"Regionale ontwikkelings planning"
— ontwikkelingseconomie

DRAFT

LAND USE PLANNING:

AN APPLICATION OF MULTILEVEL AND MULTICRITERIA LINEAR PROGRAMMING MODELS

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GLOSSARY OF ACRONYMS

FU	farm unit
FULUT	combination of a farm unit with a land utilization type
FULUTs	plural of FULUT
FUs	plural of FU
LEFSA	land evaluation-farming systems analysis
LP	linear programming
LU	land unit
LULUT	combination of a land unit with a land utilization type
LULUTs	plural of LULUT
LUs	plural of LU
LUT	land utilization type
LUTs	plural of LUT
N	suitability class 'not'
RHS	right hand side
Rs.	Rupees
S1	suitability class 'good'
S2	suitability class 'fair'
S3	suitability class 'poor'

1 INTRODUCTION

This paper deals with two topics. In the first place, it discusses the relations between economic analyses at the farm level and analyses at the level of a region; and in the second place, it addresses the introduction of multiple criteria in such analyses. Both topics will be studied with the help of linear programming models within the context of land use planning applied to a case study in Sri Lanka.

The relations between analyses at the micro level on the one hand, and at the sectoral or macro level on the other hand are theoretically among the most difficult problems in economics. In most approaches to land use planning the aggregation process (from the micro to the meso level, and from the meso to the macro level) remains problematic. Some major aggregation problems are:
- variables that are exogenous at the micro level may be endogenous at the meso or macro level;
- aggregation bias; and
- aggregate decision problems involve choices on at least two levels.

In the transition from farm-level to sector-level analysis there is an aggregation problem with respect to the nature of the variables. Variables that are **exogenous** at the micro level may be **endogenous** at the meso or macro level. Product prices, for instance, are normally considered as given for individual producers, but may be variable for a region as a whole.

E.g.: The price of a crop may be taken as exogenous for the individual farmer since the volume of his produce is only of marginal importance compared to the total district production. However, the district production would notably increase if all farmers decided to grow this crop. A notable increase in production, in combination with a limited market, could cause a decline in the price.

The entire service sector is normally considered as given for individual producers, but is naturally variable for the district as a whole. It is at the district or higher level that resources have to be devoted to the service sector. Notable examples are the extension service and formal credit facilities.

In the transition from farm-level to sector-level analysis, an **aggregation bias** arises because all farms are not alike. Ideally, to cause the aggregation to be correct, a model should be constructed for every individual farm. These individual models could then be linked together to form a sector model. Since in practice this is infeasible, two approaches may be considered (Hazell & Norton, 1986: 143-144).

1. Aggregate regional model: this involves aggregating the resources of a region and modelling these aggregated variables as if it were a single large farm.
2. Representative farms model: this involves classification of the universe of farms into a smaller number of homogeneous groups. A model is then constructed for a *'representative'* farm from each group. These farm models are then aggregated in the sector model using the number of farms in each group as weights. To limit aggregation bias, this procedure places a high demand on the proper definition of the representative farms and the weighing procedures.

Both approaches overstate resource mobility by enabling farms to combine resources in proportions that are not available to them individually. Both approaches also carry the implicit assumption that all the aggregated farms have equal access to the same technologies of production. Aggregation bias is therefore always in a upward direction (Hazell & Norton, 1986: 145)[1].

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1 To illustrate the nature of aggregation bias consider the following example (adapted from Hazell & Norton, 1986: 144):

E.g.: Consider the following two farm problems formulated in the linear programming format, each with two cropping activities (X_i):

(continued...)

In order to avoid or minimize aggregation bias, farms are classified into groups or regions defined according to rigid requirements of homogeneity. Day (1963, as discussed in Hazell & Norton, 1986: 145-146) established a comprehensive set of conditions or criteria for classification to avoid aggregation bias:

- *'technological homogeneity'*: this implies that each farm in a class has the same types of resources and constraints, the same levels of technology, and the same levels of managerial ability;
- *'pecunious proportionality'*: this implies that individual farms in a class hold expectations concerning unit activity returns that are proportional to average expectations; and
- *'institutional proportionality'*: this implies that the constraint vector of the programming model for each individual farm should be proportional to the constraint vector of the average or aggregate farm.

Day's requirements are very demanding, and several authors have proposed less stringent conditions. Some of these are based on the reasoning that an optimal solution of a linear programming (LP) model can be stable even when several coefficients are perturbed. This concept is supported by post-optimality analysis which usually shows that there is a tolerable range for each coefficient. The coefficient can be varied over this range without causing a change in the optimal basis. As long as the farms included in a group have coefficients within a tolerable range of the solution basis of the average farm model, their optimal solution vectors will remain proportional. The main problem with this approach is that the tolerable ranges for the coefficients are unique for a single optimal solution. Hence, farms that can be grouped together for one experiment with a representative farm model, may have to be regrouped for any other experiment. But one cannot possibly know in which group to classify individual farms for each experiment without knowledge equivalent to knowing the optimal solution vector for each farm. Aggregation criteria based on this approach have therefore not proved useful (Hazell & Norton, 1986: 146).

Other approaches have been sought to provide methods which minimize, rather than eliminate, aggregation bias. In practice, the aggregation criteria usually are reduced to grouping farms according to a few simple rules. These rules include (Hazell & Norton, 1986: 147-148):

- similar proportions in resource endowments: most often this implies similar land-to-labour ratios, *i.e.* grouping farms by size class;

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[1](...continued)

Farm A	X_1	X_2	RHS
Profit	60	90	Maximize
Resource 1	1	2	≤ 5
Resource 2	1	1	≤ 10

Farm B	X_2	X_3	RHS
Profit	90	100	Maximize
Resource 1	2	1	≤ 10
Resource 2	1	2	≤ 5

The optimal strategy for farm A is to grow 5 units X_1, while farm B should grow 5 units of X_2. For farm A the profit is 300 while for farm B the profit is 450.
The two farms can be aggregated to form one large aggregate farm. The aggregate farm problem would be as follows:

Aggregate Farm	X_1	X_2	X_3	RHS
Profit	60	90	100	Maximize
Resource 1	1	2	1	≤ 15
Resource 2	1	1	2	≤ 15

The optimal solution to this problem is 5 units of X_2 and 5 units of X_3. For the aggregate farm profit is 950. This amount exceeds the sum of the profits obtained from the individual farm models, which was 750.

- similar yields: this implies looking out for differences in climate, soils, and elevation which alone (apart from the technology employed) can cause significant yield differences, but also irrigated and non-irrigated farms should be put into separate classes; and
- similar technologies: this implies separating farms according to predominant crops and technologies used.

Several other criteria can be important too for defining producer classes, depending on the issues to be studied. *E.g.* in irrigation studies, the plot's position along the canal can be important.

Aggregate decision problems involve choices on at least two levels. At one level, the macro level, a policy maker is trying to decide how best to allocate funds in the face of:

- more than one objective;
- uncertainty about what the allocational consequences will be.

