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Sub-regional linear programming models in land use analysis: a case study of the *Neguev* settlement, Costa Rica

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Abstract

The present paper deals with linear programming as a tool for land use analysis at the sub-regional level. A linear programming model of a case study area, the *Neguev* settlement in the Atlantic zone of Costa Rica, is presented. The matrix of the model includes five sub-matrices each encompassing a different farm type. The farm types are distinguished on the basis of land-labour ratios, considering farm size and three different soil types, and assuming a fixed availability of household labour. Land use activities are included in the form of Land Use Systems & Technologies. These represent land use systems with fixed input-output coefficients. Two indicators for sustainability are taken into account: soil nutrient depletion and biocide use. These are built into the model via constraints, marking upper limits to the use of renewable resources and to the waste flow into the environment. The linear programming model forms part of the USTED (*Uso Sostenible de Tierras En el Desarrollo*) methodology for the analysis and planning of sustainable land use. Several land use scenarios are analysed to assess whether the income of all farms in the Neguev can increase through an improved, and sustainable, land use. First, a base scenario is calculated to serve as a reference for assessing the impact of policy measures or changing socio-economic conditions. A striking feature of the base scenario is the large area with palm heart in comparison to the actual area. Sustainability related policy measures studied are increasing biocide prices, and quantitative restrictions on biocide use and soil nutrient losses. Doubling the biocide price hardly affects its use, while a quantitative restriction on the use of biocides per ha of 50% in comparison to the base scenario use, reduces average incomes with less than 1%. A similar conclusion applies to soil nutrient depletion. Restricted to 'critical nutrient losses' per year over a ten year period, specified per land unit per farm type, average incomes are reduced with hardly 3%. Other scenarios concern the impact of decreasing palm heart prices, as a consequence of increased supply, the influence of increasing wages and the role of the discount rate.

Keywords: Costa Rica, land use analysis & planning, linear programming, scenarios, sustainable agricultural development

Introduction

Following Fresco *et al.* (1992), land use planning[1] is considered a form of (regional) agricultural planning. Land use planning is directed at the 'best' use of land, in view of accepted objectives, and of environmental and societal opportunities and constraints. It is meant to indicate what is possible in the future with regard to land use (potentials) and the time path of interventions to go from the present situation to a future one, in other words, how to change land use. Looking for the 'best' or 'optimal' land use, in view of accepted objectives, and of environmental and societal opportunities and constraints, is akin to the principle of linear programming, or other optimisation models, in which an objective function is maximised by selecting from alternative activities (opportunities), subject to constraints. Linear programming can thus be of help in the search for the 'best' land use.

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

An important aspect of the USTED methodology is the differentiation between levels of analysis: LUST, farm, sub-region, region and nation, comparable to those in the LEFSA (Land Evaluation & Farming Systems Analysis) sequence in Fresco *et al.* (1992). Levels of analysis are related to levels of decision making. At what level which decision is made, depends on the specific circumstances. In the *Neguev* settlement as a sub-region of the Northern part of the Atlantic Zone of Cost Rica, land use decisions are made at the farm level, influenced by policy decisions at the national level, and, albeit progressively less important, at the regional and sub-regional level. Up to now only three levels of analysis (LUST, farm and sub-region) are incorporated in USTED. However, in the linear programming model two levels of decision making are part of the analysis: land use decisions at the farm level and policy decisions at the sub-regional level.

More levels of analysis give rise to aggregation issues. In the context of land use analysis three points are at stake (Erenstein & Schipper, 1993). (1) The use of land is often considered without 'knowing' the behaviour of the farm households responsible for the actual use of land. (2) The aggregation bias, as individual farmers have

[1] In the title of the paper reference is made to *land use analysis* instead of land use planning. Land use planning has a connotation with 'designing', 'making' and 'deciding' land use for the actual land users. However, in most situations land users themselves decide about the use of their land, not the land use planners nor decision makers at a policy level. Thus, land use planning can only analyse possible land uses – in the past, at present and in the future – and advise about the 'best' land use. Therefore, the term 'analysis' is preferred above the term 'planning'.

resources at their disposal in different proportions from the aggregated resources of a region. (3) Variables that are exogenous at the micro level become endogenous at higher levels. For example, individual farms may not perceive of markets as a constraining factor, but if most farmers in an area act in the same way, price adjustments in input and output markets will occur. The same applies to factor markets. An individual farmer, being a marginal actor, may hire as much labour as he would like, but if all farmers intend to do so, they will come up against a regional labour constraint. These problems are well known from efforts to build (linear programming) models at a national or regional level (Hazell & Norton, 1986). In the USTED methodology, the first aggregation issue is approached by using a – for farm households – plausible objective function for a linear programming model: maximisation of the difference between the value and the cost of production, including household and hired labour, plus off-farm earnings. This objective function could be called economic surplus (see Table 4 for a definition) and is calculated as the farm household income (see Table 4 for a definition) less a valuation of on-farm household labour (see Table 3 for a definition). The aggregation bias is diminished by incorporating five farm types in the sub-regional model, each with specific resource availabilities with regard to land, specified according to six types, and to household labour. The problem of exogenous variables becoming endogenous is side-stepped by supposing that the sub-region is 'small' in relation to the country and that supply forthcoming from the sub-region is too small to influence prices of products. On the other hand, a restricted sub-regional labour supply forms part of the model: all farms together cannot hire more labour than is available within the sub-region. However, the price of hired labour is fixed.

This paper describes and discusses a sub-regional linear programming model that has been constructed for the *Neguev* settlement. The approach to land use analysis aims at deriving relevant options for land use by balancing economic criteria for agricultural production on the one hand and ecological criteria on the other. The paper starts with outlining the methodological background of the approach, after which the methodology itself is exposed. Results are presented by analysing land use scenarios to examine whether incomes of farms in the *Neguev* can increase through an improved land use from a sustainability point of view. The paper ends with a discussion about the strengths and limitations of the methodology, and suggestions for future research.

Linear programming as a tool for land use analysis

Agricultural sector models

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

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

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

The model for the Neguev area applies to a limited number of land use types only: cassava, logged forest, maize, palm heart, pasture with cattle, pineapple, plantain and tree plantation. This was done in view of the emphasis on the development of a methodology for land use analysis.

Applying the above elements to the sub-regional model of the Neguev case, some remarks should be made. (1) In the model the behaviour of the producers is described by assuming that each farm type maximises its return to land, own capital and management of the farm (see Table 3 for a definition), in conjunction with possible off-farm labour income. This objective is the same as the economic surplus above. (2) Production functions are specified through the LUSTs, which are specific combinations of soil types, land use types and technologies with fixed input and output quantities per hectare; the fixed input and output coefficients also include the sustainability parameters. Given the circumstances in the Atlantic Zone, soil nutrient depletion and biocide use are considered the most relevant sustainability criteria (Jansen *et al.*, 1995). (3) Resource endowments with regard to land (per soil type) and household labour are specified per farm type and per month; the impact of the selected LUSTs on resources related to the sustainability parameters is appraised at both the farm as well as the sub-regional level. (4) The market for agricultural products is assumed to be unaffected by producer decisions in the sub-region: all products can be sold or purchased at a fixed price. However, with respect to the labour market it is assumed that working off-farm as hired labour on other farms inside the sub-region is limited by the aggregated demand for such labour, while off-farm work outside the sub-region on (banana) plantations is restricted; wages are fixed, depending only on the type of work. (5) The policy environment is hardly specified, except in the scenarios restricting the impact on environmental resources.

