This issue could be addressed by developing a recursive version of MERALM, in line with the approach taken by Barbier (1996). Land use in an individual year would then be determined by solving the objective function over a limited number of years. The first year of the optimal land use pattern determines the land use in the year under consideration. The model is then solved again for the following year, while looking a number of years ahead with respect to the objective function and accounting for the land use decisions in previous periods. Repeated optimizing over a period of for example five years would capture most of the dynamics of perennial crops since they generally require a net investment in the first two to three years. This approach would eliminate the side-effects of annuities and modeling of multi-year periods since the objective function can comprise individual years. Furthermore, since the optimal land use pattern is determined by the first year of the planning period there is no degradation of soils in the last period due to the absence of a following period with lower yields.

However, using a planning period of only five years means that perennials which start rendering benefits after these five years have to be excluded from the analysis. The option of tree plantations which is included in the present version of MERALM thus could not be considered.

Furthermore, limiting the analysis to a short number of years also implies that the long term effects of agricultural land use are not taken into account by the model. Although a short time-horizon is justified from a farmer's point of view, society can be assumed to be concerned with using the soil in a way which is sustainable in the long run. Therefore a long term framework will be needed to address the long run sustainability of agricultural land use and policies, next to short run models for more accurate predictions of the responses of farmers.

9.5.2 Extensions of the economic relations

Two important factors influencing actual land use decisions are not incorporated in the present structure of MERALM. In the first place the amount of risk associated with each different LUST. As has been discussed in Section 9.4, risk-aversion causes farmers to be reluctant with respect to growing cassava and increases the attractiveness of livestock. This is in line with the study of Cárcamo et al. (1994) which found that risk-aversion can have a considerable impact on production decisions as well as on the adoption of conservation measures. Given the effect of the fluctuations of cassava prices on the production decisions, incorporation of price risks seems the most important extension of MERALM in this respect.

A second element which should be included in MERALM is the availability of capital. Especially in the case of perennial crops a lack of capital can hamper cultivation, as is illustrated by the higher costs of planting material which slows the increase in palm heart area. Not only the availability of capital in one period, but also the relations between periods in terms of capital and produce should be added to the model. These relations could include savings from previous periods, obligations with respect to the repayment of loans and stocks of produce and inputs.

Other possible extensions of the model structure are related to utilizing the fact that a sub-regional level of analysis allows modeling of the interactions between farms. Two types of interaction could be added to the model. First of all the present incorporation of an exchange of labor could be developed into the modeling of a labor market in which farms compete for available labor. The wage rate in each quarter can then be determined by the supply of and demand for labor instead of being fixed at the same level for each quarter. In this way the effect of land use patterns on labor-peaks can be incorporated in the land use decisions. A second way in which advantage could be taken of the sub-regional character of MERALM is by including a land market. Over an extended period of time farm sizes change as a result of the buying and selling of land. Analogue to the labor market a land market could be modeled in which farmers compete for the available land.

9.5.3 Expansions of the biophysical relations

An essential feature of MERALM is the determination of the effect of land use activities on soil fertility. However, the present definition of land degradation in terms of potential nitrogen supply is a rather crude approximation of the complicated land degradation processes. More detailed plant-growth models could be adopted, like for example the EPIC model. Extensions of MERALM in this direction would allow for a definition of soil classes on the basis of more variables than just nitrogen supply. Next to this, it would also offer the opportunity for a crop-specific relation between yield and fertility classes. In the present specification it has been assumed that the yields of all crops are 25 and 50 percent lower on soils of the second and third fertility class. However, some crops might be more sensitive to changes in soil characteristics. Thus, whereas one crop might have 50 percent lower yield on a soil of the third fertility class, the yield of another crop might not be affected by the decrease in fertility.

The way in which the effects of land degradation are measured results in some inaccuracies. The effect crops have on soil fertility is measured at the end of each period. Only if a LUST causes sufficient degradation to reduce the nitrogen supply to a level within the boundaries of the next fertility class, a transition of the soil takes place. However, although a LUST might not shift a soil to a lower fertility class still some degradation might occur. This limited amount of degradation is not tracked by MERALM. A larger number of fertility classes covering smaller ranges of differences in nitrogen supply will allow for a more precise approximation of gradual changes in soil fertility, but this greatly increases the size of the model.

A second source of inaccuracy with measuring land degradation is caused by the use of averages to determine the area of the crops. As a result the multiple growing of a crop is not explicitly registered in the present specification of MERALM: growing 20 hectare once or cultivating 10 hectare twice in a period are both registered as the cultivation of 20 hectare. This procedure can result in an underestimation of the amount of land degradation since the effect of a LUST on soil fertility has been calculated on the basis of one cropping cycle. However, if a crop is grown multiple times within a period it might cause a transition of the soil to a lower fertility class, even if growing it only once does not cause such a shift. Increasing the number of periods distinguished within the twenty year planning horizon would reduce the possibilities of this type of underestimation of land degradation, since shorter periods result in less opportunities for multiple cropping. Only leaving the concept of average land use and specifying each possible crop-rotation would totally eliminate this kind of inaccuracy, but this greatly increases the number of LUSTs which has to be included in the model.

In order to assess the accuracy of the land degradation measure the estimations of erosion as they are derived from the USLE should be evaluated through empirical estimates of actual erosion levels. As has been discussed in Chapter 2 the USLE has been developed in temperate regions, which in combination with its empirical basis implies that it can only be used with extreme caution in humid tropical conditions. Furthermore, the USLE does not take the effect of single storms or sedimentation processes into account, nor does it include other forms of erosion than sheet and rill erosion. Next to the amount of erosion data should be collected on soil conservation measures. Since no data are yet available on the effect of technologies on erosion degradation-prone land has to be left fallow to prevent future productivity losses. In case conservation measures would be included in the model these fields could be used, since the degradation could be offset or reduced to an acceptable level by conservation practices.

Finally, the mechanism which has been developed in this study to assess the effects of land use on soil fertility could also be employed for other sustainability measures. As long as the effects of a land use activity are known beforehand and can be translated into a range of different quality classes, the effects can be tracked throughout the whole planning horizon. Depending on the type of indicator and the availability of data the effects can then be related to changes in production and a feedback mechanism working through the objective function can be employed. For example, the accumulation of biocide residues on specific fields could be tracked through the whole planning horizon, in a similar way as the potential supply of nitrogen is tracked in the present specification of MERALM.

9.6 Concluding remarks

With respect to the land use models discussed in Chapter 3 this study has resulted in two contributions to the analysis of agricultural land use. In the first place the structure of MERALM allows for an endogenous interaction between current land use decisions and their effects on future agricultural possibilities within a linear programming framework. Furthermore these effects of land use are tracked in a location specific manner; if only a limited part of the available land is degraded the remaining land is left unaffected. This approach a possible concentrated character of land degradation into account, and thus permits a more accurate assessment of the need for conservation measures.

The mechanism which has been developed for the changes in soil fertility could be used for other measures of land degradation, like for example the presence of biocides. This type of extensions to the current specification would further increase the accuracy of the assessment of the sustainability of agricultural practices. Finally, with respect to the development of agricultural policies the present version of MERALM is a first step towards a framework which evaluates the long run sustainability of agricultural land use practices and policy measures.

Bibliography

Barbier, E. B. (1990) "The farm-level economics of soil conservation: the uplands of Java" in *Land economics*, Vol. 66, No. 2, May: 199-211.

Barbier, B. (1996) *Impact of market and population pressure on production, incomes and natural resources in the dryland savannas of West Africa: bioeconomic modeling at the village level.* EPTD Discussion Paper No. 22, Environment and Production Technology Division. Washington D.C.: International Food and Policy Research Institute.

Berg, P. van de & R. Droog (1992) *Quantification of farming systems in the Neguev settlement.* Field Report 92, Phase 2, Atlantic Zone Programme (CATIE-WAU-MAG), Turrialba, Costa Riça.

Beyers & Partners (1993) *OMP manual: preliminary release 10.6.1993.* Braasschaat: Beyers & Partners.

Bork, H.R. (1991a) "Does soil formation compensate soil erosion?" in W. G. Vahrson, M. Alfaro & G. Palacios (eds.) *Taller de erosion de suelos, memoria*. Collection of the presentation of a workshop held in Heredia, Costa Rica, July 22-24. Heredia (Costa Rica): FAO-PRODHAF-IPGH.

Bork, H.R. (1991b) "The estimation of soil erosion and deposition processes using simulation models" in W. G. Vahrson, M. Alfaro & G. Palacios (eds.) *Taller de erosion de suelos, memoria*. Collection of the presentation of a workshop held in Heredia, Costa Rica, July 22-24. Heredia (Costa Rica): FAO-PRODHAF-IPGH.

de Bruin, S. (1992) *Estudio detallado de los suelos del asientamiento Neguev*. Field Report 25, Phase 2, Atlantic Zone Programme (CATIE-WAU-MAG), Turrialba, Costa Rica.

Campbell, J.C., J. Radke, J.T. Giess & R.M. Wirtshafter (1992) "An application of linear programming and geographic information systems: cropland allocation in Antigua" in *Environment and planning A*, Vol. 24: 535-549.

Cárcamo, A.J., J. Alwang & G.W. Norton. (1994) "On-site economic evaluation of soil conservation practices in Honduras" in *Agricultural economics*, Vol. 11: 257-269.