At the other level, the micro level, farmers have their own decision problem. They have to decide how best to respond to the new policy environment, given their own objectives and limitations of action (Hazell & Norton, 1986: 139). It is, however, not known beforehand at the macro level what this response at the micro level will be. It is this *'not knowing'* that causes the uncertainty at the macro level about the allocational consequences.

In order to solve the macro or policy problem, the uncertainty about micro responses has to be reduced. In other words, some means of simulating the probable response of farmers is required before the policy decision is taken. The usual way to simulate producer decisions is to build a model that reflects their constraints, opportunities, and objectives. This model is then solved under varying assumptions about the policy environment affecting producers. Agricultural producers, however, differ widely in their resources, wealth endowments, and economic opportunities. An adequate investigation of producer response to policy changes therefore requires models of several representative farms (Hazell & Norton, 1986: 139).

The simulation of the probable response of farmers is further complicated by the fact that farmers normally have a variety of objectives and preferences. This precludes the establishment of profitability, for example, as a sole choice criterion (Diltz, 1980: 7).

E.g.: An imaginary farmer may strive to achieve the following objectives (in order of importance):

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

But no matter how good the simulation of probable response of farmers is, in the end it is the farmer who decides on, and is responsible for, the actual use of the land.

Achieving the ends of a policy therefore requires the cooperation of farmers. Even in highly centralized economies there are limits to the extent that governments can dictate cropping patterns and other production decisions, much less in market-oriented economies. Therefore, finding the *'optimal'* cropping patterns from a viewpoint of policy may not be very useful unless ways are also found to induce farmers to adopt those cropping patterns (Hazell & Norton, 1986: 139).

Objective of this study

The so-called *'LEFSA-sequence'*[2] (Fresco *et al.*, 1990) emphasizes the importance of including data from different levels in the regional (agricultural) planning process. It specifically distinguishes the farm and the (sub)regional level. However, the precise way of aggregation is still a matter of research.

The present study aims to contribute to this research via the construction of regional agricultural planning models that incorporate the distinguished levels. In the first instance a planning model is developed at the regional level. This model includes the regional and subregional (*i.e.* zonal) levels. In the second instance a special case of this model is designed involving multiple criteria as objectives. In the third instance a planning model is developed at the regional level with farming systems. This

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2 A procedure for land use planning based on the integration and combination of Land Evaluation and Farming Systems Analysis.

model includes the farm level next to the regional and zonal level. The outcome of the second and third models are compared with the outcome of the first model to assess the effects of, respectively a multicriteria and a multilevel programming approach.

The planning models are constructed with the following purposes:

- to structure the choice between alternative land use types in a clear way, taking into account various constraints and possibilities;
- to show that the *'optimal'* land use plan depends on assumptions regarding objectives and prices.

An important feature of the present models is the inclusion of a differentiated land resource base (79 land units, each with different qualities and different suitabilities, and thus yields, for each crop).

The different models developed for this study are meant to show different categories of land users, planners and decision makers the kind of major options which exist with regard to the use of land.

Framework of this study

The regional agricultural planning models developed for this study are based on data from Matara district in Sri Lanka[3] (amongst others Polman, Samad & Thio, 1982). The models generate *'optimal'* land use plans for Matara district in the year 2000.

The different models developed for this study have some common features. All models can be classified as being agricultural **sector models** as they include only the agricultural sector of Matara district. They also can be classified as being **fixed price models** as all the prices, both the economic as the financial, are exogenously determined. This applies to input prices (*e.g.* fertilizer), to factor prices (*e.g.* wages) as to agricultural product prices.

All models are **linear programming (LP) models**. LP models optimize a mix of production processes, subject to a set of constraints. The production processes are defined as *'activities'*, each with its set of inputs and related outputs. The objective function to be optimized can be any of the outputs or inputs. The inputs draw on the regional resources which are limited, and therefore can constrain the choice of production processes (de Wit *et al.*, 1988: 212).

The linear programming format is a particularly suitable one for economic modelling in agriculture. Farmers, agronomists, and other agricultural specialists share a common way of thinking about agricultural inputs and outputs in terms of the annual cropping cycle, and about input-output coefficients per hectare or other unit of land. From this way of visualizing agricultural production in numbers, it is but a short step to forming the column vectors of inputs and outputs that constitute the backbone of the LP model. Similarly, agriculturalists often pose their problems in terms of inequality constraints, such as upper bounds on seasonal resource availability. In addition the LP model provides valuable information in the form of the valuations that are assigned to fixed resources, such as land and water supplies, *i.e.* the shadow or dual prices (Hazell & Norton, 1986: 3-4).

Linear programming models can be used in regional planning when one attempts to optimize land use in view of one or more goals under the constraints imposed by a region. Linear programming therefore allows an optimizing approach to land use planning.

There are also non-optimizing approaches to land use planning which are, in practice, more used. These approaches aim to improve land use without striving to optimize it. They use more qualitative methods and are less data demanding. See, for example, FAO (1989), Schipper (1987) or Polman, Samad & Thio (1982).

The present study presents three different LP models:

- a regional model;
- a regional model with multiple criteria analysis; and
- a regional model with farming systems.

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[3] The Matara district was subject of a regional agricultural planning study from 1979 to 1982 by a team from the Agrarian Research and Training Institute, Colombo, and the Department of Development Economics of Wageningen Agricultural University. The Matara district is also used to illustrate the *'LEFSA-sequence'* in Fresco *et al.* (1990).

The **regional model** (chapter 2) assumes an aggregate zonal approach. This implies that homogeneous land units within each of the three distinguished zones of Matara district (not necessarily involving contiguous land) are aggregated over all farms in a zone. The same applies to all other relevant resources (*e.g.* labour force). The total of these aggregated resources within each zone is then modelled as a single large farm (Hazell & Norton, 1986: 144). The regional model thus consists of three *'super'*-farms.

The model includes various variables measuring:
- the production of agricultural outputs;
- the use of labour and capital inputs;
- the acreages of land use types[4].

The various constraints included in the model are imposed by:
- the availability of the various land units; these land units have different suitabilities for the different land use types;
- the availability of labour;
- the availability of buffalo;
- the availability of irrigation;
- the limited markets for a number of products.

The following land use types are included.

a. Agricultural production activities (mostly cropping activities, including tea, rubber, coconut, paddy, cinnamon, citronella and homesteads) with their respective input demand (labour, fertilizer and other inputs) and physical output. The physical output is dependent on the suitability of the natural resource basis.
b. Non-agricultural activities (forests, towns and water bodies). These are included to account for the regional area they occupy and they have no further influence on the model's solution.