Sustainability parameters in linear programming models

As a 'working' definition of sustainable development, the research team adopted the Pearce & Turner (1990) definition 'maximising the net benefits of economic development, subject to maintaining the services and quality of natural resources over time'. Economic development is seen as a vector of a number of elements, including not just increases in real per capita income, but also other elements of social welfare (e.g. improvements in nutrition, health, education, and housing). For economic development to occur, each of these elements should increase, or at least not decrease.

In contrast to most other definitions of sustainable development, including the Brundtland (Anonymous, 1987) one, Pearce and Turner speak about maximising the net benefits of economic development. Obviously, the net benefits of economic development do not only refer to benefits in the present. Benefits are spread over the years and thus involve an element of time. In a way, one tries to compare the distribution of the benefits in a dynamic context.

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

Sustainable development as defined by Pearce & Turner (1990) can be narrowed down to sustainable land use and, therefore, seems a good starting point for analysis. The given 'rules' for resource use can be applied to the circumstances in a specific area. The main natural resources are land and water. With regard to each of these resources, parameters can be designed to measure its quantity and quality. As noted earlier, soil nutrient depletion and biocide use are considered the most relevant sustainability criteria in the case study area. These parameters can be related to rules (a1) and (a2), respectively, for resource use. Moreover, they can be thought of as the relevant sustainability indicators (Opschoor & Reijnders, 1991) of the 'environmental (utilisation) space' (Opschoor, 1992; Wetering & Opschoor, 1994) with regard to land use in the research region.

Linear programming optimises resource use given a certain objective, in other words, it strives for a maximum efficiency, rule (b) for sustainable development. Efficiency is optimised subject to the substitutability between resources and technical progress. The effects of substitution can be traced via shadow prices of constraints and sensitivity analysis. The notion of 'technical progress' (or innovations, leading to a more productive use of resources) is part of the model: each land use type is specified according to technology and combined with a land unit (the LUSTs). In the optimal solution the most efficient technologies or LUSTs, and thus resource use, in view of all options and constraints, and, of course, the objective function, are chosen.

Single and multiple goal linear programming

In land use planning usually more than one goal is pursued, leading to the use of multiple goal linear programming, or, more general, a multiple criteria analysis (Romero & Rehman, 1989). At the farm level, households might strive for short-term cash income, food security, minimum risk and long-term viability, while at the policy level economic goals like (regional) income, employment and distribution, are often pursued. At both levels sustainability goals may play a role. In the context of linear programming four methods of multiple criteria analysis exist: goal programming, multi-objective programming, compromise programming and interactive multiple goal programming (Romero & Rehman, 1989). Recently, the latter is often used in land use planning studies (e.g. Ayyad & Van Keulen, 1987; Veeneklaas, 1990; De Wit *et al.*, 1988, and Anonymous, 1992). An application of compromise programming can be found in Erenstein & Schipper (1993). However, these multiple criteria methods are all based on the classical – single goal – linear programming set-up. Activities, constraints and coefficients of the matrix are the same as in a linear programming model with a single objective function, except that in multiple criteria analysis the programming model is solved, in subsequent runs, with more than one objective function (each run with a different objective). Therefore, the present model can be seen as a forerunner of a subsequent analysis with multiple criteria.

Linear programming and economic analysis in agriculture

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

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

However, many economists (but also crop production ecologists) are more inclined to think in terms of continuous production functions. Such functions allow for econometric estimates of coefficients, and are comparable with the use of crop growth simulation models. At the level of the individual farm, for each LUST, continuous production functions are difficult to construct. Furthermore, at that level econometric estimation is impossible, while estimation of continuous functions with data collected at different farms comes across theoretical objections (Ellis, 1993). Econometric estimations of supply and demand elasticities, based on time series data, are more justified. However, objections can be made to these estimations as well (Hazell & Norton, 1986). Firstly, often too many elasticities have to be estimated from too few data, especially if there are many cross-elasticities. Secondly, the quality of the data is often inadequate, especially in developing counties. Thirdly, the resulting estimates are based on aggregate historical data, not specified per technology and not taking into account new technologies.

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

Land use systems as core activities in the models

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

Farm classification and models

Day (1963) formulated three criteria for the classification of individual farms into groups in order to obtain a perfect aggregation in linear models. All farms in one group must have:
1) proportional to each other's per unit activity revenue expectations (proportional

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

The farm groups were formed with the help of cluster analysis. The clustering was based upon the area of each farm (relative to the largest farm) and the proportion of each of the three soil types. Two clustering approaches were used, a hierarchical agglomeration schedule and a non-hierarchical technique, procedures 'CLUSTER' and 'QUICK CLUSTER' of Anonymous (1990), respectively. Often, it is a matter of good judgement and convenience how many groups should be formed (Hair *et al.*, 1992). Five groups of farms, or farm types, were formed which are relevant in the light of local experience, four groups of 'small' farms (average farm size 14 ha) and one group with 'large' farms (average size 32 ha). The four groups of small farms differ according to the importance of the soil types. Three groups out of these four have one dominating soil type, SFP in farm type 1, SFW in farm type 4 and SUW in farm type 5, respectively. The fourth group of small farms (farm type 3) has about as much SFW as SUW soils. The group of large farms has mostly SUW soils (farm type 2). The results of the clustering are summarised in Table 1. The respective land-labour ratios can also be observed. These ratios are based on an assumed labour availability of 2.0 labour-years per household.

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

In the sub-regional linear programming model, a number of variables are included

Table 1. Clustering of *Neguev* farms into five groups.

Farm type	Number of farms	Average area (ha)	Area with soil type (%) SFP	SFW	SUW	Land/labour ratio (ha labour-year^{-1}) total	SFP	SFW	SUW
1	33	15.7	60	12	28	7.9	4.7	1.0	2.3
2	4	32.1	12	10	78	16.2	1.9	1.7	12.7
3	46	13.5	7	52	41	6.4	0.5	3.5	2.8
4	35	14.1	3	91	6	7.1	0.2	6.5	0.4
5	189	13.1	6	6	88	6.6	0.4	0.4	5.8
total/ average	307	13.8	13	23	64	7.0	0.9	1.6	4.6

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

Next to variables, a number of constraints are stipulated per farm type as well: the availability of land, specified per land unit, and the availability of household labour, both specified per month. Furthermore, depending on the (variant of the) scenario, also the constraints with regard to soil nutrient depletion and biocide use can be specified per farm type.

Sub-regional models with farm types

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

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

Hired labour on one farm type is restricted by the available off-farm labour from the other farm types within the *Neguev*. This being a mutual constraint, for every month the supply of off-farm labour is equal to the demand for hired labour within the Neguev.