Cuesta, M.D. (1994) "Economic analysis of soil conservation projects in Costa Rica" in *Economic and institutional analyses of soil conservation projects in Central America and the Caribbean*. Washington D.C.: The World Bank: 40-52.

Easter, C.D. (1975) "Some agronomic aspects of factors underlying production in the New South Wales grazing industry" in *Quarterly review of agricultural economics*, Vol. 28: 177-199.

Ellis, F. (1988) *Peasant economics: farm households and agrarian development*. Cambridge etc.: Cambridge University Press.

Eppink, L. (1984) *Bodemtechniek: deel E, inleiding tot de erosie, erosiebestrijding en bodembescherming*. Wageningen: Vakgroep Cultuurtechniek, Landbouwhogeschool Wageningen.

Ervin, C.A. & D.E. Ervin. (1982) "Factors affecting the use of soil conservation practices: hypotheses, evidence, and policy implications" in *Land economics*, Vol. 58, No. 3. August: 277-292.

Finnema, J.M. (1991) *Farming systems in the Neguev settlement*. Field Report 72, Phase 2, Atlantic Zone Programme (CATIE-WAU-MAG), Turrialba, Costa Rica.

Gilles, M., D. Perkins, M. Roemer & D. Snodgrass (1987) *Economics of development*. New York: Norton.

Gittinger, J.P. (1982) *Economic analysis of agricultural projects*. Johns Hopkins University Press, Baltimore.

de Groot, J.P. (1994) *Policies for soil conservation*. Paper presented at the workshop on policies for sustainable land use in Costa Rica, Heredia, Costa Rica, March 25-25. 16 p.

Guiking, F.C.T, D.M. Jansen & L.O. Fresco (1994) "The use of simplified nutrient balances at farm level to determine boundary conditions for sustainable production" in J.K. Syers & D.L. Rimmer. *Soil science and sustainable land management in the tropics*. Wallingford, UK: CAB International.

Hazell, P.B.R. & R.D. Norton (1986) *Mathematical programming for economic analysis in agriculture*. New York: Macmillan Publishing company.

Hudson, N. (1973) *Soil conservation*. London: B T Batsford limited. Second edition.

Jansen, D.M., J.J. Stoorvogel & R.A. Schipper (1995) "Using sustainability indicators in agricultural land use analysis: an example from Costa Rica" in *Netherlands journal of agricultural science*, Vol. 43, No. 1, April: 61-82.

Jansen, D.M. & R.A. Schipper (1995) “A static, descriptive approach to quantify land use systems” in *Netherlands journal of agricultural science*, Vol. 43, No. 1, April: 31-46.

Jansen, G.P., A. van Tilburg, J. Belt & S. Hoekstra (1996) *Agricultural marketing in the Atlantic Zone of Costa Rica; a production, consumption and trade study of agricultural commodities produced by small and medium-scale farmers*. Serie Técnica, Informe Técnico No. 271, Catie, Turrialba, Costa Rica.

Kramer, R.A., W.T McSweeny & R.W. Stavros. (1983) "Soil conservation with uncertain revenues and input supplies" in *American journal of agricultural economics*, November: 694-702.

Kuiper, M.H. (1997) *The Neguev revisited: a study of the agricultural changes between 1987 and 1996 in the Neguev settlement, Costa Rica*. Field Report 112, Phase 2, Atlantic Zone Programme (CATIE-WAU-MAG), Turrialba, Costa Rica.

Lal, R. (1976) "Soil erosion on lafilsols in Western Nigeria, I. Effects of slope, crop rotations and residue management" in *Geoderma*, Vol. 16: 363-375.

Lal, R. (1985) "Soil erosion and sediment transport research in tropical Africa" in *Hydrological sciences - journal - des sciences hydroligiques*, Vol. 30, No. 2: 239-256.

Lal, R., G.F. Hall & F.P. Miller (1989) "Soil degradation: I. Basic processes" in *Land degradation & rehabilitation*, Vol. 1: 51-69.

Landon, J.R. (1991) *Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics*. Thame, United Kingdom: Boker Tate Ltd.

Lutz, E., S. Pagiola & C. Reiche (1994) "Lessons from economic and institutional analyses of soil conservation projects in Central America and the Caribbean" in *Economic and institutional analyses of soil conservation projects in Central America and the Caribbean*. Washington D.C.: The World Bank: 3-18.

Maddala, G.S. (1992) *Introduction to econometrics*. (2nd edition) New York etc.: Macmillan Publishing Company.

McConnell, K.E. (1983) "An economic model of soil conservation" in *American journal of agricultural economics*, February: 83-89.

Midmore, D.J., H.G.P Jansen & R.G. Dumsday (in print) "Soil erosion and environmental impact of vegetable production in the Cameron Highlands, Malaysia" in *Agriculture, ecosystems and environment*.

Miranowski, J.A. (1984) "Impacts of productivity loss on crop production and management in a dynamic economic model" in *American journal of agricultural economics*, February: 61-71.

Moxey A.P. (1995) "The economic component of NELUP" in *Journal of environmental planning and management*, Vol. 38, No.1: 21-34.

Mucher, C.A. (1992) *A study on the spatial distribution of land use in the settlement Neguev*. Field Report 9, Phase 2, Atlantic Zone Programme (CATIE-WAU-MAG), Turrialba, Costa Riça.

Norton, R.D. (1995) *Review of the agricultural models for Costa Rica being developed by Wageningen Agricultural University*. Panamá: Norton Advisory Services, Inc.

Norton, R.D. & V. Santaniello (1996) *A model of structural adjustment in agriculture*. Mimeo.

O'Callaghan, J.R. (1995) "NELUP; an introduction" in *Journal of environmental planning and management*, Vol. 38, No.1: 5-20.

de Oñoro, M.T. (ed.) (1990) *El asientamiento Neguev: interacción de campesinas y estado en el aprovechamiento de los recursos naturales*. Atlantic Zone Programme, Serie Técnica, Informe Técnico No. 162, Programme Paper No. 7. Turrialba: CATIE-UAW-MAG.

Orazem, P.F & J.A. Miranowski (1994) "A dynamic model of acreage allocation with general and crop-specific soil capital" in *American journal of agricultural economics*, Vol. 76, August: 385-395.

Parton, K.A. (1996) "Socioeconomic modeling of agricultural land degradation" in M. Sebillotte, D, Aviat, J. Bodichon & M. Feifer (eds.) *System oriented research in agriculture and rural development: international symposium, Montpellier, France - 21 to 25 November 1994*. Montpellier: CIRAD-SAR.

Pagiola, S. (1995) "Price policy and returns to soil conservation in Kitui and Machakos, Kenya". Mimeo.

Pearce, D. W. & J. J. Warford (1993) *World without end, economics, environment and sustainable development*. New York: Oxford University Press.

Pimentel, D., C. Harvey, P. Resosudarno, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saffouri & R. Blair (1995) "Environmental and economic costs of soil erosion and conservation benefits" in *Science*, Vol. 267, No. 5201, February 24: 1117-1123.

Sanchez, M.A., & G.P. Alvarez (1991) "Applicacion de la EUPS a nivel de una microcuena, el caso de la Quebrada Pital, Costa Rica" in W. G. Vahrson, M. Alfaro & G. Palacios (eds.) *Taller de erosion de suelos, memoria*. Collection of the presentation of a workshop held in Heredia, Costa Rica, July 22-24. Heredia, Costa Rica: FAO-PRODHAF-IPGH.

Schipper, R.A. (1993) *Una caracterización de fincas en Neguev, Río Jiménez y Cocori Zona Atlantica, Costa Rica: informe en base a una encuesta dentro del marco de estudios de base*. Field Report 49, Phase 2, Atlantic Zone Programme (CATIE-WAU-MAG), Turrialba, Costa Rica.

Schipper, R.A. (1996) *Farming in a fragile future: Economics of land use with applications in the Atlantic zone of Costa Rica*. Dissertation for the Department of Development Economics, Wageningen Agricultural University.

Stoorvogel, J.J (1995) *Geographical information systems as a tool to explore land characteristics and land use: with reference to Costa Rica*. Bennekom: Drukkerij Modern.

Stoorvogel, J.J., R.A. Schipper & D.M. Jansen (1995) "USTED: a methodology for quantitative analysis of land use scenarios" in *Netherlands journal of agricultural science*, Vol. 43, No. 1, April: 5-18.

Vahrson, W. (1991) "Aspectus climaticos de la erosion hidrica en Costa Rica, America Central" in W. G. Vahrson, M. Alfaro & G. Palacios (eds.) *Taller de erosion de suelos, memoria*. Collection of the presentation of a workshop held in Heredia, Costa Rica, July 22-24. Heredia (Costa Rica): FAO-PRODHAF-IPGH.

Vahrson, W. & C. Cervantes (1991) " Escorrentia superficial y erosion laminar en Puriscal, Costa Rica" in W. G. Vahrson, M. Alfaro & G. Palacios (eds.) *Taller de erosion de suelos, memoria*. Collection of the presentation of a workshop held in Heredia, Costa Rica, July 22-24. Heredia (Costa Rica): FAO-PRODHAF-IPGH.