Furthermore, two types of objective function are considered.

a. National-economic: this type of objective function represents the regional optimal plan as seen in the national-economic context. It thereby uses the economic farm gate prices and the shadow price of labour. The precise value of the latter is however unknown. Therefore two versions of the national-economic objective function are presented, one assuming the shadow wage rate to be Rs. 15 manday^{-1} [5], the other assuming it to be Rs. 0 manday^{-1}.[6] These two versions are considered as the:
   - maximization of surplus[7] at economic prices;
   - maximization of value added[8] at economic prices.
b. Private-financial: This type of objective function calculates the regional optimal plan as seen in the *'super'*-farmers context[9]. It thereby uses the financial farm gate prices and the actual wage rate. This objective function is considered as the maximization of surplus at financial prices.

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4 A land use type is a specific kind of land use under stipulated biophysical and socio-economic conditions (current or future). A land use type can be described according to its setting, technical specifications and requirements (Fresco *et al.*, 1990: 164).

5 This shadow wage rate is based on the assumption that the actual wage rate of Rs. 15 manday^{-1} is a good approximation of the real value of labour.

6 This extreme low shadow wage rate is based on the assumption that the actual wage rate greatly overvalues the real value of labour. This assumption might be justified in view of the very high unemployment rates.

7 Surplus is defined here as the return to land and capital, *i.e.* the value of production minus the value of current inputs minus the value of labour inputs.

8 Value added is defined here as the return to land, labour and capital, *i.e.* the value of production minus the value of current inputs. In other words, the value added is equal to the surplus plus the value of labour inputs. In the case that the shadow wage rate is considered to be Rs. 0 manday^{-1}, the value added is equal to the surplus.

9 It should be remembered that the entire region is assumed to consist of three *'super'*-farms, hence the denomination *'super'*-farmers.

The **regional model with multiple criteria analysis** has the same variables and constraints as the regional model. The differences are related to the formulation of the objective function. This model allows the simultaneous maximization of:
- value added at economic prices;
- surplus at financial prices; and
- employment.

The **regional model with farming systems** assumes an aggregate farm approach for the northern zone and an aggregate zonal approach for the other zones. In the northern zone we distinguish six farm type classes. The homogeneous land units of all the farms belonging to a farm type class are aggregated over all farms belonging to that farm class. The same applies to all other relevant resources. For the central and southern zone the resources within each of the two zones are aggregated over all farms in the zone (as in the regional model).

The model includes the same variables and constraints as the regional model but distinguishes an extra level for each (in the northern zone). As objective function is considered the maximization of surplus at financial prices, as this is assumed to approximate the '*super*'-farmers' point of view.

Most of the data used in this study were collected around 1980. It should be noted, however, that the retrieval of data from this limited 1980 data base has two major consequences for the quality of the data used.

a. Some data are now outdated: the actual 1990 situation can be considered to be substantially different from what it was expected to be in 1980. Reasons for this discrepancy are amongst others the politically unstable situation in Sri Lanka, and Matara district in particular. However, no attempt was made to update the data for the actual 1990 situation. The main reason to stick to the outdated data is the unavailability of precise data to replace the outdated data.
b. Some data are incomplete: some of the data now required for this study were not gathered at all, are unclear or inconsistent. Where necessary assumptions are made in this study.

But apart from the limitations with regard to data availability and the inherent limitations of linear programming itself, a number of limitations relate to the way linear programming is applied. These are discussed at length in chapter 5.

2 THE REGIONAL MODEL

In this chapter the regional linear programming model and the results it produces are presented. Before doing so we shortly introduce the Matara district.

2.1 The Matara district

Matara district is located in the South of Sri Lanka (see Figure 2.1, page 8). The district lies in the so-called *'wet-zone'* of Sri Lanka. The climate is tropical, characterised by heavy rainfall and relatively constant high temperatures and humidity. The major part of the district lies within the drainage basin of the Nilwala Ganga, the major river in the district. The district itself (128,800 ha) can broadly be divided in 3 zones (see Figure 2.2, page 9):

- the southern (coastal) zone (20,500 ha);
- the central zone (61,400 ha);
- the northern zone (46,900 ha).

Elevation increases from the coast in the South to the slopes of the central massif in the North. Elevation is the main determinant for the distinction between the zones, primarily due to its influence on rainfall and temperature, and thus on land use (Polman, Samad & Thio, 1982).

In the low southern zone bordering the coast line coconut and paddy are the dominant crops. In the central zone one finds cinnamon, rubber and tea, as well as coconut and paddy. In the northern zone tea is the main crop. A wide range of tropical vegetables, fruit trees and spice crops are grown in homesteads throughout the district. Livestock farming is insignificant in the district, except for dairy farming, which is being practised on a limited scale. There is hardly any possibility for the cultivation of new lands, except for recultivating some abandoned scrub lands. Clearing the last remnants of forest for cultivation purposes would highly increase the risk of erosion (Polman, Samad & Thio, 1982).

The salient features of Matara district, which are common to most of the *'wet-zone'* districts of Sri Lanka, include (Polman, Samad & Thio, 1982):

- high population densities;
- acute man-land ratios;
- virtually stagnant non-agricultural sector;
- high unemployment rates;
- labour force dominated by educated youths who cannot find suitable employment within the region.

The economy of the district is depressed and it is hard to imagine that this will change radically in the near future. The district has no other natural resources than land and water (Polman, Samad & Thio, 1982).

Agriculture dominates the economy of the region. The agricultural sector exhibits a typically dualistic structure: a well developed state-owned plantation sector, alongside a large number of small and medium sized private holdings. Agriculture is dominated by perennial crops, such as tea, rubber, coconut and cinnamon. These traditional export crops are grown on both small holdings and plantations. Paddy occupies the first place among the annual crops. Paddy is principally grown on small holdings (Polman, Samad & Thio, 1982).

The government charges various export taxes and levies on agricultural products. These taxes and levies vary between 30 and 50 % of the F.O.B. price, dependent on the product, causing a considerable divergence between economic and financial prices (Fresco *et al.*, 1990). Both prices are measured at the farm-gate. Agricultural inputs in Matara district generally can be valued at market prices. A notable exception is formed by fertilizers, which are heavily subsidized (Polman, Samad & Thio, 1982).