The sub-regional model also contains constraints with regard to soil nutrient depletion and biocide use. In this way, rules a1 and a2 for resource use of the Pearce & Turner definition of sustainable development are also incorporated into the model at the sub-regional level.

The objective function of the sub-regional model consists of the net benefits to all farms, the economic surplus, defined as the value of production, less input costs, less hired labour costs, less value of on-farm household labour, plus off-farm work labour income. The objective function, being the sum of the same objective functions of each farm type, is measured in *Colones* per year.

The Neguev settlement

The Neguev settlement (approximate location 83°33'E and 10°12'N) has an area of 5340 ha. The altitude is between 10 and 50 m above sea level (De Bruin, 1992) in a region which climate is classified as very humid tropical, without dry months (Herrera & Gómez, 1993). The average annual rainfall is 3630 mm (1972–1988) with an air temperature of about 25 °C (1976–1988; average between daily maximum and minimum temperatures). Soils in the area are classified into three types (De Bruin, 1992): (1) young poorly drained volcanic soils of relatively high fertility (Entisols and Inceptisols), (2) young alluvial well drained volcanic soils of relatively high fertility (Inceptisols and Andisols), and (3) old well drained soils developed on fluvio-laharic sediments of relatively low fertility (Oxisols and Inceptisols).

The settlement had its origin in an occupation by land squatters of the *hacienda* Neguev in september 1979. The IDA (*Instituto de Desarrollo Agropecuario*) parcelled the *Neguev* into farms of 10, 15 or 17 ha. Later, a number of farms were subdivided. Farmers were not allowed to sell or rent their land until 1991. Nevertheless, unofficially, many farmers did leave their farms in view of the difficult farming circumstances. In these cases the farms were, de-facto, rented to other farmers or the 'improvements' (*mejoras*) were sold. For sake of the case study, the Neguev is considered to be sub-divided into 307 farms with a total area of 4236 ha available for agriculture or forestry. The settlement is divided into two parts, separated by the river Parismina. The Northern part has a relatively good access, whereas the Southern part is more isolated. Although its main entrance road is connected to the highway San José-Limón, no bus service was provided till 1992, when a second entrance road was created. Until the introduction of this 'two-times-a-day' bus service, the minimum distance to walk to the highway was about six km, while the maximum distance was about 14 km, which had a negative impact on the marketing possibilities and prices of the different crops in this part of the Neguev.

The tasks of the IDA consisted of providing titles, extension, credit via the *Caja Agraria* and marketing assistance to the farms, and creating a simple infrastructure: rural roads and five small villages with a communal centre, a primary school, a soccer field and one or two small shops. No electricity nor telephone lines were installed, except in the main centre, Milano, where also the head office of the IDA is located. The IDA executed programmes to stimulate the cultivation of crops like cacao, chile, palm heart, passion fruit, pineapple, roots and tubers.

The average farm size is 13.8 ha, with 1.2 ha fertile poorly drained soil, 3.2 ha fertile well drained soil and 8.6 ha unfertile well drained soil. Except for a few larger farms, the farm size is rather uniform (Schipper, 1993). However, the three soil types are not equally distributed over the farms; for details refer to the earlier Section on farm classification and models (Table 1). Land use in the period 1985 to 1991 can be observed in Table 10 in the later Section on the present land use system scenario.

The role of scenarios in land use analysis

Scenarios are defined as 'possible trends in land use determinants and/or policy measures' (Alfaro *et al.*, 1994). A number of factors determining land use can be envisaged, for example population growth, wages, discount rates, relative product prices, and natural events, like flooding, volcanic eruptions and earthquakes. With regard to those factors assumptions can be made as to how they will change in the future. Each of these assumptions is either called a scenario, or a variant of a scenario. Table 2 provides an overview of the eight different scenarios discussed below.

Three scenarios related to land use determining factors will be discussed: price of palm heart, price of labour and discount rate. Possible policy measures and their influence on land use will be studied in three other scenarios: biocide, price of biocide and soil nutrient depletion. All the scenarios are compared with a *base* scenario, in which 1991 prices are used and no restriction is placed on either biocide use or soil nutrient depletion. In this base scenario the model can choose from all possible technologies in all land use systems.

However, in contrast to scenarios in which farms can select from LUSTs with present technologies and from LUSTs with potential technologies, in reality – Neguev, 1991 – farms operated with a certain number of actually available technologies. Therefore, a present land use systems scenario, in which the model can select only the LUSTs with technologies defined on the basis of a farm survey (Jansen & Schipper, 1995), was calculated as well. Such a scenario serves two purposes: first, it allows for a comparison with the actual land use in the Neguev, known from other sources; second, by comparing the present land use scenario with the base scenario, it provides a measure for the magnitude and impact of possible changes.

Base scenario

In the base scenario, each of the five farm types in the model can choose from 105 LUSTs (based on six land units, eight land use types, and, depending on the land unit land use type combination, a number of technologies; Jansen & Schipper, 1995). No restriction is placed on the use of biocides and on the depletion of soil nutrients N, P and K. Wages are set at C. 100 per hour (C. is *Colón*, the currency of Costa Rica; in 1991, on average, one US$ valued 122 *Colones*) for hired labour, while work on other farms within the Neguev pays C. 90 per hour and work on a plantation outside the Neguev has an hourly wage of C. 188. For on-farm work by members of a household a 'reservation' wage of C. 67 per hour is assumed. The rationale for a 'reservation' wage is that people are not willing to work on their own farms if they cannot earn a certain minimum return per hour worked. By imposing such a reservation wage, the linear programming model will not select an activity with a return to family labour lower than the reservation wage, unless forced to by other constraints. Alternatively, it can be said that a reservation wage reflects the preference for leisure of a house-

Table 2. An overview of the scenarios.

Scenarios and their variants:	
Name	base scenario
Constraints	no restriction on biocide use and nutrient depletion
Data	actual and potential LISTs
Results	optimal land use under assumed base conditions
Name	present land use systems scenario
Constraints	as in base scenario
Data	only actual (based on 1991/1992 *Neguev* farm survey) LUSTs
Results	optimal land use under assumed actual conditions (only actual LUSTs)
Name	biocide scenario
Constraints	biocide use index; three variants: 50% of base scenario, at *Neguev* level, at farm type level, and at *Neguev* level per ha, respectively
Data	as in base scenario
Results	effects of restricting biocide use on land use
Name	price of biocide scenario
Constraints	as in base scenario
Data	increase of biocide prices with 100%
Results	relation between biocide price (as a possible incentive) and biocide use
Name	soil nutrient depletion scenario
Constraints	soil nutrient depletion at the level of land units within farm types
Data	as in base scenario
Results	effects of restricting soil nutrient depletion on land use
Name	price of palm heart scenario
Constraints	as in base scenario
Data	% price reductions of palm heart of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50
Results	relation between price of palm heart and its production
Name	price of labour scenario
Constraints	as in base scenario
Data	changes in labour costs from −25 to +25% (in steps of 5%)
Results	relation between labour costs and land use
Name	discount rate scenario
Constraints	as in base scenario
Data	separate calculations with % discount rates of 0, 3, 5, 10 (= base), 15 and 20
Results	relation between discount rate and land use

hold (Hazell & Norton, 1986). The discount rate is assumed to be 10%, while all input and output prices are 1991 farm gate prices.