Walker, D.J. (1982) "A damage function to evaluate erosion control economics" in *American journal of agricultural economics*, November: 690-698.

Walker, D.J. & D.L. Young. (1986) "The effect of technical progress on erosion damage and economic incentives for soil conservation" in *Land economics*, Vol. 62, No 1, February: 83-93.

World Resources Institute (1991) *Accounts overdue. Natural resource depletion in Costa Rica.* Washington D.C.: WRI.

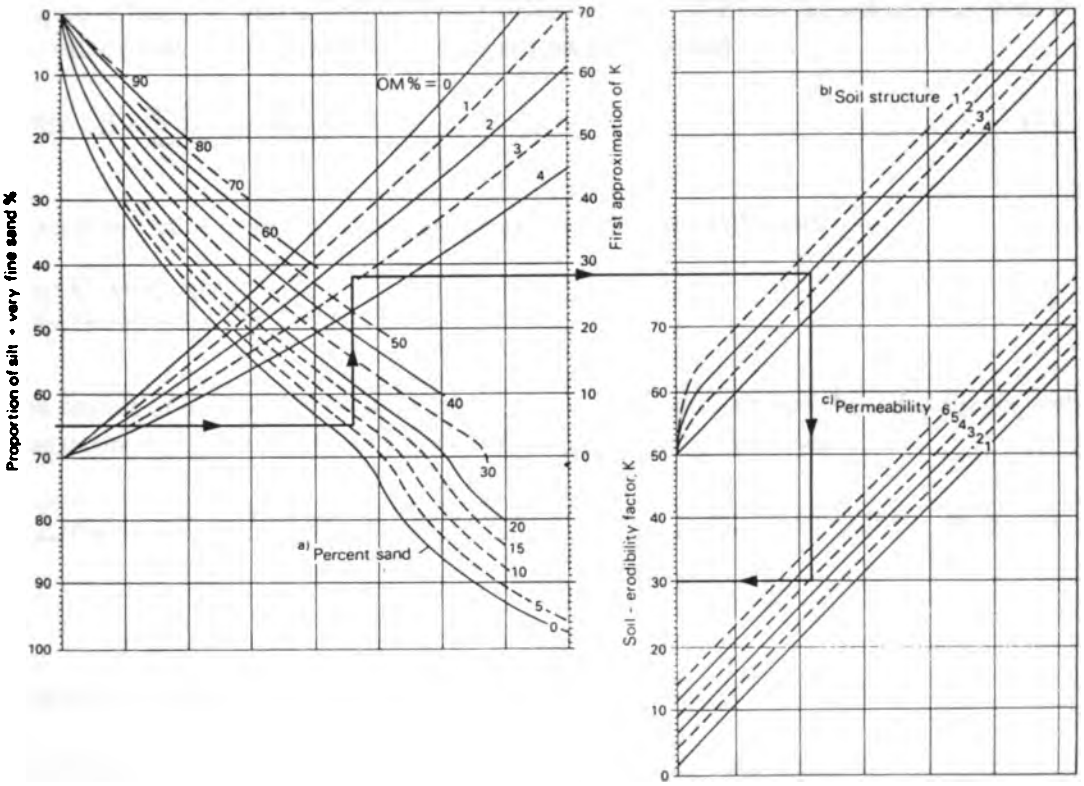
Appendix A

SOIL MAPPING UNITS OF EACH SOIL TYPE

Code	Description	Mapping units
SFW	Fertile well drained soil	Do3 Do3.K2 Do2 Pa De De_ De4= De3= De2= Li LuIII BoIII Fl
SFP	Fertile poorly drained soil	Lu Wi Wi2= Bo Tu u
SIWa	Flat to almost flat SIW soil (0 -1%)	Ne/A Mi/A
SIWb	Undulated SIW soil (: 1- 3%)	Mi.K2/B Si/B Ne/B Mi/B Ne/BC
SIWc	Strongly undulated to inclined SIW soil (5 - 8%)	Si/C Ne/C Ne/CD Si/CD+u
SIWd	Hilly to moderately steep SIW soil (10 - 16%)	Si/D Ne/D Si/DE+u
SIWe	Steep SIW soil (20 - 30%)	Si/E Ne/E Mi/E
SIWf	Very steep SIW soil (45 - 65%)	Mi/F

Appendix B

NOMOGRAPH USED TO DETERMINE THE K-FACTOR



Source: Landon (1991)

With: a Sand taken as particles with diameter 0.1 to 2.0 mm

b Key to structural classes:
1 Very fine granular
2 Fine granular
3 Medium or coarse granular
4 Blocky, platy or massive

c Key to permeability classes:
1 Rapid
2 Moderate to rapid
3 Moderate
4 Slow to moderate
5 Slow
6 Very slow

Appendix C

CONCISE DESCRIPTION OF THE MODEL

Objective function:

Objective function: maximization of the discounted value of the net returns of all periods and the value of returns occurring beyond the last period (C./year):

$$Max \quad Z = \sum_{p} d_p Y_p + R \qquad (1)$$

Discounted value of returns occurring beyond the last period (C./year):

$$-\sum_{f}\sum_{s}\sum_{l}\sum_{t}\sum_{i} m_{fslti} X_{fslti,p=4} + R \leq 0 \qquad (2)$$

Net returns of each period: value of production - input costs - on farm household labor costs - transaction costs of hired labor + income from plantation work (C./year):

$$-\sum_{j} p_{jp} Q_{jp} + I_p + \sum_{f}\sum_{q} w_{rfqp} F_{fqp} + \sum_{f}\sum_{q} t_{fqp} H_{fqp} - \sum_{f}\sum_{q} w_{afqp} P_{fqp} + Y_p \leq 0 \quad \text{all p} \quad (3)$$

Production and inputs:

Annuity production per farm type & total per period (kg or units'/year):

$$\sum_{s}\sum_{l}\sum_{t}\sum_{i} -y_{jfsltip} X_{fsltip} + Q_{jfp} \leq 0 \qquad \text{all j, f, p} \qquad (4)$$

$$-\sum_{f} Q_{jfp} + Q_{jp} \leq 0 \qquad \text{all j, p} \qquad (5)$$

Annuity input costs per farm type & total per period (C./year):

$$\sum_{s}\sum_{l}\sum_{t}\sum_{i} c_{fsltip} X_{fsltip} - I_{fp} \leq 0 \qquad \text{all f, p} \qquad (6)$$

$$\sum_{f} I_{fp} - I_p \leq 0 \qquad \text{all p} \qquad (7)$$

Land use and availability:

Use of land units per LUST, farm type quarter and period (ha/year):

$$\sum_l \sum_t \sum_i a_{fsltiqp} X_{fsltip} \leq q_{qp} A_{fsp} \qquad \text{all f, s, q, p} \tag{8}$$

Restriction on the use of land in the first year of each period (ha/year):

$$\sum_l \sum_t \sum_i o_{fsltip} X_{fsltip} \leq A_{fsp} \qquad \text{all f,s and p} \geq 2 \tag{9}$$

Availability of land per period (ha/year):

$$A_{fs,p=1} = r_{fs,p=1} \qquad \text{all f,s} \tag{10}$$

$$A_{fs,p-1} + \sum_l \sum_t \sum_i k_{fslti,p-1} X_{fslti,p-1} = A_{fsp} \qquad \text{all f,s and p} \geq 2 \tag{11}$$

Perennial crops from earlier periods which have to be maintained (ha/year):

$$X_{fslti,p-1} + h_{slti,p-1} X_{fslti,p-1} = X_{fsltip} \qquad \text{all s, l, t, i} \in \alpha \text{, f, p} \geq 2 \tag{12}$$

Labor use and availability:

Labor use for each LUST balanced by labor supply, per farm type, quarter and period (hours/year):

$$\sum_s \sum_l \sum_t \sum_i v_{fsltqip} X_{fsltip} - F_{fqp} - H_{fqp} \leq 0 \qquad \text{all f,q,p} \tag{13}$$

Household labor availability per farm type, quarter and period (hours/year):

$$F_{fqp} + O_{fqp} + P_{fqp} \leq g_{fqp} \qquad \text{all f,q,p} \tag{14}$$

Household labor availability per farm type and period (hours/year):

$$\sum_q F_{fqp} + \sum_q O_{fqp} + \sum_q P_{fqp} \leq g_{fp} \qquad \text{all f, p} \tag{15}$$

Hired work availability for the Neguev (equals off-farm labor of the farm types):

$$\sum_f H_{fqp} - \sum_f O_{fqp} = 0 \qquad \text{all q, p} \tag{16}$$

Availability of plantation work outside the Neguev (hours/year):

$$\sum_{f} P_{fqp} \leq p_{qp} \qquad \text{all q,p} \tag{17}$$

Environmental indicators:

Biocide balance per farm type and period (index value/year):

$$\sum_{s}\sum_{l}\sum_{t}\sum_{i} b_{fsltip} X_{fsltip} - B_{fp} = 0 \qquad \text{all f,p} \tag{18}$$

Nutrient balances per nutrient, farm type and period (kg/year):

$$\sum_{s}\sum_{l}\sum_{t}\sum_{i} -u_{nfsltip} X_{fsltip} - N_{nfp} = 0 \qquad \text{all n,f,p} \tag{19}$$