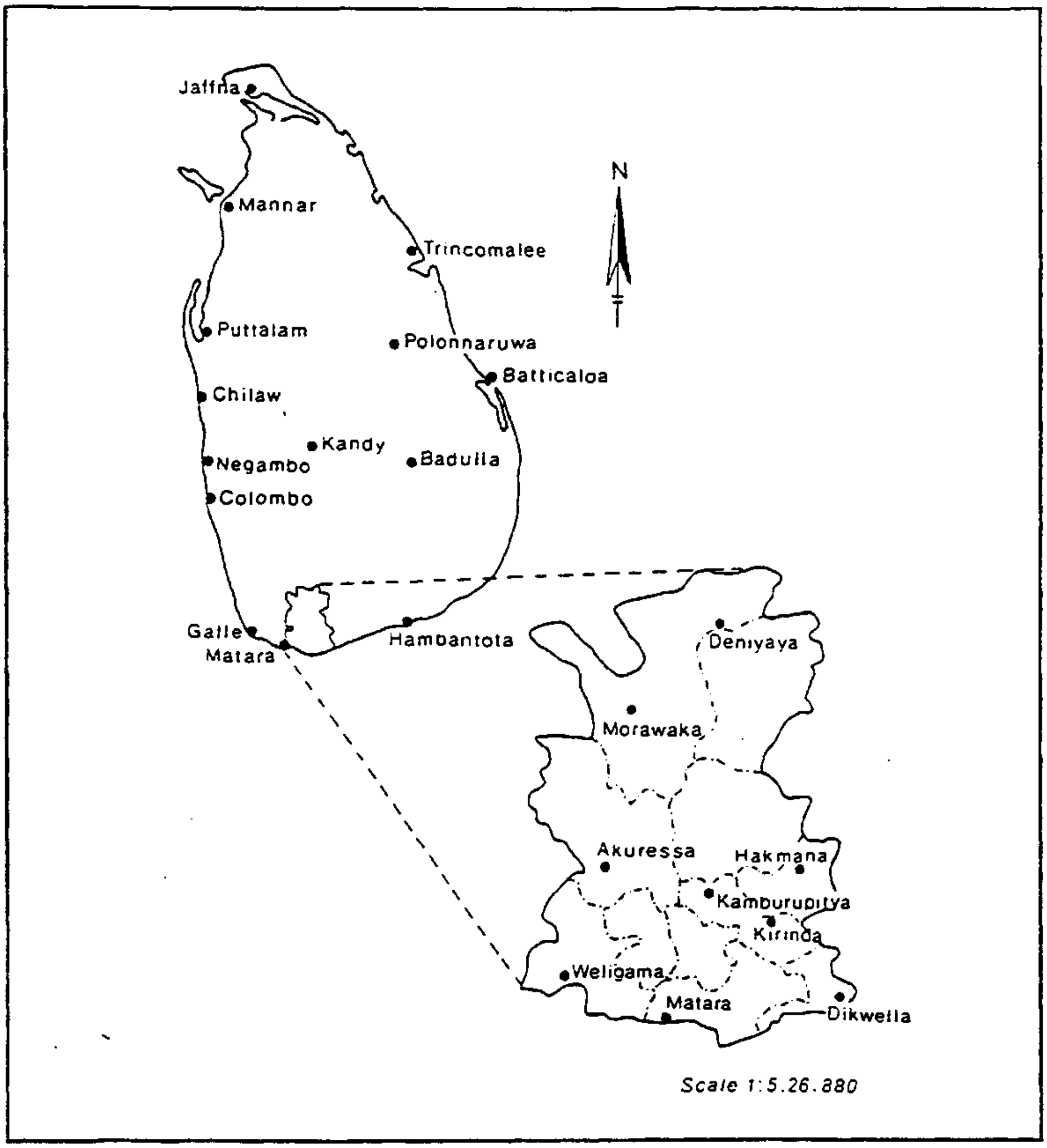
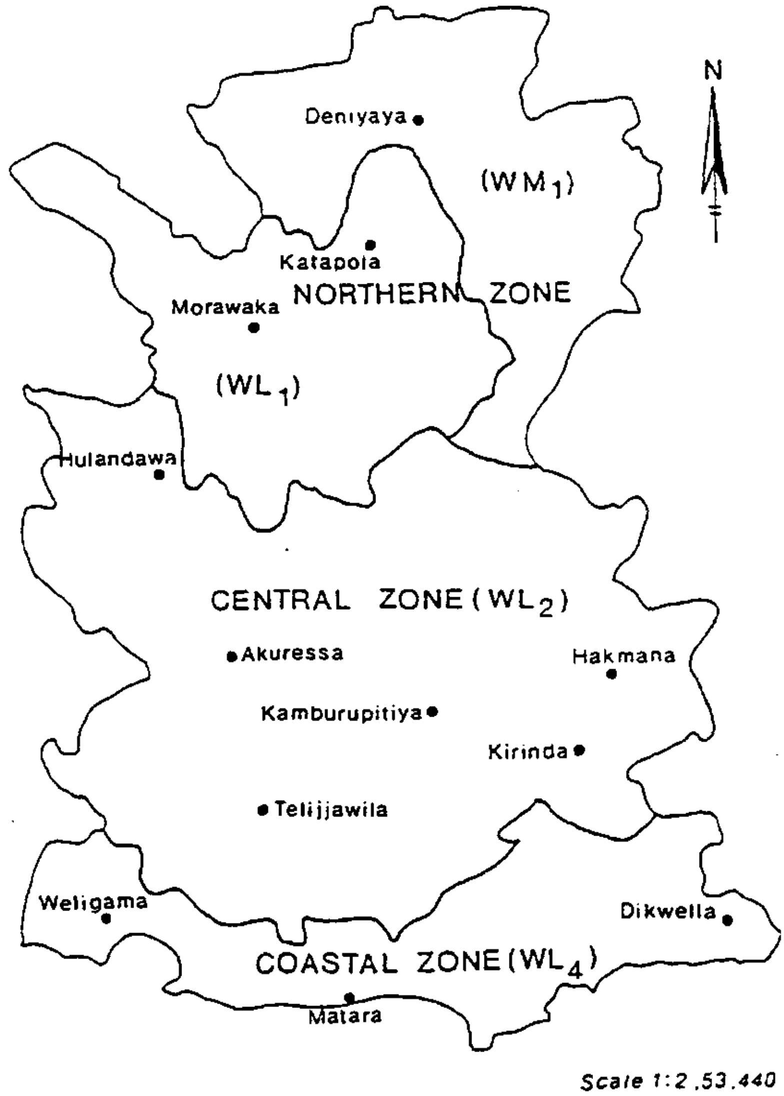


Figure 2.1 *Location of the Matara district (Wijeratne, 1988).*

The land use types

The land use types (LUTs) considered in this study are predominantly based on present land use in the district. In total 19 LUTs are distinguished. They can broadly be divided into:

- agricultural production activities (16): These include perennial crop based, annual crop based and homestead LUTs, each with their respective input demand (labour, fertilizer and other inputs) and physical output.
- non-agricultural activities (3, notably forests, towns and water bodies): These are included to account for the regional area they occupy. Both agricultural input use as output production are considered to be zero.



Agro-ecological zones: WM1: Wet zone, mid country
WL1-WL4: Wet zone, low country

Figure 2.2 *Zonal division of the Matara district (Wijeratne, 1988).*

The **perennial crop** based LUTs are pure stands of tree crops. Mixed stands also occur in Matara district but these are considered to be part of the homegarden crops (see below). The various perennial crop based LUTs distinguished in this study are:

- vegetatively propagated (VP) tea;
- seedling tea;
- rubber;
- coconut;
- coconut with buffalo;
- cinnamon;
- citronella.