The results of the base scenario will be presented under seven topics: objective function, farm production economics, income structure, employment, land use, soil nutrient depletion and biocide use. Each time the value for the sub-region *Neguev* will be presented, as well as the values per farm type. The first shows the average for all farm types, while the second provide an insight into the differences between the farm types.

The value of the objective function in the base scenario is C. 418 10^6 $year^{-1}$ (Table 9), equivalent to US$ 3.4 10^6. The objective function value differs per farm type, which is reflected in the differences with regard to the production economic data (Table 3). For example, compare between farm types, the gross margin or the return to land, own capital and management of the farm. It is interesting to relate these data with the available farm resources (Table 1). Only land related resources are discussed, because each farm type is assumed to have 2.0 labour-year labour resources available. Farm type 1 has an average farm area of 15.7 ha of which 60% is SFP soil, only 12% SFW soil and 28% SUW soil. SFP can hardly be used, while SUW is less suitable for agricultural production than SFW. In summary, farm type 1 is the worst endowed farm type, which is reflected in the worst farm performance. Farm type 2 is relatively large (32.1 ha) with 12% SFP, 10% SFW and 78% SUW. Because this farm type has more land, its farm performance is the best. Farm type 3 is small (13.5 ha) with 7% SFP, 52% SFW and 41% SUW. Thus, it is somewhat better endowed than an average farm, with corresponding performance. Farms of type 4 have an average area of 14.1 ha with 3% SFP, 91% SFW and 6% SUW. These farms are qualitatively best endowed. Their farm performance is also the best after that of the 'large' farm type 2. Finally, farms of type 5, the largest group, have an average area of 13.1 ha with 6% SFP, 6% SFW and 88% SUW. Its resources are less than average, while the same applies to its performance. In summary, it can be concluded that there is a close relation between the quantity and quality of the land resources and the farm performance.

The performance of each farm type is also reflected in the corresponding income structure (Table 4) and labour use (Table 5). Farm types 1 and 5 compensate relative-

Table 3. Production economic data per farm type: base scenario (*Colones* 10^3 $year^{-1}$).

Farm type	1	2	3	4	5	average
Value of production[1]	879	2727	1531	2106	1284	1390
Input costs[2]	89	181	123	118	115	115
Hired labour[3]	0	92	8	51	0	8
Gross margin[4]	790	2454	1400	1938	1169	1267
Own labour[5]	82	265	149	215	126	136
Return to land, own capital & management of farm[6]	708	2189	1252	1723	1043	1131

[1] Value of production: physical output, valued at farm gate prices.
[2] Input costs: costs for current input goods (e.g. seeds, fertilizers, biocides) and capital services (e.g. use of machete, knapsack sprayer); in case of own capital goods, capital services include operation costs and depreciation per hour of use; in case of hired goods, capital services are expressed as a rental rate per hour.
[3] Hired labour: costs for hired labour.
[4] Gross margin = Value of production – Input costs – Hired labour.
[5] Own labour: valuation of on-farm household labour at a reservation wage.
[6] Return to land, own capital and management of farm = Gross margin – Own labour.

Table 4. Income structure per farm type: base scenario (*Colones* 10^3 $year^{-1}$).

Farm type	1	2	3	4	5	average
Gross margin	790	2454	1400	1938	1169	1267
Work on other farms[1]	31	0	0	0	6	7
Plantation work[2]	308	63	193	70	246	222
Farm household income[3]	1130	2516	1596	2007	1421	1496
Own labour	82	265	149	215	126	136
Economic surplus[4]	1048	2251	1446	1792	1295	1360

[1] Work on other farms: remuneration for work on other farms within *Neguev*.
[2] Plantation work: remuneration for work on plantation outside *Neguev*.
[3] Farm household income = Gross margin + Work on other farms + Plantation work.
[4] Economic surplus = Farm household income – Own labour; it represents the returns to land, own capital and management of farm, and to labour employed off-farm; calculated as a balance, it is an indicator of the postulated objective of the farm households. It coincides with the objective function of the linear programming model in all scenarios.

Table 5. Labour use per farm type: base scenario (days $year^{-1}$).

Farm type	1	2	3	4	5	average
Own labour[1]	145	334	255	329	215	228
Hired labour[2]	0	105	9	58	0	9
Work on other farms[3]	40	0	0	0	8	9
Plantation work[4]	186	37	117	42	149	134

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

ly low returns for farming activities by working more off-farm, both on other farms within the Neguev, as well as on plantations outside the *Neguev*. Family members of the remaining farm types do not work on other farm types, while working less on plantations as well.

The creation of income and work in the Neguev is largely based on the use of land by different farm types. Land units SFW and SUW are mainly used for palm heart (2676 ha), followed by cassava (254 ha) and tree plantations (29 ha). Land unit SFP (422 ha) is not used at all. The forest land units are logged on a sustainable basis. Details on the land use can be found in Table 6. It is important to note that the outcome of the base scenario is heavily biased towards palm heart: 79% of the available area should be planted to palm heart. The optimal solution selects a zero fertilizer technology, yielding about 80% of the potential production of 10,000 palm hearts ha^{-1} $year^{-1}$ on the SFW soils, three years after planting (5,000 plants ha^{-1}). On the less fertile SUW soils this technology yields about 5,000 units ha^{-1} $year^{-1}$. Given the relative prices, inputs and labour use, this appears to be an attractive technology and crop.

Table 6. Land use[1] per farm type: base scenario (ha $year^{-1}$).

Farm type	1	2	3	4	5	average	*Neguev* total
Logged forest on FFP[2]	2.5	0.9	0.1	0.0	0.2	0.4	118
Logged forest on FFW[2]	0.5	0.1	2.1	1.2	0.4	0.7	222
Logged forest on FUW[2]	1.0	3.4	1.3	0.1	2.2	1.7	515
Palm heart on SFW[2]	1.4	0.6	4.9	11.1	0.4	2.4	732
Cassava on SFW[2]	0.0	0.2	0.0	0.0	0.0	0.0	1
Tree plantation on SFW[2]	0.0	2.5	0.0	0.5	0.0	0.1	29
Palm heart on SUW[2]	2.5	21.4	3.5	0.2	8.5	6.3	1944
Cassava on SUW[2]	1.0	0.2	0.7	0.4	0.9	0.8	253
Available area	15.7	32.1	13.5	16.5	13.1	13.8	4236

[1] Excluding SFP[2] area of each farm type (422 ha in total).
[2] Land unit codes:

SFP	Fertile, poorly drained soil	FFP	Fertile, poorly drained soil, with a forest cover at present
SFW	Fertile, well drained soil	FFW	Fertile, well drained soil, with a forest cover at present
SUW	Unfertile, well drained soil	FUW	Unfertile, well drained soil, with a forest cover at present

Although the area planted to palm heart has been steadily increasing since 1987, the 1991 area under palm heart (about 140 ha, Table 10) was significantly less than the area as calculated by the base scenario. Therefore, the base scenario results should be interpreted as an indication that in the future more palm heart could be planted. Field observations during 1993 and 1994 confirm that farms are still planting new palm heart. In this respect, a main bottleneck will be the market for palm hearts. Palm heart is a luxury product with relatively a small domestic and international market, though, given rising incomes, both will grow. Main importers are France and the USA. However, the international market is crowded by competitors, especially Brazil and Colombia. It has to be realised that the present production of palm hearts in Costa Rica is supplied by about 2000 ha. An area of 2676 ha with palm heart in the Neguev would double the national production, with falling prices as a most likely consequence. This problem is addressed in the price of palm heart scenario.