Erosion balance per farm type and period (ton/year):

$$\sum_{s}\sum_{l}\sum_{t}\sum_{i} e_{fsltip} X_{fsltip} - E_{fp} = 0 \qquad \text{all f,p} \quad . \tag{20}$$

Appendix D

INDICES, VARIABLES AND COEFFICIENTS OF MERALM

Table D-1: Indices

Indices	Description	OMP sets	Elements
f	farm type	FARM	selection depends on model version[1]
i	starting period	S	S1, S2, S3, S4
j	products	PROD	various cassava, maize, pineapple, plantain, palm heart livestock and tree products
l	land use types	LUT	cassava, maize, pineapple, plantain, palm heart, livestock, tree plantations
n	nutrients	NUTRI	N, P, K[2]
p	periods	PER	P1, P2, P3, P4
q	quarters	QUART	Q1, Q2, Q3, Q4
s	soil types	SOIL	selection depends on model version[3]
t	technology	TECH	included technologies are: 01, 02, 03, 04, 10, 11, 40, 41, 43, 44, 49

Note: [1] In all model versions of Chapter 8 only one farm type, the Neguev as a whole, is distinguished

[2] These elements refer to nitrogen, phosphate and potassium

[3] In case eight soil types are distinguished the soils SFP, SFW1, SFW2, SFW3, SIWa1, SIWa2, SIWa3 trough SFWf1, SFWf2, SFWf3 are incorporated. In the three soil type models the soil types SFP, SFW1, SFW2, SFW3, SIW1, SIW2 SIW3 are included.

Table D-2: Variables

Variables	**Description**	**Unit**	**Definition in OMP**
A_{fsp}	land availability	ha/year	LANDAV.FARM(&).SOIL(&).PER(&)
B_{fp}	biocides	index value/ year	BIOC.FARM(&).PER(&)
E_{fp}	soil loss per farm type	ton/year	SLOSS.FARM(&).PER(&)
F_{fqp}	on-farm work by family members	hours/year	OWNLAB.FARM(&).QUART(&).PER(&)
H_{fqp}	on-farm work by hired labour	hours/year	HIRLAB.FARM(&).QUART(&).PER(&)
I_p	annuity current input use	¢/year	ANNINPUT(&).PER(&)
I_{fp}	annuity current input use	¢/year	ANNINPUT(&).FARM(&).PER(&)
N_{nfp}	nutrients	kg/year	NUTBAL.NUTRI(&).FARM(&).PER(&)
O_{fqp}	off-farm work by family members on other farms	hours/year	OFFLAB.FARM(&).QUART(&).PER(&)
P_{fqp}	plantation work by family members	hours/year	PLANTLAB.FARM(&).QUART(&).PER(&)
Q_{lp}	annuity production	kg or 'units' /year	PROD(&).PER(&)
Q_{lfp}	annuity production	kg or 'units' /year	PROD(&).FARM(&).PER(&)
R	returns occurring after the last period	¢/year	DRETURN
X_{fsltsp}	LUSTs	ha/year	FARM(&).SOIL(&).LUT(&).TECH(&).S(&).PER(&)
Y_p	value of objective function	¢/year	OBJECT.PER(&)
Z	total value of objective function	¢/year	-

Note: All variables are continuos and larger than or equal to zero. The only exception is N_{nfp}, which is larger than minus infinity. Monetary values are expressed in *Colón* (¢) the currency unit of Costa Rica. In the OMP definition '(&)' refers to all set-elements.

Table D-3: Coefficients

Coefficients	**Description**	**Units of measurement**	**Definition in OMP**
$a_{fsltqip}$	average land use	ha/ha	LAND
b_{fsltip}	average biocide index value	index value/ha	BIOCIDE
c_{fsltip}	annuity input costs	¢/ha	INPUT
d_p	discount factors objective values	-	DISCOUNT
e_{fsltip}	soil loss	ton/year	EROSION
g_{fp}	household labour availability per year	hours/year	YLABAV
g_{fqp}	household labour availability per quarter	hours/year	QLABAV
h_{sltip}	effect of perennial crops on soil fertility	ha/ha	DEG1, DEG2, DEG3N, DEG3P, NODEG1, NODEG2, NODEG3 [1]
k_{fsltip}	effect of land quality in previous periods	ha/ha	DELTAP1, DELTAP2, DELTAP3
m_{fslt}	discounted value of returns beyond the last period	¢/year	DVALUE
o_{fsltip}	use of land in the first year of a period	ha/ha	YEAR2, YEAR3, YEAR4
p_j	product price	¢/kg or ¢/'unit'	PRICE
p_{qp}	plantation employment availability	hours/year	PLANTAV
q_{qp}	unity matrix	-	UNITY
r_{fsp}	land availability in period 1	ha/year	LANDP1
t_p	transaction costs hired labor	¢/hour	TRANS
$u_{nfsltip}$	average nutrient loss or gain	kg/ha	NUTRIENT
v_{fsltip}	annuity labour use	hours/ha	LABOR
w_{eqp}	off-farm on plantation wages	¢/hour	PLANWAGE
w_{rp}	reservation wage	¢/hour	RESWAGE
y_{fsltip}	annuity yield	kg/ha or 'units'/ha	PRODUCT

Note: [1] In order not to exceed the maximum number of spreadsheet columns the equations with respect to the maintaining of perennial crops had to be separated. The equations have been divided into perennials which do and do not cause degradation. Furthermore, for the third period perennials which cause degradation the equations are separated into one accounting for the decrease in perennials and one which calculates the area of perennials on the new soil fertility class (see also Appendix E). As a result of these operations more variables in the OMP model represent h_{sltip}.

The OMP modeling language imposes a restriction on the column labels of the data-files. As a result the OMP model definition contains more sets, variables and coefficients than the mathematical description of MERALM given in Table D-1, D-2 and D-3. The column labels cannot exceed 8 characters, including the '.' to required to separate the sets. The definition of LUSTs, consisting of the components SOIL, LUT, TECH and S, clearly requires more than 8 characters. However limiting the definition of soils, land use activities, technologies and starting periods to 1 character makes the model listing and reports difficult to read and hamper the checking for errors. Therefore a short denomination of LUSTs is only used if necessary due to restriction on the length of column labels.

In order to facilitate the interpretation on the model description in the OMP modeling language Tables D-4, D-5 and D-6 describe the additional sets, variables and coefficients of the OMP model. Since the variables are described in terms of sets more sets result in the definition of additional variables. Furthermore, since the constraints with the short-hand LUSTs descriptions have to be related to the rest of the model, additional coefficients are needed to translate the short-hand description to the full description of the LUSTs.

Table D-4: Additional sets in the OMP specification

OMP set	**Description**
DSOIL	changed soil types
O	soils types
L	land use types
T	technology
I	starting period

Table D-5: Additional variables in the OMP specification

OMP variable	**Unit**	**Description**
DELTA.DSOIL.(&).FARM(&).PER(&)	ha/year	change in soil fertility class as a result of land use
DL.FARM(&).O(&).L(&).T(&).I(&).PER(&)	ha/year	short definition of LUSTs
DN. FARM(&).O(&).L(&).T(&).I(&).P3	ha/year	short definition of LUSTs, decrease in area
DP. FARM(&).O(&).L(&).T(&).I(&).P3	ha/year	short definition of LUSTs, increase in area

Note: The last three variables are the short hand definition of the LUSTs in order to be able to put the LUSTs as column labels. In the case of the third period the number of perennials exceeds the maximum number of spreadsheet columns. Therefore the equation has been split in one which calculates the perennials which are disappearing (they are transformed in perennials on a different fertility class) and an equation which accounts for the area of perennials created on the new soil fertility class (see also Appendix E).

Table D-6: Additional coefficients in the OMP specification

OMP coefficients	**Unit**	**Description**
TRPER1, TRPER2 TRPER3N, TRPER3P	ha/ha	unity matrix to translate the short hand description to the full length LUST description
SW1, SW2 SW3N, SW3P	-	switches to assure that only the relevant equations are formulated

Appendix E

SOIL TRANSITIONS AND MAINTAINING OF PERENNIALS

G.1 Calculation of changes in soil fertility

The available soil types in period $p \geq 2$ are determined by the stock of soil in the previous period and by the land use activities in that period. Mathematically this relationship is expressed by the equation:

$$A_{fs,p-1} + \sum_{l}\sum_{t}\sum_{i} k_{fslti,p-1} X_{fslti,p-1} = A_{fsp} \qquad \text{all f, s and } p \geq 2 \qquad (7.11)$$

The first term on the left hand side represents the stock of land in the previous period. In case this period is the first period this stock is determined exogenous of the model (see Equation 7.10 in Chapter 7). This initial stock of land is adjusted by the second term on the left hand side for the consequences of land use for soil fertility. The effects specified for each LUST are captured by the coefficient $k_{fslti,p-1}$. Table D-1 presents part of the matrix of the coefficient $k_{fslti,p-1}$ for period 1

Table E-1: Part of the matrix of the coefficient $k_{fslti,p-1}$

LUST	SIWd1	SIWd2	SIWd3	SIWf1	SIWf2	SIWf3
SIWd1.LBG.43.S1	0	0	0	0	0	0
SIWd1.LME.10.S1	-1	1	0	0	0	0
SIWf1.LME.10.S1	0	0	0	-1	0	1

Note:	
SIWd1, SIWd2, SIWd3:	infertile well drained hilly to moderately steep soil of fertility class 1, 2 and 3
SIWf1, SIWf2, SIWf3:	infertile well drained very steep soil of fertility class 1, 2 and 3
LBG.43.S1:	palm heart, cultivated with technology number 43, starting in period 1
LME.10.S1:	cassava, cultivated with technology number 10, starting in period 1

The matrix specifies for each LUSTs in the first column the effect on the fertility of the soil types on which they are planted. The palm heart LUST has no effect on soil fertility, thus all cells in this row contain a zero. The two cassava LUSTs do have an effect of soil fertility. The first cassava LUST causes the SIWd1 soil on which it is cultivated to degrade to fertility class 2. This means that as a result of the cultivation of one hectare of cassava in the first period, one hectare of SIWd1 disappears (indicated by the -1) and one hectare of SIWd2 soil is created. On balance there is still the same amount of SIWd soil, the amount of SIWd1 has decreased with the same amount as the SIWd2 has increased. In the same way the second cassava LUST causes the SIWf1 soil to degrade to fertility class 3. Again the gain in fertility class 3 is fully compensated by the loss of fertility class 1, thus no additional land is created.