Paddy is the only **annual crop** of some importance in Matara district. The various annual crop based LUTs distinguished in this study are all variants of paddy cultivation:

- irrigated paddy using hand labour[10];
- irrigated paddy using animal traction[11];
- irrigated paddy using mechanized traction;
- rainfed paddy using hand labour;
- rainfed paddy using animal traction;
- rainfed paddy using mechanized traction.

Homesteads include all family residential areas consisting of houses with homegardens. In the homegardens various crops and fruit trees are grown. A distinction can be made between homesteads on basis of their cropping pattern, which is zone dependent. The various homestead LUTs distinguished in this study are:

- northern homesteads;
- central homesteads;
- southern (or coastal) homesteads.

A qualitative, physically oriented land evaluation was executed for Matara district by Dimantha & Jinadasa (1981). A qualitative physical land suitability classification expresses the results in qualitative terms only, without quantitative estimates of outputs and inputs (Fresco *et al.*, 1990). For a linear programming model, however, there is a need for quantitative estimates. The qualitative suitability classes are therefore converted into quantitative estimates that can be used in the linear programming models. This was done by defining a maximum normative yield for each (agricultural) LUT, given a fixed input and management level and under the best biophysical conditions in view of regional circumstances. Using the qualitative grading of suitabilities, four quantitative suitability classes are distinguished, based on the range of the yield in relation to the normative yield (see Table 2.1) (Fresco *et al.*, 1990). For computational convenience point estimates of the yields are used in the model and the rest of this study.

Table 2.1 *Suitability classes (Fresco et al., 1990).*

Suitability class: adjective	Suitability class: symbol	Range of yield[1]	Point estimate of yield[1]
'Good'	S1	76 -100 %	90 %
'Fair'	S2	51 - 75 %	67.5 %
'Poor'	S3	26 - 50 %	45 %
'Not'	N	< 26 %	0 %

[1] Relative to normative yield at a fixed input level.

The different suitability classes of a particular LUT have a fixed input level with the exception of the inputs related to harvesting and agricultural processing. For most LUTs these inputs are related to the yield level.

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10 The use of hand labour refers to a land preparation that uses no traction power, *i.e.* land preparation is done with the mammoty.

11 The use of animal traction refers to a land preparation that uses buffalo draught power.

2.2 Structure of the regional model

In this paragraph the regional model is presented. The regional model assumes an aggregate zonal approach. This implies that homogeneous land units within each of the three distinguished zones of Matara district (not necessarily involving contiguous land) are aggregated over all farms in a zone. The same applies to all other relevant resources (*e.g.* labour force). The total of these aggregated resources within each zone is then modelled as a single large farm (Hazell & Norton, 1986: 144). The regional model thus consists of three *'super'*-farms. The model is developed for the situation in the year 2000.

An overview of the regional model is presented in Table 2.2. This table attempts to summarize the relationships that exist between the variables, the constraints and the objective function. The rest of this paragraph will elaborate on each of the model components.

Variables

The model consists of 479 variables, being 36 output variables, 12 input variables, 347 land use variables and 84 labour source variables.

The **output variables** keep track of the sum of annuities of production of various agricultural products. The model distinguishes nine agricultural outputs: tea, rubber, coconut, curd (*i.e.* processed buffalo milk), cinnamon quills, value of other cinnamon products (*i.e.* sticks and leaf oil), citronella, paddy and the value of other agricultural products (*i.e.* the value of homestead production other than cinnamon and the value of buffalo calves). For each of these agricultural outputs, both zonal and regional production are accounted.

The output variables are used as pricing activities. They are used to calculate the gross value of agricultural production at zonal and/or regional level. To make the different LUTs comparable use is made of annuities of production. These annuities are based on net present values at a 10 % discount rate of all physical production over the life cycle of each crop.

The **input variables** keep track of the sum of annuities of agricultural input use. The model distinguishes one labour and two capital inputs, namely fertilizer and other capital input (*i.e.* all capital inputs other than fertilizer[12]). For each of these inputs, both zonal and regional use are accounted.

The input variables are used as costing activities. They are used to calculate the input costs at zonal and/or regional level. To make the different LUTs comparable use is made of annuities of input use. These annuities are based on net present values at a 10 % discount rate of the input use over the life cycle of each crop.

The **land use variables** keep track of the land use found on each type of land within the district. Differences in the quality of resources can be incorporated into linear programming models by treating each resource quality as a different resource with its own set of activity requirements (Hazell & Norton, 1986: 41). Differences in quality of land resources clearly exist in Matara district (Dimantha & Jinadasa, 1981) and are assumed to be of a permanent nature. Each land unit[13] (LU) is therefore considered as a separate resource.

The suitability of a LU for a LUT is however not only dependent on the LU but also on the LUT. In other words, the same LU can have different suitabilities for different LUTs. Each possible combination between a LU and a LUT must therefore be distinguished as a separate activity in a linear programming model. Such a combination will from here on be referred to as a *'LULUT'*, *i.e.* a particular LU in combination with a particular LUT.

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[12] Two separate capital input counters are used because of the discrepancy between the economic and the financial fertilizer prices due to subsidies. For all the other capital inputs no such discrepancy exists.

[13] A land unit is land evaluation term for an area of land demarcated on a map and possessing specified land characteristics and/or qualities (Fresco *et al.*, 1990: 163).

Table 2.2 *Overview of the regional model.*

			Input/output variables				LULUT variables			Labour source variables: NO		Labour source variables: CE			Labour source variables: SO		
			X1 MA	X13 NO	X25 CE	X37 SO	X49 NO	X193 CE	X334 SO	X396 NO	X408 CE	X420 CE	X432 NO	X444 SO	X456 SO	X468 CE	RHS
Objective function	Y0	Return	PR								-2		-2	-2		-2	Maximize
Informative rows	Y1	??????	PR								-2		-2	-2		-2	Free
	Y7	NO???????		PR							-2						Free
	Y13	CE???????			PR								-2	-2			Free
	Y19	SO???????				PR										-2	Free
Input/output balance	Y25	???CN	-1	1	1	1											= 0
	Y37	NO???CN		-1			AN										= 0
	Y49	CE???CN			-1			AN									= 0
	Y61	SO???CN				-1			AN								= 0
Land unit constraints	Y73	NO??					1										≤ ?????
	Y104	CE??						1									≤ ?????
	Y134	SO??							1								≤ ?????
Labour balance	Y152	NOMD??A					AV			-1	-1						= 0
	Y164	CEMD??A						AV				-1	-1	-1			= 0
	Y176	SOMD??A							AV						-1	-1	= 0
Labour constraints	Y188	NOMD??								1			1				≤ ?????
	Y201	CEMD??									1	1				1	≤ ?????
	Y214	SOMD??												1	1		≤ ?????
Buffalo constraint	Y227	BUFFALO					1	1	1								≤ 7.058
Irrigation constraints	Y228	NOIRRAR					1										≤ 0.200
	Y229	CEIRRAR						1									≤ 5.600
	Y230	SOIRRAR							1								≤ 1.300
Market constraints	Y231	TEAMARK					AV	AV	AV								≤ 27.000
	Y232	CINMARK					AV	AV	AV								≤ 2.400
	Y233	CURMARK					AV	AV	AV								≤ 1.100

Legend:
PR : matrix containing prices
AN : matrix containing annuities
AV : matrix containing averages
'1' : matrix composed of '1' and '0' elements
'-1': matrix composed of '-1' and '0' elements
'-2': matrix composed of '-2' and '0' elements
? : wild character ('joker'), meaning that it can take on a certain value (letter or number)
'X?': column number of first column of matrix
'Y?': row number of first row of matrix

The land use (or LULUT) variables are used as production activities. As such they are the backbone of the model, using inputs (which draw on the regional resources) and producing outputs. The actual costing of inputs and pricing of outputs, however, is performed by the costing and the pricing activities respectively[14].