Soil nutrient depletion in the base scenario is shown in Table 7. The average yearly soil depletion for N and K are 16.6 and 12.7 kg ha^{-1} $year^{-1}$, respectively, while 2.4 kg ha^{-1} $year^{-1}$ of P is added to the soil. Of course, these numbers differ per farm type and soil type, depending on the land use. The consequences of a restriction on the depletion of nutrients at the level of land units within each farm type are examined in the soil nutrient depletion scenario.

Table 7. Soil nutrient depletion per farm type: base scenario (kg ha^{-1} $year^{-1}$).

Farm type	1	2	3	4	5	average
N	−7.1	−16.9	−16.8	−22.1	−17.4	−16.6
P	2.6	0.3	2.1	0.8	2.8	2.4
K	−6.0	−11.7	−13.4	−18.2	−12.8	−12.7

Table 8. Biocide use index per farm type: base scenario (index value ha^{-1} $year^{-1}$).

Farm type	1	2	3	4	5	average
Biocide use index	14	30	29	36	32	30

Table 9. Value of objective function: base scenario versus present land use and sustainability policy related scenarios (*Colones* 10^6 $year^{-1}$).

Farm type	1	2	3	4	5	average
Base	35	9	66	63	245	418
Present land use	23	9	41	27	218	319
Biocide a (50% reduction Neguev level)	35	9	66	63	241	414
Biocide b (50% reduction per farm type)	35	9	66	62	242	414
Biocide c (50% reduction per ha)	35	9	66	62	242	414
Price of biocide	34	9	66	62	241	412
Nutrient depletion	34	9	64	60	240	406

The value of the biocide use index (Jansen *et al.*, 1995) amounts to 30 ha^{-1} $year^{-1}$ for the whole Neguev. There are large differences between the farm types (Table 8). The consequences of imposing a limitation on the use of biocides are reviewed in the biocide scenario.

In the following sections, the features and results of each scenario will be discussed in relation to the base scenario. To save space, Table 9 is presented with the value of the objective function of the base scenario and the present land use systems scenario, and of the sustainability policy related scenarios: biocide (three variants), price of biocide and nutrient depletion.

Present land use systems scenario

In the present land use systems scenario the farms can only select LUSTs defined on the basis of the farm survey data, i.e. the actual technologies currently in use, not the potential ones.

The value of the objective function is C. 319 10^6, i.e. 24% lower than in the base scenario (Table 9). However, per farm type the picture varies greatly. The SFW soils are used for low income yielding tree plantations, while nearly all SUW soils are planted to palm heart. The present technology needs much labour, resulting in a lot of off-farm work on other farms within the Neguev. Therefore, no labour can be spared to work on plantations outside the Neguev, reflecting the collective view point of the model: the objective function is the sum of the farm type incomes. From an individual farm type point of view, some would be better off by working on a plantation. For example, farm type 1 works 187 days on other farms in the Neguev at a wage of C. 90 per hour. On a plantation the wage is C. 188 per hour. Nevertheless, by working for other farmers, these other farmers are able to produce more palm heart, resulting in the highest (collective) objective function value.

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

Even though only present LUSTs were used, the optimal land use in the present land use systems scenario differs from the actual land use in the *Neguev* at the end of the 1980s (Table 10). Most obvious are the discrepancies in the areas with pasture (no pastures in the present land use systems scenario) and with annual and perennial crops (nearly 2,700 ha with palm heart, no other crops in the present land use systems scenario). Several reasons might be forwarded for the difference between land use in reality and in the present land use scenario.

Firstly, linear programming is not the most suitable methodology to explain present land use. Three main arguments exist. a) Although the objective of maximising the net benefits might be plausible as a first approximation of the actual farmer objectives, farm households typically have complex objectives of which income maximisation might be one. Other possible objectives are food security, regularity of cash income, risk minimisation and socially induced objectives. b) With regard to the activities, the model takes into account only eight land use types, while in reality more options exist. Also, the input-output coefficients used in the model can only be an estimation of the varied coefficients in reality. c) The constraints regarding available resources are limited to land and labour in the model, while in reality farms face other constraints as well, for example credit.

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

Table 10. Land use in the Neguev: 1985, 1987, 1989 and 1991 (ha).

Major land use type & crop	1985[1]	1987[2]	1989[3]	1991[4]
Annuals	460	998	282	356
Perennials	238	364	335	383
Pastures	2346	1745	2519	2407
Forest & wasteland	1194	1073	1101	1090
Total	4236	4236	4236	4236
Maize	414	589	181	154
Cassava	30	118	76	187
Pineapple	–	90	13	18
Plantain	–	23	25	44
Palm heart	–	–	90	138

[1] Anonymous (1985): based on an inventory of all farms.
[2] Waaijenberg (1990): based on a random sample survey of 53 farms.
[3] Mücher (1992): based on air-photo interpretation of six non-randomly selected sample areas with a total area of 1273 ha; the areas per land use type for the Neguev as a whole are obtained by weighing the sample data with the area of the three main soil types.
[4] Mücher (1992): based on 1989 air-photos, corrected for observed changes in 1991.

Finally, linear programming indicates an optimal solution in the long term. In reality, short term considerations, like actual land use, credit availability and gestation periods of perennial crops, are important as well.

Biocide scenario

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

Comparing the three biocide scenario variants, the reduction of biocide use differs per farm type (Table 11). In variant a), nearly the complete reduction of biocide use is obtained through a reduced biocide use in farm type 5, while in variants b) and c) the reduction is more evenly spread among the farm types.

The effects on income are rather small (Table 9), at less than 1%. Slightly more labour is employed within the *Neguev* and less on plantations. The land use pattern is similar to that in the base scenario. However, in palm heart, herbicides are replaced by manual weeding, while maintaining other inputs and outputs at the same level as in the base scenario. The replacement is larger in variant c) than in variant b) than in variant a). Finally, nutrient depletion in the biocide scenarios (all variants) is exactly the same as in the base scenario. This is due to the fact that fertilizer inputs and yields are the same.