Table E-1 gives the effect of one hectare of a crop. In order to get the total effect of land use on soil fertility the matrix is multiplied by the number of hectares of each LUST ($X_{fslti,p-1}$). Thus if 50 hectare of the second cassava LUST are cultivated, 50 hectare of SIWf1 soil will disappear and 50 hectare of SIWf3 soil will be created. The summing over crop, technology and starting period of the second term in Equation 7.11 calculates the total of each column. The result is the total change in fertility classes for each soil type caused by the LUSTs of period one.

Finally, in order to determine the availability of soil types in the second period the total change in soil types is added to the availability in period one. For example, the loss of the 50 hectare SIWf1 soil and creation of 50 hectare SIWf3 soil due to the second cassava LUST is added to the availability at the start of period done. In period 2 then 50 hectare less of the SIWf1 and 50 more of the SIWf3 soil are available than in period 1.

G.2 Maintaining of perennials with soil degradation

In the case of perennials which cause land degradation the area in *p-1* cannot be equated to the area in period *p* because the crop will be standing on a soil of a different fertility class. Thus, as with the changes in soil availability discussed above, the initial area of the perennials is adjusted for changes in soil fertility:

$$X_{fslti,p-1} + h_{slti,p-1} X_{fslti,p-1} = X_{fsltip} \qquad \text{all s,l,t,i} \in \alpha\text{, f,p} \geq 2 \tag{7.12}$$

The restriction is only valid for those LUSTs belonging to the α sub-group. This group consists of perennials from previous periods which have to be maintained and of which some cause a change in soil fertility. The coefficient $h_{slti,p-1}$ has the same function as $k_{fslti,p-1}$ in Equation 7.11; it defines the effect which each perennial has on soil fertility. In case the perennial does not have an effect on soil fertility $h_{slti,p-1}$ has value zero and the second term on the left hand side can be removed from the constraint. The area of these crops in period *p* is then equal to the area in period *p-1*. For the crops which do cause degradation the fertility of the soil under the crop is adjusted by $h_{slti,p-1}$. Table E-2 shows part of the matrix of $h_{slti,p-1}$ for the third period.

Table E-2: Part of the matrix of the coefficient $h_{slti,p-1}$

LUST	SIWc1.LBG.10.S1	SIWc2.LBG.10.S1	SIWc3.LBG.10.S1
SIWc1.LBG.10.S1	-1	1	0

Note: SIWc1, SIWc2, SIWc3: infertile, well drained, strongly undulated to inclined soil of fertility class 1, 2 and 3
LBG.10.S1 : palm heart using technology number 10, planted in period 1

The changes in soil fertility under perennials requires the full specification of the LUSTs in the columns[1], since the same perennial in terms of crop, technology and starting period has to be maintained, only on a different soil fertility class. As with the changes in soil fertility discussed before the area of the perennial on the initial fertility class disappears in favor of the perennial on the new fertility class. The palm heart LUST in Table E-2 causes the land to degrade from a SIWc1 to a SIWc2 soil. Therefore, if 50 hectare of the palm heart is present in the third period, 50 hectare of the palm heart on the SIWc1 soil have to disappear and 50 hectare of an identical palm heart in terms of technology and starting period have to be created on SIWc2 soil in period

---

[1] In the OMP model specification problems arise since the column labels cannot exceed 8 characters, including the '.' to separate the sets. Therefore the LUSTs in the columns are identified with a shorter code which afterwards is translated with an unity matrix to the original LUST definition.

four. This is accomplished by multiplication of the matrix for the coefficient $h_{slti,p-1}$ with the area of the LUST ($X_{flsti,\,p-1}$) and adding this to the initial area of the LUST in period 3. Again, as with the changes in soil fertility no extra area of palm heart is created; the decrease in palm heart on SIWc1 soil is equal to the created area of palm heart on the SIWc2 soil.