The **labour source variables** keep track of the amount and origin of the labour used in each zone in each month. Each zone can use labour from its own zone or from the adjacent zone(s). However, it is assumed that if travel distance increases, transport costs and travel time have to be

[14] As costing activities we distinguish the input variables and the labour source variables. As pricing activities we distinguish the output variables.

accounted for. This assumption is based on the fact that the labour market in fact is a fragmented factor market, *i.e.* additional units of input are provided at different prices. If zonal labour demand is higher than zonal labour supply, additional fees must be paid to cover transportation and relocation fees in order to attract additional labourers (Diltz, 1980: 7).

For the regional model this implies that labour is assumed to be perfectly mobile within each zone without extra costs. However, labour is only assumed to be mobile between zones if a *'transportation fee'* of Rs. 2 manday^{-1} is paid. The labour source variables are therefore used as costing activities. They are used to calculate the labour transportation costs at zonal and/or regional level. These transportation costs are deducted from the economic and financial returns.

Constraints

The model consists of 233 constraint rows, being 84 *'balance'* rows, 125 *'real'* constraints and 24 *'informative'* rows. The *'balance'* rows are accounting rows that are part of the models basic structure and which are used to equate and transport model components. They do not pose additional constraints to the model. The *'real'* constraints pose constraints to the model, *i.e.* they limit the allowable space in which the solution is to be found. The *'informative'* rows are included in the model only for informative reasons. If the model is solved without these *'informative'* rows, the same solution is obtained.

The so-called *'balance'* rows are an important part of the models basic structure. They are used in two different parts of the model, namely the input/output balance and the labour balance.

The **input/output balance rows** are used to sum all the different inputs used/outputs produced in each of the zones and the region as a whole and to transport this quantity to the relevant input/output variable. For each distinguished input/output variable exists one balance row.

Each LULUT has its own annuities of output production and input use, dependent on the LUT and the suitability of the LU on which it is found. These different annuities are listed in the relevant zonal input/output-balance rows under each LULUT variable. Each LULUT will have an annual production of a particular agricultural product equal to the relevant output-annuity multiplied with the area of the LULUT that is taken up. For input use a similar reasoning applies.

The **labour balance rows** are used to equate the agricultural labour demand with the agricultural labour supply. The labour balance works on a monthly basis. The labour balance thereby assumes that the regional agricultural demand for labour has to be met within Matara district, *i.e.* agricultural labour is considered to be perfectly immobile among districts. This interregional mobility assumption is based on the following:

- Matara district largely lies within the drainage basin of the Nilwala Ganga and as such is surrounded by mountainous region, which relatively isolates the central and the northern zone from neighbouring districts;
- wage rates and employment opportunities are assumed similar for the neighbouring districts and therefore present no stimulus for interregional mobility.

The agricultural labour demand is generated by the LULUT variables taken up in the basis. Each LULUT has its own average monthly labour use, dependent on the LUT and the suitability of the LU on which it is found. These monthly averages are listed in the zonal labour balance rows under the respective LULUT variable. Each LULUT will have a total monthly labour requirement equal to its average monthly labour demand multiplied with the area of the LULUT that is taken up.

The agricultural labour supply comes from the zonal agricultural labour forces. The model distinguishes three zonal agricultural labour forces. For each zone the labour demand can be met by a labour supply coming from the zonal labour force and/or the labour force(s) from adjacent zones. The labour source variables are used to draw labour from the zonal labour forces.

The *'real'* constraints pose constraints to the model, *i.e.* they limit the allowable space in which the solution is to be found. These *'real'* constraints can be divided into constraints concerning:

- availability of LUs (79);
- availability of labour (39);
- availability of buffalo (1);
- availability of irrigation (3);

- limited markets (3).

The **land unit constraints** are imposed as there is only a limited area of each LU available in Matara district. A particular area can only be used by one LUT at the time. It is of course allowed to split a particular area into fractional units as long as the sum of the area occupied by the various LUTs does not exceed the available area of the LU. *'Fallow'* is never explicitly considered as one of the possible agricultural LUTs in the model. However, by setting the LU constraints as a maximum the model is given the possibility to keep part of the acreage fallow (*i.e.* as slack).

The model is free to move LUTs over the different LUs with the exception of LUs that at present are occupied by either a homestead based LUT or a non-agricultural LUT (*i.e.* forest, town or water bodies). In the case of homesteads it is assumed to be socially unacceptable to consider other alternatives than present land use. In the case of non-agricultural LUTs it would not be realistic to consider other (agricultural) alternatives as the model only includes the agricultural sector, *i.e.* the non-agricultural sectors are considered as given. But even if the non-agricultural sectors were included in the model it would probably be advisable to keep the LU under the present LUT in view of the excessive costs of conversion (notably towns and water bodies), social unacceptability (notably towns) and environmental hazards (notably forest). LUs unsuitable for any of the considered LUTs are assumed to be reforested.

The assumptions underlying the labour balance (see above) imply that there is only a limited agricultural labour force in each of the three zones[15]. The labour balance draws labour from each of these three forces through the use of the labour source variables. It is the task of the **labour constraints** to see that not more labour is used from each zone than the labour that can actually be supplied by that zone.

The labour constraint in each zone is split up into an annual constraint and twelve monthly constraints. The assumption behind the split labour constraint is that people are not willing to work more than a certain number of days per year. The same people, however, are assumed to be willing to work harder and longer for shorter periods if required, *e.g.* in tight periods (Hazell & Norton, 1986: 44). The annual constraint assumes an availability of 250 mandays person^{-1} year^{-1}. The monthly constraints assume that each person will work up to a maximum of 6 days out of every 7, even in peak periods. This results in 5 labour free days month^{-1}.

The labour source variables are used to draw labour from both the annual as the relevant monthly labour constraint. As long as the annual labour constraint is not binding, labour can be taken up to the monthly maximum in each zone. However, as soon as the annual labour constraint is binding no more labour can be taken up from that zone for any month, unless labour used in another month is displaced.