Price of biocide scenario

In the price of biocide scenario the prices of all biocides are doubled, for example, by an extra sales tax. The effect of this considerable price increase of the biocides is a 1.3% reduction in the objective function (Table 9), 0.4% more than in the biocide scenarios, while the use of biocides is hardly reduced at all. Land use is the same as

Table 11. Biocide use index per farm type for base and biocide scenarios (index value ha^{-1} $year^{-1}$).

Farm type	1	2	3	4	5	Neguev
Base	13.8	30.8	29.4	35.8	32.3	30.0
Biocide a (50% reduction *Neguev* level)	13.8	30.8	29.1	35.8	6.7	15.0
Biocide b (50% reduction per farm type)	6.9	15.0	14.7	17.9	16.2	15.0
Biocide c (50% reduction per ha)	13.8	15.0	15.0	15.0	15.0	14.8

in the base scenario. The reason for this low reduction of biocide use is the small fraction that the costs of biocides form in the total input costs. In addition, even at a 100% increase in biocide price, substitution of herbicides by hand weeding is still relatively expensive.

Soil nutrient depletion scenario

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

The restriction on the depletion of soil nutrients results in a 2.8% reduction of the objective function in comparison to the base scenario (Table 9). Similar reductions of this function occur for each farm type. Employment is also hardly changed. Part of the area with the palm heart zero fertilizer technology is replaced by palm heart with a technology that uses 50% of the amount of fertilizer (with N, P and K) needed to reach the highest possible yield (Jansen & Schipper, 1995). In this way, the depletion caused by the zero fertilizer technology is compensated, while the farm types are able to maintain the area with palm heart as a whole. Also, more tree plantations are created than in the base scenario. The changed land use results in a 4% reduction of the biocide use index.

The most critical nutrient is K. The critical nutrient loss per ha per year limit is reached on the land units SFW and SUW in all farm types.

Price of palm heart scenario

In the price of palm heart scenario the influence of the price of palm heart on the area cultivated with palm heart, and thus on the objective function, is evaluated (Table 12).

As palm heart is selected in the base scenario's optimal solution, it is obvious that a price decrease of palm heart will reduce the objective function's value. However,

Table 12. Relative value of objective function and areas with palm heart, per land unit and total: base scenario (index values = 100) compared to price of palm heart scenario.

Scenario	Base	Price of palm heart									
price palm heart	100	95	90	85	80	75	70	65	60	55	50
objective function	100	98	92	88	85	82	80	78	75	73	72
palm heart on SFW	100	100	100	99	4	0	0	0	0	0	0
palm heart on SUW	100	100	100	100	102	102	100	90	90	54	52
total palm heart	100	100	100	100	75	74	73	66	66	39	38

there is only a drastic reduction in area under palm heart when the price is 20% lower than the base scenario price of C. 26 per palm heart. Still, even at a 50% reduction of its price, the total area with palm heart (1004 ha) remains much larger than the actual area in the *Neguev* (138 ha, Table 10). This is an indication that palm heart is a very attractive land use compared to the alternatives in the model. It is interesting to note that the palm heart area is first reduced on more fertile lands, although the yields are higher than on unfertile lands. The rationale behind this finding is that fertile lands have relatively better alternatives for palm heart than unfertile lands.

The differences in land use between scenarios can be displayed on maps prepared by the geographic information system of MODUS. As an example, in Figure 1, the land use in the base scenario is compared with that in the 50% reduction variant of the palm heart price scenario. It clearly shows the reduction of the palm heart area together with the consequent increases of areas with cassava, pasture with cattle, and tree plantation.

Price of labour scenario

Labour forms a significant proportion of production costs and therefore the objective function can be expected to be sensitive to its price. However, since land use systems use labour in different amounts, the influence of a change in the price of labour depends on the relative use of labour in relation to the net benefits of an activity. Labour is both a cost (household on-farm labour and hired labour), as well as a benefit (off-farm work on other farms within the Neguev and on plantations). This implies that a-priori the effects of wage changes on the model are rather restricted. The total amount of hired labour is equal to the amount of off-farm work on other farms and, since the hired labour wage is 10% higher than the wage for off-farm work on other farms, it implies a net cost to the model. As the (reservation) wage in the base scenario for household on-farm labour is lower than the wage for plantation work, an equal percentage decrease in all wages increases the attractiveness of on-farm activities relatively to working on a plantation, while an equal percentage increase in all wages has the opposite effect.

Analysing changes in the price of labour, it can be observed that a price change leads to a less than proportional reduction in the objective function (Table 13). Decreasing the price of labour with 5% leads to somewhat more palm heart (0.1%) and less off-farm work on plantations (–3.7%), as expected. Further decreases in the price of labour (at least up to –25%) have no effect at all on land use. Because the area of palm heart increases slightly, also the soil nutrient depletion is slightly high-

Table 13. Changes in objective function: base scenario compared to price of labour scenario.

% change in wages	–25	–20	–15	–10	–5	0	5	10	15	20	25
% change in objective function value	–1.4	–1.1	–0.8	–0.6	–0.6	0	0.3	0.6	0.9	1.2	1.6