Appendix F

OMP SPECIFICATION OF MERALM

```
*===================================================================================
*
*          DYNAMIC MODEL FOR THE NEGUEV SETTLEMENT
*
*                            NEG_DYN1.MOD
*
*
* CHARACTERISTICS:
*  - 22 soil types (SFP, SFW1, SFW2, SFW3, SIWA1, SIWA2, SIWA3 through SIWF 1, SIWF2,
*    SIWF3)
*  - 924 LUSTs
*  - no farmtypes
*  - division in 4 periods (P1, P2, P3, P4)
*  - periods are divided in four quarters (Q1, Q2, Q3, Q4)
*  - land availability is determined by previous land use
*  - LUSTs are also defined in terms of planting time
*  - maintainment of perennial takes land degradation into account
*  - production is affected by erosion
*
*
************************************************************************************
*                               OBJECTIVE FUNCTION
*
MAXimize sum of the discounted value of the net benefits of four periods,
*   plus the discounted value of the benefits occuring beyond the fourth period.
*
*   The net benefits consist of the value of production,less current input costs,
*   less costs of household on-farm labor, plus income from work on plantations
*   outside of the Neguev (C./year).


************************************************************************************
*                                SET DEFINITION
*
*  Set of farm types
SET=FARM:       NE

*  Set of quarters
SET=QUART:      Q1, Q2, Q3, Q4

*  Set of periods
SET=PER:        P1, P2, P3, P4

*  Set of starting periods of LUSTs
SET=S:          S1, S2, S3, S4

*  Set of soil types
SET=SOIL,       F=PRODUC_1.WK1,   L=1

*  Set of land use types
SET=LUT,        F=PRODUC_1.WK1,   L=2

*  Set of technologies
SET=TECH,       F=PRODUC_1.WK1,   L=3

*  Set of products
SET=PROD,       F=PRODUC_1.WK1,   C=1

*  Set of nutrients
SET=NUTRI:      N, P, K
*  Additional sets to enable calculations with changed soils

*  Set of changed soil types to determine total change in soil quality
SET=DSOIL,      F=DELTA1_1.WK1,   C=1
```

```
*  Set of changed soils for perennial crops
SET=O,          F=ALUST_1.WK1,    L=1

*  Set of LUSTs for maintaining perennial crops
SET=L,          F=ALUST_1.WK1,    L=2

*  Set of technologies for maintaining perennial crops
SET=T,          F=ALUST_1.WK1,    L=3

*  Set of starting periods for maintaining perennial crops
SET=I,          F=ALUST_1.WK1,    L=4



*********************************************************************************
*                                  RELATIONS
*
*   Existence of crops in each period
REL=REXIST,     S=SOIL(&).LUT(&).TECH(&).S(&).PER(&) ,           DATA=DEXIST
*   Existence of perennials with land degradation
REL=PERDEG1,    S=O(&).L(&).T(&).I(&).P1,                     DATA=PERDEG1
REL=PERDEG2,    S=O(&).L(&).T(&).I(&).P2,                     DATA=PERDEG2
REL=PERDEG3,    S=O(&).L(&).T(&).I(&).P3,                     DATA=PERDEG3



*********************************************************************************
*                   VARIABLES & OBJECTIVE FUNCTION COEFFICIENTS
*
*
*  OBJECTIVE FUNCTION
*
*  Value of the objective function per period (C./year)
X=OBJECT.PER(&)=C                                                  $ /DISCOUNT/
*  Returns occuring after the last period (C.)
X=DRETURN=C                                                              $ 1


*  PRODUCTION AND INPUTS
*
* Land use systems and technonolgies, LUSTs (ha/year)
X=FARM(&).SOIL(&).LUT(&).TECH(&).S(&).PER(&)=C                            $ 0
*  Annuity of production per farm type & total (kg/year or 'units'/year)
X=PROD(&).FARM(&).PER(&)=C                                                $ 0
X=PROD(&).PER(&)=C                                                        $ 0
*  Annuity of current input costs per farm type & total (C./year)
X=ANNINPUT.FARM(&).PER(&)=C                                               $ 0
X=ANNINPUT.PER(&)=C                                                       $ 0


*  LAND USE AND AVAILABILITY
*
*  Availability of land per farm, soil and period (ha/year)
X=LANDAV.FARM(&).SOIL(&).PER(&)=C                                         $ 0
*  Changes in land quality as a result of LUSTs (ha/year)
X=DELTA.DSOIL(&).FARM(&).P1=C                 >-INFINITY                  $ 0
X=DELTA.DSOIL(&).FARM(&).P2=C                 >-INFINITY                  $ 0
X=DELTA.DSOIL(&).FARM(&).P3=C                 >-INFINITY                  $ 0
*  Definition of LUSTs for maintaing perennial crops (ha/year)
X=FARM(&).O(&).L(&).T(&).I(&).P1=C            >-INFINITY                  $ 0
X=FARM(&).O(&).L(&).T(&).I(&).P2=C            >-INFINITY                  $ 0
X=FARM(&).O(&).L(&).T(&).I(&).P3=C            >-INFINITY                  $ 0
X=DEL.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P1=C   >-INFINITY               $ 0
X=DEL.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P2=C   >-INFINITY               $ 0
X=DEL.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P3=C   >-INFINITY               $ 0


*  LABOR USE AND AVAILABILITY
*
*  Household (own) on-farm work per farm type per quarter (hours/year)
X=OWNLAB.FARM(&).QUART(&).PER(&)=C                                        $ 0
*  Off-farm work by family members on plantations outside the Neguev
*  per farm type per quarter & total (hours/year)
X=PLANTLAB.FARM(&).QUART(&).PER(&)=C                                      $ 0
```

```
*  ENVIRONMENTAL INDICATORS
*
*  Biocide index per farm type & total (index value/year)
X=BIOC.FARM(&).PER(&)=C                                                             $ 0
*  Nutrient balance per nutrient per farm type (kg/year)
X=NUTBAL.NUTRI(&).FARM(&).PER(&)=C                    >-INFINITY                    $ 0
*  Soil loss per farmtype
X=SLOSS.FARM(&).PER(&)=C                                                            $ 0



************************************************************************************
*                                  CONSTRAINTS
*
*
*  OBJECTIVE FUNCTION
*
*  (2) Discounted value of returns occuring beyond the last period (C./year)
C=RETURN = - /DVALUE/*FARM(S&).SOIL(S&).LUT(S&).TECH(S&).S(S&).P4
           + DRETURN                                                                < 0
*
*  (3) Net returns of each period for the Neguev as a whole (C./year)
C=CALOBJECT.PER(&) = - /PRICE/*PROD(S&).PER(&)
                     + ANNINPUT.PER(&)
                     + /RESWAGE/*OWNLAB.FARM(S&).QUART(S&).PER(&)
                     - /PLANWAGE/*PLANTLAB.FARM(S&).QUART(S&).PER(&)
                     + OBJECT.PER(&)                                                < 0


*  PRODUCTION AND INPUTS
*
*  (4&5) Annuity of product balances per farm type and total (kg/year)
C=BALPROD.PROD(&).FARM(&).PER(&)=
  -/PRODUCT/*FARM(&).SOIL(S&).LUT(S&).TECH(S&).S(S&).PER(&) + PROD(&).FARM(&).PER(&) < 0
C=BALPROD.PROD(&).PER(&)= -PROD(&).FARM(S&).PER(&)+PROD(&).PER(&)                   < 0
*
*  (6&7) Annuity of input cost balances per farm type and total (C./year)
C=BALCOST.FARM(&).PER(&) =
               +/INPUT/ * FARM(&).SOIL(S&).LUT(S&).TECH(S&).S(S&).PER(&)
               -ANNINPUT.FARM(&).PER(&)                                             < 0
C=BALCOST.PER(&)= ANNINPUT.FARM(S&).PER(&)-ANNINPUT.PER(&)                          < 0


*  LAND USE AND AVAILABILITY
*
*  (8) Use of land units by LUSTs per farm type per quarter, per period (ha/year)
*
C=LAND.FARM(&).SOIL(&).QUART(&).PER(&) =
             + /LAND/ * FARM(&).SOIL(&).LUT(S&).TECH(S&).S(S&).PER(&)
             - /UNITY/*LANDAV.FARM(&).SOIL(&).PER(&)                                < 0
*
*  ()  Use of land units by perennial crops on a yearly basis (ha/year)
C=YLAND.FARM(&).SOIL(&).P2 =
             + /YEAR2/ * FARM(&).SOIL(&).LUT(S&).TECH(S&).S(S&).P2
             - LANDAV.FARM(&).SOIL(&).P2                                            < 0
C=YLAND.FARM(&).SOIL(&).P3 =
             + /YEAR3/ * FARM(&).SOIL(&).LUT(S&).TECH(S&).S(S&).P3
             - LANDAV.FARM(&).SOIL(&).P3                                            < 0
C=YLAND.FARM(&).SOIL(&).P4 =
             + /YEAR4/ * FARM(&).SOIL(&).LUT(S&).TECH(S&).S(S&).P4
             - LANDAV.FARM(&).SOIL(&).P4                                            < 0

*
*  (10) Change in soil quality for each farm type and period (ha/year)
*
C=CHANGE.DSOIL(&).FARM(&).P2 =
    + /DELTAP1/*FARM(&).SOIL(S&).LUT(S&).TECH(S&).S(S&).P1 = DELTA.DSOIL(&).FARM(&).P1
C=CHANGE.DSOIL(&).FARM(&).P3 =
    + /DELTAP2/*FARM(&).SOIL(S&).LUT(S&).TECH(S&).S(S&).P2 = DELTA.DSOIL(&).FARM(&).P2
C=CHANGE.DSOIL(&).FARM(&).P4 =
    + /DELTAP3/*FARM(&).SOIL(S&).LUT(S&).TECH(S&).S(S&).P3 = DELTA.DSOIL(&).FARM(&).P3
*
```

```
*  (9&10) Land availability per farm type and period (ha/year)
*
C=AVLAND.SOIL(&).FARM(&).P1 = LANDAV.FARM(&).SOIL(&).P1                    < /LANDP1/
C=AVLAND.SOIL(&).FARM(&).P2 =
+ /SOILS/*DELTA.DSOIL(S&).FARM(&).P1+LANDAV.FARM(&).SOIL(&).P1=LANDAV.FARM(&).SOIL(&).P2
C=AVLAND.SOIL(&).FARM(&).P3 =
+ /SOILS/*DELTA.DSOIL(S&).FARM(&).P2+LANDAV.FARM(&).SOIL(&).P2=LANDAV.FARM(&).SOIL(&).P3
C=AVLAND.SOIL(&).FARM(&).P4 =