The **buffalo stock constraint** is imposed as there is only a limited buffalo stock in Matara district[16]. Buffalo are held for draught power and for milk production. It is assumed that the buffalo cows can not be held for both purposes at the same time[17].

The **irrigation constraints** are imposed as there is only a limited area in each zone where irrigation facilities were present and where irrigation was actually possible (Polman, Samad & Thio,

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15 The zonal agricultural labour force is here defined as the zonal labour force minus the persons having permanent non-agricultural employment within the zone. It was estimated that in 2000 the zonal agricultural labour force would total 35,500 in the south, 56,900 in the centre and 46,500 in the north.

16 The distribution of this stock over the three zones is not mentioned in the 1980-studies. The buffalo constraint is therefore set only at the regional level and not at the zonal level. In 1978 this stock numbered 4,100 heads. Assuming a growth rate of 2.5 % the buffalo stock in the year 2000 would be 7,058 heads.

17 No distinction is made between buffalo cows and bulls. This was assumed not to be necessary since the curd market constraint (see below) allows for only ±1,000 cows to be held for milk production.

1982). It was not foreseen that this irrigated area would expand in the near future. It is therefore assumed that the irrigated area in the year 2000 is equal to the irrigated area in the year 1980[18].

The regional model is a fixed price model as all prices are exogenously determined. This presents no problem if all the products of concern have an unlimited market. This would allow the marketing of all produce at the same exogenously determined price. However, if the market for the produce is only limited, large scale production of the produce in question may influence the prices, *i.e.* keeping the prices constant would not be realistic. In this case **market constraints** have to be imposed to limit production to that quantity that can be marketed at the exogenously determined prices.

It is assumed that rubber, coconut, citronella and paddy can be marketed without limits at the same price. For rubber, coconut and citronella this is based on the assumption that these commodities can be exported to the world market, where Sri Lanka only has a very small share for each product. For paddy this is based on the fact that Matara district is a paddy deficit area and that the paddy produced in Matara only forms a small part of the national production. There are, however, market constraints for three agricultural products produced in Matara district, namely for tea, cinnamon and curd (processed buffalo milk).

The world market for **tea** is restricted and the demand for tea is only slowly growing (inelastic own-price and income elasticities of demand). As Sri Lanka has a large share of the world market for tea (about 20 %), it should not increase the tea supply too much. Based on the room on the world market and the share of Matara district in the national tea production, it was estimated that the Matara district tea production in the year 2000 should not exceed $27*10^6$ kg of made tea (Fresco *et al.*, 1990 and Polman, Samad & Thio, 1982).

The world market for **cinnamon** is also restricted. A reasoning similar to the one mentioned above for tea applies to cinnamon. Sri Lanka has a share as large as 70 % of the world market for cinnamon. It was estimated that the Matara district cinnamon production in the year 2000 should not exceed $2.4*10^6$ kg of quills (Fresco *et al.*, 1990 and Polman, Samad & Thio, 1982).

It was estimated that the total Matara district production of **curd** in the year 2000 should not exceed $1.1*10^6$ litres. This estimation is based on the following assumptions:

- all buffalo milk is processed into curd (as curd fetches higher prices and prevents the milk from mouldering);
- all curd is consumed locally (*i.e.* within the district);
- the district is self-sufficient for curd;
- the demand for curd will grow in accordance with the income-demand elasticity at a constant price. This results in an increase in the curd consumption per head from 0.67 litre $year^{-1}$ in 1980, to 1.63 litre $year^{-1}$ in 2000 (Klijn, Moll & Schipper, 1990).

The *'informative'* rows are included in the model only for informative reasons. They are included to provide insight on the value of various attributes at both zonal and regional level. If the model is solved without these *'informative'* rows, the same solution is obtained.

Six different attributes are included in the present model, namely value added and surplus both at economic and financial prices, employment and government revenue. All attributes are annuities, based on net present values at a 10 % discount rate.

The **value added at economic prices** attribute presents the national economic return to land, labour and capital. It thereby uses the economic farm gate prices of inputs and outputs. The value added at economic prices on a regional (zonal) basis is calculated as:

$$ECOVAL = P_{EC} - F_{EC} - O - T$$

where:

P_{EC}: regional (zonal) annuity of the economic value of production;
F_{EC}: regional (zonal) annuity of the economic cost of fertilizer use;
O: regional (zonal) annuity of the other (economic) costs;
T: regional (zonal) annuity of the (economic) transportation fees.

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18 The zonal area with irrigation facilities totals 1,300 ha in the south, 5,600 ha in the centre and 200 ha in the north.

The **surplus at economic prices** attribute presents the national economic return to land and capital. It thereby uses the economic farm gate prices of inputs and outputs. All labour input is valued against a shadow wage rate of Rs. 15 manday^{-1}. The surplus at economic prices on a regional (zonal) basis is calculated as:

$$ECOSUR = P_{EC} - F_{EC} - O - T - L_{EC}$$

where:

P_{EC}: regional (zonal) annuity of the economic value of production;
F_{EC}: regional (zonal) annuity of the economic cost of fertilizer use;
O: regional (zonal) annuity of the other (economic) costs;
T: regional (zonal) annuity of the (economic) transportation fees;
L_{EC}: regional (zonal) annuity of the economic cost of labour use.

The **value added at financial prices** attribute presents the private financial return to land, labour and capital for the *'super'*-farmers. It thereby uses the financial farm gate prices of inputs and outputs. The value added at financial prices on a regional (zonal) basis is calculated as:

$$FINVAL = P_{FI} - F_{FI} - O - T$$

where:

P_{FI}: regional (zonal) annuity of the financial value of production;
F_{FI}: regional (zonal) annuity of the financial cost of fertilizer use;
O: regional (zonal) annuity of the other (financial) costs;
T: regional (zonal) annuity of the (financial) transportation fees.

The **surplus at financial prices** attribute presents the private financial return to land and capital for the *'super'*-farmers. It thereby uses the financial farm gate prices of inputs and outputs. All labour input is valued against a wage rate of Rs. 15 manday^{-1}. The surplus at financial prices on a regional (zonal) basis is calculated as:

$$FINSUR = P_{FI} - F_{FI} - O - T - L_{FI}$$

where:

P_{FI}: regional (zonal) annuity of the financial value of production;
F_{FI}: regional (zonal) annuity of the financial cost of fertilizer use;
O: regional (zonal) annuity of the other (financial) costs;
T: regional (zonal) annuity of the (financial) transportation fees;
L_{FI}: regional (zonal) annuity of the financial cost of labour use.

The **employment** attribute presents the annual agricultural labour use. The employment on a regional (zonal) basis is simply equal to the regional (zonal) labour input variable.

The **government revenue** attribute presents the net return to the government, *i.e.* agricultural tax revenue net of agricultural subsidy expenditure. It thereby uses the difference between economic and financial farm gate prices of inputs and outputs. The government revenue on a regional (zonal) basis is calculated as:

$$GOVREV = P_{EC-FI} - F_{EC-FI}$$

where:

P_{EC-FI}: regional (zonal) annuity of the government agricultural tax revenue;
F_{EC-FI}: regional (zonal) annuity of the government agricultural (fertilizer) subsidy expenditure.