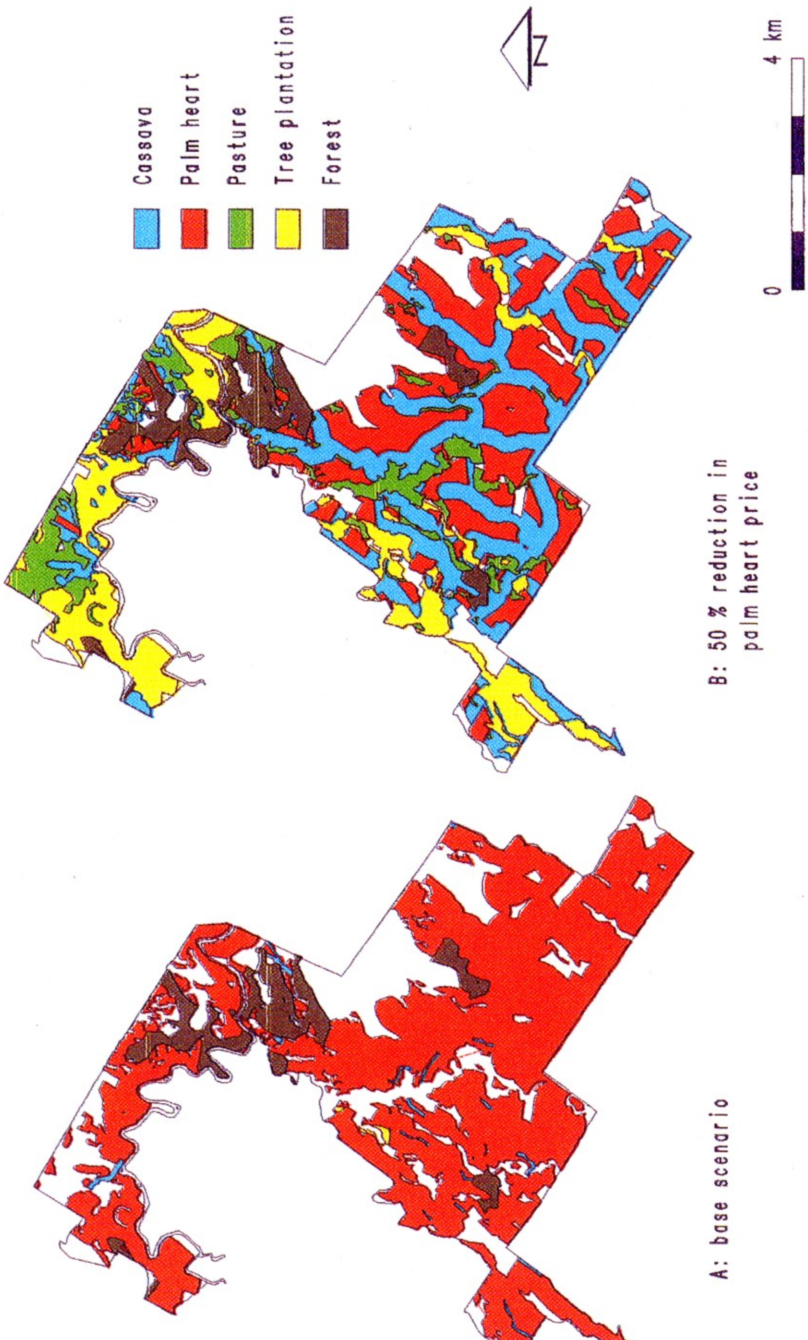

Figure 1. Maps of land use in the *Neguev*: base and 50% palm heart price reduction scenario.

er, as well as the use of biocides. Increases in the price of labour (at least up to 25%) also do not have any effect on land use and on plantation work.

Discount rate scenario

The discount rate is used to value in today's terms future cost and benefits in order to calculate net present values and annuities. A positive rate discounts the value of future (cash) flows when calculated back to the present time. The higher the discount rate, the less a future cash flow is worth today.

With perennials, benefits tend to be concentrated in later years, while most costs are made in the initial years, which explains that the objective function decreases with an increasing discount rate (Table 14). The reverse is true with plantation work. This is a yearly activity, with equal net benefits in all years. At higher discount rates such activities are more attractive than 'investment' activities like perennials.

The change in land use patterns as a result of a change in the discount rate is more difficult to explain. At low rates, extensive cattle production is attractive, while at higher rates the benefits in later years count relatively little. This especially applies to the valuation of the stock in year 20, the last year in the pasture with cattle LUSTs. Note also that at discount rates of less then 10%, it is worthwhile to use SFP soils, while at rates of 10% or higher this is not the case.

With regard to the SFW soils, teak plantation is attractive at discount rates 0 and 3%, melina plantations at rates 5 and 10%, while no tree plantations would be created at rates of 15 and 20%. At comparable wood prices, teak is harvested later than melina, thus explaining a change from teak to melina at higher discount rates.

The explanation of changes in the areas under palm heart and cassava is problematic. First, the changes are not consistent. On the SFW soils with increasing discount rates, the area under palm heart increases first slightly up to 10%, and decreases thereafter. In conjunction with these changes, and also because of the disappearance of tree plantations, more cassava is planted at higher discount rates. The main conclusion is that, although the benefits per hectare of palm heart decrease at higher discount rates, it still is the most attractive land use, in view of the alternatives of-

Table 14. Value of objective function, plantation work and land use: base scenario compared to discount rate scenario.

discount rate (%)	0	3	5	10	15	20
objective function value (*Colones* 10^6 year^{-1})	453	443	435	416	400	382
plantation work (days 10^3 year^{-1})	314	329	329	329	332	332
extensive cattle production on SFP (ha)	372	422	422	0	0	0
cassava on SFP (ha)	50	0	0	0	0	0
palm heart on SFW (ha)	725	727	727	732	690	692
cassava on SFW (ha)	0	0	0	1	70	69
teak plantation on SFW (ha)	37	35	0	0	0	0
melina plantation on SFW (ha)	0	0	35	29	0	0
palm heart on SUW (ha)	1950	1944	1944	1944	2012	2011
cassava on SUW (ha)	248	254	254	254	185	186

fered to the model. A similar conclusion can be reached for the SUW soils. Up to a discount rate of 10%, the area of palm heart is slightly reduced in favour of cassava, while at rates of 15 and 20%, the area of palm heart is increased at the expense of cassava.

As land use changes do occur with changing discount rates it is to be expected that soil nutrient depletion and biocide use also change. However, the overall effects turn out to be small. Because of the larger area in use at discount rates up to 5%, the soil nutrient depletion and the biocide use is somewhat higher than at rates of 10 to 20%.

Discussion

The sub-regional land use model as presented in this paper has its strengths and limitations. The model is part of a comprehensive methodology for land use analysis and planning (USTED), incorporating a module to store quantitative LUST data and linked to a geographical information system. The model is extensive with regard to the technology options for the land use systems considered. Moreover, the location of each land use can be indicated.

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

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

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

The model leaves out a number of important aspects of reality. First, the model should include more land use types if it is to represent the full range of possibilities available. Examples include bananas, roots and tubers (other than cassava), pumpkins and ornamentals, although not all those land use types are relevant for all farm types. Also, different pasture types should be specified, which lead to another limitation: the way animal production systems are incorporated. At present cattle is connected to pasture at fixed stocking rates. Supplementary feeding from other land use types is not allowed for, which might be realistic for the majority of local pastures with extensively held cattle. However, for more intensive management systems with improved pastures, legumes, supplementary feeding etc, fixed stocking rates would no longer be a realistic assumption. The solution can be found in defining animal production systems with certain technology levels (APSTs), which use products (pasture, cobs, bananas, leguminous leaves) from LUSTs as inputs. These inputs provide the necessary calories, proteins and dry matter to the APSTs. Products of APSTs (e.g. dung) could be used by LUSTs as inputs.

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

The base scenario showed possible attractive future land uses. Given yields, input use, and the relative input and output prices, palm heart appears to be an attractive activity. Even with a 50% reduction of its price, the acreage with this crop would increase. This supports the present trend of extending the palm heart cultivation in the Neguev. However, such a scenario outcome requires a thorough analysis of the marketing prospects of palm heart.

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

Though arbitrary, it is not too complicated to construct a biocide use index. However, firm statements about the impact of biocides on the environment and about the real assimilative capacity of the environment are next to impossible, at least at present. In the biocide scenario an arbitrary reduction of biocide use of 50% of the base scenario is assumed, showing that such a reduction in biocide use is possible with small effects the farm incomes. On the other hand, doubling the price of biocides did not affect its use.

Notwithstanding the difficulties mentioned with regard to the sustainability indicators used, a more general model should also be able to use other indicators of sustainability, for example soil erosion. Obviously, this is not an easy task.

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

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References

Akkermans, J., 1993. The 'why' of decisions taken by farmers in the Agrimaga settlement. Atlantic Zone Programme, Phase 2, Report No. 50. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba, Costa Rica, 27 pp.

Alfaro, R., 1993. Análisis de inventario en una comunidad campesina de la Zona Atlántica de Costa Rica: el caso de Agrimaga. Atlantic Zone Programme, Phase 2, Report No. 43. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba, Costa Rica, 35 pp.