+ /SOILS/*DELTA.DSOIL(S&).FARM(&).P3+LANDAV.FARM(&).SOIL(&).P3=LANDAV.FARM(&).SOIL(&).P4
*
*  (11) Maintaing perennial crops per farm type and period (ha/year)
*       - Perennial crops without a change in land quality
C=NC.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P2=
        +/NODEG1/*FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P1 =
        +/NODEG1/*FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P2
C=NC.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P3=
        +/NODEG2/*FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P2 =
        +/NODEG2/*FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P3
C=NC.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P4=
        +/NODEG3/*FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P3 =
        +/NODEG3/*FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P4
*
*      - Perennial crops under which degradation does occur, changed LUSTs
C=DEGRAD.FARM(&).O(&).L(&).T(&).I(&).P1 =
  +/DEG1/*FARM(&).SOIL(S&).LUT(S&).TECH(S&).S(S&).P1 = FARM(&).O(&).L(&).T(&).I(&).P1
C=DEGRAD.FARM(&).O(&).L(&).T(&).I(&).P2 =
  +/DEG2/*FARM(&).SOIL(S&).LUT(S&).TECH(S&).S(S&).P2 = FARM(&).O(&).L(&).T(&).I(&).P2
C=DEGRAD.FARM(&).O(&).L(&).T(&).I(&).P3 =
  +/DEG3/*FARM(&).SOIL(S&).LUT(S&).TECH(S&).S(S&).P3 = FARM(&).O(&).L(&).T(&).I(&).P3
*       Calculation of change in perennial LUSTs whith soil degradation
C=D.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P1 =
   +/TRPER1/*FARM(&).O(S&).L(S&).T(S&).I(S&).P1=
   +/SW1/*DEL.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P1
C=T.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P2=
   +/SW1/*FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P1
   +DEL.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P1=
   +/SW1/*FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P2
C=D.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P2=
   +/TRPER2/*FARM(&).O(S&).L(S&).T(S&).I(S&).P2=
   +/SW2/*DEL.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P2
C=T.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P3=
   +/SW2/*FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P2
   +DEL.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P2=
   +/SW2/*FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P3
C=D.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P3=
   +/TRPER3/*FARM(&).O(S&).L(S&).T(S&).I(S&).P3=
   +/SW3/*DEL.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P3
C=T.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P4 =
   +/SW3/*FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P3
   +DEL.FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P3=
   +/SW3/*FARM(&).SOIL(&).LUT(&).TECH(&).S(&).P4


*  LABOR USE AND AVIALABILITY
*
*  (12) Labor use for each LUST, balanced by labor supply, per farm type, per quarter,
*       per period (hours/year)
C=LABCOST.FARM(&).QUART(&).PER(&)=
          +/LABOR/*FARM(&).SOIL(S&).LUT(S&).TECH(S&).S(S&).PER(&)
          - OWNLAB.FARM(&).QUART(&).PER(&)                                       < 0
*
*  (13&14) Household labour availability per farm type per quarter & per period
*          (hours/year)
C=OWNOFF.FARM(&).QUART(&).PER(&)=  +OWNLAB.FARM(&).QUART(&).PER(&)
                                   +PLANTLAB.FARM(&).QUART(&).PER(&)         </QLABAV/
C=OWNOFF.FARM(&).PER(&)=  +OWNLAB.FARM(&).QUART(S&).PER(&)
                          +PLANTLAB.FARM(&).QUART(S&).PER(&)                 </YLABAV/
*
*  (16) Off-farm plantation work availability per quarter (hours/year)
C=PLANTATION.QUART(&).PER(&)= PLANTLAB.FARM(S&).QUART(&).PER(&)             < /PLANTAV/
```

```
*  ENVIRONMENTAL INDICATORS
*
*  (17) Balances of biocide use per farm type (index value/year)
C=BIOBAL.FARM(&).PER(&) =
                  +/BIOCIDE/  * FARM(&).SOIL(S&).LUT(S&).TECH(S&).S(S&).PER(&)
                  -BIOC.FARM(&).PER(&)                                          = 0
*
*  (18) Nutrient balances per nutrient, per farm type (kg/year)
C=NUTBAL.NUTRI(&).FARM(&).PER(&) =
                         -/NUTRIENT/ * FARM(&).SOIL(S&).LUT(S&).TECH(S&).S(S&).PER(&)
                         -NUTBAL.NUTRI(&).FARM(&).PER(&)                        = 0
*
*  (19) Soil loss per farm type (ton/year)
C=SLOSSBAL.FARM(&).SOIL(&).LUT(&).PER(&)=
                          +/EROSION/*FARM(&).SOIL(S&).LUT(S&).TECH(S&).S(S&).PER(&)
                          - SLOSS.FARM(&).PER(&)                                = 0


*************************************************************************************
*                               DATA DEFINITIONS
*
*
*  OBJECTIVE FUNCTION
*
*    discount factor for net returns of each period
DATA=DISCOUNT, F=DCOUNT_1.WK1,      C=DISCOUNT,         L=PER(&)
*    discount value of the returns occuring beyond the last period
DATA=DVALUE,   F=DVALUE_1.WK1,      C=DVALUE,           L=SOIL(&).LUT(&).TECH(&).S(&)
*    product prices
DATA=PRICE,    F=PRICE_1.WK1,       C=PRICE,            L=PROD(&)
*    reservation wage on-farm household labor
DATA=RESWAGE,    F=WAGE_1.WK1,      C=RESWAGE,          L=PER(&)
*    plantation wages
DATA=PLANWAGE,   F=WAGE_1.WK1,      C=PLANWAGE,         L=PER(&)


*   PRODUCTION AND INPUTS
*
*    yields of products by LUST
DATA=PRODUCT,    F=PRODUC_1.WK1,    C=PROD(&).PER(&),   L=SOIL(&).LUT(&).TECH(&).S(&)
* use of inputs by lusts
DATA=INPUT,      F=INPUT_1.WK1,     C=PER(&),           L=SOIL(&).LUT(&).TECH(&).S(&)



*   LAND USE AND AVAILABILITY
*
*    average use of land units by lusts per quarter
DATA=LAND,       F=LAND_1.WK1,     C=QUART(&).PER(&), L=SOIL(&).LUT(&).TECH(&).S(&)
*    dummy to enable calculations per quarter
DATA=UNITY,       F=QUART_1.WK1,     C=PER(&),         L=QUART(&)
*    use of land by perrenial crops
DATA=YEAR2,      F=LAND_1.WK1,     C=YEAR2,           L=SOIL(&).LUT(&).TECH(&).S(&)
DATA=YEAR3,      F=LAND_1.WK1,     C=YEAR3,           L=SOIL(&).LUT(&).TECH(&).S(&)
DATA=YEAR4,      F=LAND_1.WK1,     C=YEAR4,           L=SOIL(&).LUT(&).TECH(&).S(&)
*    change in land quality as a result of LUSTs
DATA=DELTAP1,    F=DELTA1_1.WK1,   C=DSOIL(&),        L=SOIL(&).LUT(&).TECH(&).S(&).P1
DATA=DELTAP2,    F=DELTA2_1.WK1,   C=DSOIL(&),        L=SOIL(&).LUT(&).TECH(&).S(&).P2
DATA=DELTAP3,    F=DELTA3_1.WK1,   C=DSOIL(&),        L=SOIL(&).LUT(&).TECH(&).S(&).P3
*    availability of land units per farm type for period 1 (ha/year)
DATA=LANDP1,     F=LANDP1_1.WK1,   C=FARM(&),         L=SOIL(&).P1
*    conversion from changes in soils to soils
DATA=SOILS,      F=SOILS_1.WK1,    C=DSOIL(&),        L=SOIL(&)

*    perennial crops which have to be maintained, without soil degradation
DATA=NODEG1,     F=NODEG1_1.WK1,   C=NODEG1,          L= SOIL(&).LUT(&).TECH(&).S(&)
DATA=NODEG2,     F=NODEG2_1.WK1,   C=NODEG2,          L= SOIL(&).LUT(&).TECH(&).S(&)
DATA=NODEG3,     F=NODEG3_1.WK1,   C=NODEG3,          L= SOIL(&).LUT(&).TECH(&).S(&)
*    perennial crops which have to be maintained, with soil degradation
DATA=DEG1,       F=DEG1_1.WK1,     C=O(&).L(&).T(&).I(&), L=SOIL(&).LUT(&).TECH(&).S(&)
DATA=DEG2,       F=DEG2_1.WK1,     C=O(&).L(&).T(&).I(&), L=SOIL(&).LUT(&).TECH(&).S(&)
DATA=DEG3,       F=DEG3_1.WK1,     C=O(&).L(&).T(&).I(&), L=SOIL(&).LUT(&).TECH(&).S(&)
*    conversion of changed LUSTs to LUSTs
DATA=TRPER1,     F=TRPER1_1.WK1,    C=O(&).L(&).T(&).I(&), L=SOIL(&).LUT(&).TECH(&).S(&)
DATA=TRPER2,     F=TRPER2_1.WK1,    C=O(&).L(&).T(&).I(&), L=SOIL(&).LUT(&).TECH(&).S(&)
DATA=TRPER3,     F=TRPER3_1.WK1,    C=O(&).L(&).T(&).I(&), L=SOIL(&).LUT(&).TECH(&).S(&)
```

```
*    switch to secure that only the relevant equations are formulated
DATA=SW1,        F=SW1_1.WK1,       C=SW1,                  L= SOIL(&).LUT(&).TECH(&).S(&)
DATA=SW2,        F=SW2_1.WK1,       C=SW2,                  L= SOIL(&).LUT(&).TECH(&).S(&)
DATA=SW3,        F=SW3_1.WK1,       C=SW3,                  L= SOIL(&).LUT(&).TECH(&).S(&)


*   LABOR USE AND AVAILABILITY
*
*   annuity on-farm labor use by lusts per quarter
DATA=LABOR,      F=LABOR_1.WK1,     C=PER(&).QUART(&),  L=SOIL(&).LUT(&).TECH(&).S(&)
*   labor availability per farm per quarter and per year
DATA=QLABAV,     F=QLABAV_1.WK1,    C=QUART(&).PER(&),  L=FARM(&)
DATA=YLABAV,     F=YLABAV_1.WK1,    C=FARM(&),          L=PER(&)
*    plantation work availabilities per quarter
DATA=PLANTAV,    F=PLANAV_1.WK1,    C=PLANTLAB,         L=QUART(&).PER(&)


*    ENVIRONMENTAL INDICATORS
*
*    biocide use per LUST
DATA=BIOCIDE,    F=BIOC_1.WK1,      C=BIOC.PER(&),      L=SOIL(&).LUT(&).TECH(&).S(&)
*    nutrient balance per LUST
DATA=NUTRIENT,   F=NUTBAL_1.WK1,    C=NUTRI(&).PER(&),  L=SOIL(&).LUT(&).TECH(&).S(&)
*    erosion per LUST
DATA=EROSION,    F=USLE_1.WK1,      C=PER(&),           L=SOIL(&).LUT(&).TECH(&).S(&)


*   RELATIONS to minimize number of variables
*
DATA=DEXIST,   F=EXIST_1.WK1,       C=PER(&),           L=SOIL(&).LUT(&).TECH(&).S(&)
DATA=PERDEG1,  F=LSTCH2_1.WK1,      C=P1,               L=O(&).L(&).T(&).I(&)
DATA=PERDEG2,  F=LSTCH3_1.WK1,      C=P2,               L=O(&).L(&).T(&).I(&)
DATA=PERDEG3,  F=LSTCH4_1.WK1,      C=P3,               L=O(&).L(&).T(&).I(&)
```