Alfaro, R., J. Bouma, L.O. Fresco, D.M. Jansen, S.B. Kroonenberg, A.C.J. van Leeuwen, R. A.

Schipper, R.J. Sevenhuysen, J.J. Stoorvogel & V. Watson, 1994. Sustainable land use planning in Costa Rica: a methodological case study on farm and regional level. In: L.O. Fresco, L. Stroosnijder, J. Bouma & H. van Keulen (Eds.), The future of the land: mobilizing and integrating knowledge for land use options. John Wiley & Sons Ltd, Chichester, pp. 183–202.
Anonymous, 1985. Condición de la parcela. Instituto de Desarrollo Agropecuario, San José. (Non-published data).
Anonymous, 1987. Our common future. World Commission Environment and Development, Oxford University Press, Oxford, 387 pp.
Anonymous, 1990. SPSS/PC+ Statistics 4.0. SPSS Inc, Chicago, 308 pp.
Anonymous, 1992. Ground for choices: four perspectives for the rural areas in the European Community. Netherlands Scientific Council for Government Policy, The Hague, 134 pp.
Anonymous, 1993. OMP manual: preliminary release 10.06.1993. Beyers & Partners, Braasschaat, 358 pp.
Ayyad, M.A. & H. van Keulen (Eds.), 1987. The 'Mariut' project. Final report submitted to Directorate General for International Cooperation (DGIS), Part 13. Centre for Agrobiological Research, Wageningen.
Bruin, S. de, 1992. Estudio detallado de los suelos del asentamiento Neguev. Serie Técnica, Informe Técnico No. 191; Atlantic Zone Programme, Phase 2, Report No. 25. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba, Costa Rica, 35 pp & soil map.
Celís, R., 1989. Factor substitution in linear programming: a methodology and an application to cane alcohol pricing in Costa Rica. The University of New Mexico, Albuquerque, 123 pp.
Day, R.H., 1963. On aggregating linear programming models of production. *Journal of Farm Economics* 45: 797–813.
Ellis, F., 1993. Peasant economics: farm households and agrarian development. Cambridge University Press, Cambridge, 298 pp.
Erenstein, O.C.A. & R.A. Schipper, 1993. Linear programming and land use planning: a case study of Matara district, Sri Lanka. Wageningen Economic Studies, No. 28. Pudoc, Wageningen, 95 pp.
Fresco, L.O., H. Huizing, H. van Keulen, H.A. Luning & R.A. Schipper, 1992. Land evaluation and farming systems analysis for land use planning: FAO working document. FAO, Rome, ITC, Enschede and Wageningen Agricultural University, Wageningen, 208 pp.
Goreux, L.M. & A.S. Manne (Eds.), 1973. Multi-level planning: case studies in Mexico. North-Holland Publishing Company, Amsterdam, 551 pp.
Hair, J.F., R.E. Anderson, R.L. Thatham & W.C. Black, 1992. Multivariate data analysis. Macmillan Publishing Company, New York, 538 pp.
Hazell, P.B.R. & R.D. Norton, 1986. Mathematical programming for economic analysis in agriculture. Macmillan Publishing Company, New York, 387 pp.
Herrera, W. & L.D. Gómez, 1993. Mapa de unidades bióticas de Costa Rica. Instituto Geográfico de Costa Rica, San José.
Jansen, D.M. & R.A. Schipper, 1995. A static descriptive approach to quantify land use systems. *Netherlands Journal of Agricultural Science* 43:
Jansen, D.M., J.J. Stoorvogel & R.A. Schipper, 1995. Using sustainability indicators in agricultural land use analysis: an example from Costa Rica. *Netherlands Journal of Agricultural Science* 43:
Jeffrey, R.S., R.R. Gibson & M.D. Faminow, 1992. Nearly optimal linear programming as a guide to agricultural planning. *Agricultural Economics* 8: 1–19.
Kruseman, G., R. Ruben, H. Hengsdijk & M.K. van Ittersum, 1995. Farm household modelling for estimating the effectiveness of price instruments in land use policy. *Netherlands Journal of Agricultural Science* 43:
Mücher, C.A., 1992. A study on the spatial distribution of land use in the settlement Neguev. Atlantic Zone Programme, Phase 2, Report No. 9. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba, Costa Rica, 83 pp.
Norton, R.D. & L. Solís M. (Eds.), 1983. The book of CHAC: programming studies for Mexican agriculture. The Johns Hopkins University Press, Baltimore, 589 pp.
Opschoor, J.B., 1992. Sustainable development, the economic process and economic analysis. In: J.B. Opschoor (Ed.). Environment, economy and sustainable development. Wolters-Noordhoff, Groningen, pp. 25-52.

Opschoor, J.B. & L. Reijnders, 1991. Towards sustainable development indicators. In: O. Kuik & H. Verbruggen (Eds.). In search of indicators of sustainable development. Kluwer, Dordrecht, pp. 7–27.
Pearce, D.W. & R.K. Turner, 1990. Economics of natural resources and the environment. Harvester Wheatsheaf, New York, 359 pp.
Robinson, S., 1989. Multisectoral models. In: H. Chenery & T.N. Srinivasan (Eds.). Handbook of development economics: volume II. North-Holland, Amsterdam, pp. 885–947.
Romero, C. & T. Rehman, 1989. Multiple criteria analysis for agricultural decisions. Elsevier, Amsterdam, 254 pp.
Schipper, R.A., 1993. Una caracterización de fincas en Neguev, Rio Jiménez y Cocori; Zona Atlántica, Costa Rica: informe en base a una encuesta dentro del marco de estudios de base. Atlantic Zone Programme, Phase 2, Report No. 49. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba, Costa Rica, 45 pp.
Stoorvogel, J.J., 1995. Linking GIS and models: structure and operationalisation for a Costa Rican case study. *Netherlands Journal of Agricultural Science* 43:
Stoorvogel, J.J., R.A. Schipper & D.M. Jansen, 1995. USTED: a methodology for a quantitative analysis of land use scenarios. *Netherlands Journal of Agricultural Science* 43:
Veeneklaas, F.R., 1990. Dovetailing technical and economic analysis. Erasmus Drukkerij, Rotterdam, 158 pp.
Waaijenberg, H., 1990. Sistemas de producción. In: M.T. de Oñoro, 1990. El Neguev: interacción de campesinos y estado en el aprovechamiento de los recursos naturales. Serie Técnica, Informe Técnico No. 162; Atlantic Zone Programme, Programme Paper No. 7. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba, Costa Rica, 84 pp.
Wetering, R. & J.B. Opschoor, 1994. Towards environmental performance indicators based on the notion of environmental space. Publikatie RMNO nr. 96. Advisory Council for Research on Nature and Environment (RMNO), Rijswijk.
Wit, C.T. de, H. van Keulen, N.G. Seligman & I. Spharim, 1988. Application of interactive multiple goal programming techniques for analysis of regional agricultural development. *Agricultural Systems* 26: 211–230.