Appendix G

CONSTRUCTION OF THE OMP DATA FILES

Next to the data on soil erosion and land degradation, the calculation of which is explained in Chapter 6, data files had to be constructed for the input costs, production levels and labor use. These files are, as has been described in Chapter 4, constructed from three databases: LUST data, attribute data and farm type data. The latter consists of information about the availability of soil types at all farms in the Neguev. These individual allocations of land have been aggregated for the case study to obtain the availability of land in the Neguev as a whole. The LUST database describes all the activities needed for a single cropping cycle of a specific LUST. Since the attribute databases contain the general information on inputs and outputs, like prices, the units of measurement, percentage of N, P and K etc., the LUST database only describes activities and quantities of inputs and outputs.

The lowest level of analysis in MERALM consists of the individual land use activities or LUSTs. The input and output coefficients required by MERALM thus have to be specified for each individual LUST through combining the appropriate information from the LUST database with the attribute data. These calculations are performed by programs written for Dbase 5.0 for Windows and SPSS 6.1 for Windows. In order adapt programs for the analysis of different LUSTs a consistent system for naming the files is developed which allows the changing of a program with the 'search and replace' function of Word. The names of the data files have been divided in two parts. The first two characters of the file name indicate the type of information in the file, while the last six characters identify the LUST to which the data refer. A LUST is identified by a reference to the soil type on which it is grown, the crop and the technology used in the cultivation. To indicate the soil the S is dropped from the specification, i.e. SIW reduces to IW, SFW to FW and SFP to FP. From the crop indication the L is dropped, i.e. LAC[2] becomes AC, LBG becomes BG etc. Finally the last part of the LUST is the technology number, indicated by a two digit number. For example, 00IWAC10.DBF, is a Dbase file for SIW.LAC.10, i.e. pineaple grown on a SIW soil with technology 10, which contains the full description of all the activities (indicated by the 00). A similar file for palm heart is 00IWBG10.DBF.

The construction of the data files for inputs, production and labor use starts with a file from the LUST database which describes all the activities which take place in a single LUST. From this database a file is derived which assigns all the activities to a specific quarters and years. These two LUST specific databases are then combined with files from the attribute database containing the general information on inputs and outputs to calculatethe input and output coefficients needed by OMP.

G.1 The '00' LUST files

The starting point of the data-analysis is the '00' file in which the following groups of fields can be distinguished:

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[2] An abbreviation of the Latin name of crops used in MODUS, preceded by an L to indicate that it refers to a land use type. For exmaple, pineapple, *Ananas comosus*, becomes LAC whereas palm heart, *Bactris gasipaes*, is indicated by LBG.

- *identification number*: an unique number for each record in the file
- *operation*: the operations are identified by code numbers, the activities vary from everything from preparing the ground to harvesting the produce
- *dates*: in addition to the starting date and the ending date form the MODUS files an additional column with dates has been added which is equal to the starting date in case the ending date is missing from the file (i.e. the operation is performed on a single day)[3] and in all other cases is identical to the ending date
- *traction data*: contains the number of hours of various sources of traction, for example draught cattle, tractors or trucks
- *equipment*: the number of hours of various types of equipment, for example ploughs or machetes
- *material*: the quantity, type and the unit of measurement of a wide range of inputs and outputs, like for example animal units, fertilizers, biocides, seeds or produce specified per product

These data thus specify the activities, their timing and all materials and equipment involved in the activities. A combination of these data with the attribute data allows the calculation of the all the costs and benefits of each individual LUST. However, the first step is to transform the dates mentioned by each record to a matrix which assigns all the costs and benefits to specific quarters and years.

G.2 Assigning activities to quarters and years

In the '00' file the dates at which an activity takes place can be found in two columns with the starting date and the ending date of an activity. In order to be able to calculate the annuities needed by MERALM all inputs and outputs of production have to be assigned to specific quarters and years. This is done through the equations which can be found in the file Q.XLS. The calculations are made in three worksheets. The first worksheet, TIME_DAT, transforms the dates to serial numbers using the system of Excel in which January first 1900 is 1. The second worksheet, Q_DAYS, consists of an equation for each quarter of each year from 1988 to 2012 which evaluates the numbers in TIME_DAY to assess if the activities takes place in (part of) that quarter. In case the activity does not take place in that quarter the equation returns a 0, in all other cases it returns the number of days that the activity occupies in that quarter. In this way for all the records in the file the number of days in all quarters are determined. The last column of this worksheet calculates the total number of days that the activity takes.

The third worksheet then calculates the part of the activity which takes place in each quarter by dividing the days in each quarter through the total number of days. In this way an activity which spans multiple quarters can be assigned to the individual quarters on the basis of the relative number of days it occupies in each quarter. The result is a matrix with a number of rows identical to the number of records in the '00' file each identified by the ID number and a number of columns which spans at most all quarters from 1988 to 2012. Each cell contains the fraction of the activity taking place in that quarter.

The next step in the construction of the data files is to determine the total input, production or labor for each record and multiply this with the quarterly data matrix. The result is a matrix in which each cell contains the total input, production or labor in a each quarter of each year. The

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[3] In order for the ASCII data from MODUS to be readable for each dta has to be specified by six digits. For exmaple, the first of January of 1990 has to be specified as 010190.

calculation of the totals per record is based on a combination of the '00' file with an appropriate attribute file.

G.3 Inputs

The inputs consist of the costs of traction, equipment and materials, each of which have to be extracted from the '00' file separately. This is done in the INPUT_ID.PRG file. First the data-file is linked with the attribute file on the basis of the code of the traction, equipment or material. Then the ID number, the amount of hours (for equipment and traction) or the quantity (for materials), the code and the price are kept. Then the costs are calculated by multiplying the quantity with the price for each of the three input categories separately. Since for each record there are two possibilities to enter data for each category the result are 6 data-files which contain the costs for each record number. The second part of the file then calculates total input cost for each record by linking these 6 files and summing the costs. The result is for example the data-file INFWZM49.DBF which contains the input costs for each record for SFW.LZM.49.

The next step is to assign the costs to a specific quarter of each period. This is done in the file IYCROPS.SPS. First the Dbase file from the previous step has to be saved as a SPSS file in order to be able to execute the match command. Since the data on the occurrence of the activities are calculated on a quarterly basis and the inputs are only needed on a yearly basis first the date per quarter are summed per year to reduce the calculations after matching. Then the input data file is matched with the file with the quarterly and yearly data, using the ID number. The last step is then to assign the total input use of each record to a specific year by multiplying the inputs with the ratio for each year. Finally, the ID number and the inputs in each year are saved in for example IYFWTP04.WKS. This file contains the Inputs on a Yearly basis for SFW.LTP.04 for each record number.

In order to obtain the total input per year for the LUST the records of the IY file the sum of the rows is calculated in Excel. The result is the input use per year for the LUST and this is copied to an input file which has input costs of all LUSTs per year: T_INPUTS.WKS. The data manipulations have resulted in the data of a crop starting in 1990. Data for LUSTs starting in another period than the first are created by shifting the row to the right until the starting year corresponds tot the starting year of a new period.

Finally the last step is to calculate the annuity of the inputs for each period. Since the annuities depend on the length of the cropping cycle the number of years a crop is present has to be added to the input file. This is done by the file NR_INPUT.PRG which links the input file to a file which has the number of years each LUST is present in each period. Then the annuities can be calculated by ANN_INPT.SPS. First the net present value for each period is calculated after which the annuities are determined on the basis of the number of years each crop. The results are saved in ANN_INPT.WKS which contains the data needed by OMP.

G.4 Production

Production is determined in a similar way as the inputs are calculated. This time only one field of the '00' file is needed since the production is registered in by the materials field. However, one

LUST can produce different products. For example in the case of pineapple 10 products can be produced. Therefore each LUST database has to be searched for each possible product the LUST can produce. This is done for example by the PROD_BG.PRG file which searches for palm heart products and generates for each record the amount of a specific product produced. The result is the production of the specific product for each record in the '00' file.

These data are then linked to the quarterly data to obtain the production for each year. An example is the file PROD_BG.SPS. The result is an individual file for each product which conatins the production for each record in each year. Again, as with the inputs, the records are summed over the records to get the total production per year for each LUST. In order to facilitate the next calculations these totals per LUST and product are added in a single file per product. This file thus contains the production per year of a specific product for sevral LUSTs. e.g. the production of export pineapple for all pineapple LUSTs.

These data are then linked to the presence of the LUSTs in each period to calculate the annuities. For example the NR_PAC.PRG file links each of the 10 pineapple production files to the presence of the LUSTs, resulting in 10 data-files which have the production per year as well as the presence of the pineapple LUSTs of a specific product. Then the annuities are calculated, for example by the AN_PR_AC.SPS file. This file calculates for each product the net present value per period, followed by the annuity production per period. The last step is to combine the datafiles of the inidvidual poducts in asingle file which contains the annuity production of all products for all periods for all LUSTs.

G.5 Labor

Since the labor is a separate field in the data-file (TIME) it does not have to be extracted with Dbase. Instead the column of TIME can be multiplied directly with the quarterly data, after which an identical procedure as described above for inputs and production is followed. The number of years in each period is added with Dbase (NR_LABOR.PRG) and the annuities are calculated with AN_LABOR.SPS. The only difference with the inputs and production calculations is that labor is determined on a quarterly basis and the quarterly data thus do not have to be summed over the quarters.

G.6 Returns beyond the last period

During the calculation of the inputs, production and labor not only the data for the 4 periods are calculated but also the net present value of the activities which occur beyond the last period. These data are saved in a separate data file and used to calculate the net present value of input, labor and production costs beyond the last period. These data enter the objective function directly and thus do not have to be transformed to annuities.