For each of these attributes, both zonal and regional values are accounted. All the attributes are calculated by making use of the input variables (the so-called pricing activities) and the output- and labour source variables (the so-called costing activities). These variables are multiplied with the relevant prices[19]'informative' rows therefore contain the relevant prices under the relevant input-, output- and labour source variables.

Objective function

Two types of objective function are considered, namely national-economic and private-financial. The **national-economic** objective function calculates the regional optimal plan as seen in the national-economic context. It thereby uses the economic prices and the shadow price of labour. The precise value of the latter is however unknown. Therefore two versions of the national-economic objective function are presented, one assuming the shadow wage rate to be Rs. 15 $manday^{-1}$ [20], the other assuming it to be Rs. 0 $manday^{-1}$.[21] These two versions are considered as the:

- maximization of surplus at economic prices (calculated as ECOSUR);
- maximization of value added at economic price (calculated as ECOVAL).

The **private-financial** objective function calculates the regional optimal plan as seen in the *'super'*-farmers context. It thereby uses the financial farm gate prices and the actual wage rate. This objective function is considered as the maximization of surplus at financial prices (calculated as FINSUR).

2.3 Results of the regional model

In this paragraph the results of the regional model are presented. Firstly the returns of the optimal solutions are presented. Secondly the consequences of the optimal solutions for land use, production and employment are presented. Finally various shadow prices are presented[22].

Optimal solutions

The optimization of value added at economic prices under the constraints given results in an optimal land use plan that from here on will be referred to as *'the economic-value added-plan'*. Similarly, the optimization of surplus at economic prices resulted in *'the economic-surplus-plan'* and the optimization of surplus at financial prices resulted in *'the financial-surplus-plan'*.

It should be remembered that there is a difference in prices used between the economic and financial plans so that the returns generated by the plans are not directly comparable. Table 2.3 therefore presents the returns of the economic-value added-plan, the economic-surplus-plan and the financial-surplus-plan in both economic and financial prices.

At economic prices value added is naturally highest under the economic-value added-plan. The economic-surplus-plan and the financial-surplus-plan produce a value added at economic prices that is respectively Rs. $16*10^6$ $year^{-1}$ and Rs. $72*10^6$ $year^{-1}$ lower.

At financial prices surplus is naturally highest under the financial-surplus-plan. The economic-value added-plan and the economic-surplus-plan produce a surplus at financial prices that is respectively Rs. $106*10^6$ $year^{-1}$ and Rs. $20*10^6$ $year^{-1}$ lower.

The economic-surplus-plan always takes an intermediate position between the economic-value added and financial-surplus-plan, since it uses economic prices (as in the economic-value added-plan) but also assumes a (shadow) wage rate of Rs. 15 $manday^{-1}$ (as in the financial-surplus-plan).

The differences between the returns of the economic-value added-plan, the economic-surplus-plan and the financial-surplus-plan can be explained by the different acreages of LUTs in each case.

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[19] With the exception of the employment attribute where unity is used instead of a price.

[20] This shadow wage rate is based on the assumption that the actual wage rate of Rs. 15 $manday^{-1}$ is a good approximation of the real value of labour.

[21] This extreme low shadow wage rate is based on the assumption that the actual wage rate greatly overvalues the real value of labour. This assumption might be justified in view of the very high unemployment rates.

[22] Readers interested in the detailed results can obtain a working document (Erenstein & Schipper, 1991) and the computer listings concerning the various models. Both are available upon request from the Department of Development Economics, Wageningen Agricultural University.

These different acreages of LUTs influence production and the use of labour, fertilizer and other inputs. The consequences of the three plans for land use, production and the use of labour are discussed hereafter.

Consequences for land use

The optimization of the economic-value added, the economic-surplus and the financial-surplus objective functions results in three clearly different land use plans for the Matara district. These three land use plans are presented in Table 2.4. It should be remembered that the two economic objective functions calculate two versions of the regional optimal plan as seen in the national-economic context. However, while the first version assumes the shadow wage rate to be Rs. 0 manday^{-1}, the second assumes this to be Rs. 15 manday^{-1}. The financial objective function calculates the regional optimal plan as seen in the '*super*'-farmers context when we value all labour against the wage rate of Rs. 15 manday^{-1}.

On basis of the acreages occupied, the five most important land uses in the economic-value added-plan occupy 87 % of total district area. These land uses are: 1. rubber (23 % of district area); 2. forest (22 %); 3. homestead (21 %); 4. paddy (13 %); and 5. VP tea (9 %). In the economic-surplus-plan, the five most important land uses occupy 89 % of total district area. These land uses are: 1. coconut (24 %); 2. forest (22 %); 3. homestead (21 %); 4. paddy (13 %); and 5. VP tea (9 %). In the case of the financial-surplus-plan, the five most important land uses occupy 95 % of total district area: 1. coconut (29 %); 2. forest (29 %); 3. homestead (21 %); 4. VP tea (9 %); and 5. paddy (7 %). Other differences between the three land use plans include the division of the acreages over the distinguished zones and suitability classes.

Table 2.3 *Returns of the economic-value added-plan, the economic-surplus-plan and the financial-surplus-plan in both economic and financial prices. (The returns to the original objective functions are underlined.)*

	VALUE ADDED Rs. 10^6 year^{-1}	SURPLUS[1] Rs. 10^6 year^{-1}
ECONOMIC-VALUE ADDED LAND USE PLAN		
Expressed in:		
Economic prices	1,019	699
Financial prices	536	216
ECONOMIC-SURPLUS LAND USE PLAN		
Expressed in:		
Economic prices	1,003	724
Financial prices	580	300
FINANCIAL-SURPLUS LAND USE PLAN		
Expressed in:		
Economic prices	947	689
Financial prices	578	320

[1] All labour is valued at a wage rate of Rs. 15 manday^{-1}.

VP tea is by far the most interesting LUT (of the ones considered) as far as value added and surplus are concerned (both at economic and financial prices). However, due to the binding market constraint, tea acreage is limited and confined to the more suitable northern zone. Using **seedling tea** would allow a larger (seedling) tea acreage but gives a lower value added and surplus. This can be seen in the economic and financial maximization problems by the fact that seedling tea was never taken up in the basis.

Table 2.4 *Total acreages of the various LUTs (unit: ha) and the percentage share of each zone in the economic-value added, the economic-surplus and the financial-surplus-plan.*

LUT	Economic-value added-plan				Economic-surplus-plan				Financial-surplus-plan			
	ha	North	Centre	South	ha	North	Centre	South	ha	North	Centre	South
VP tea	11,761	100			11,549	100			11,549	100		
Rubber	29,242	6	85	10	7,600	23	77	0				
Coconut	9,419	30	12	59	30,911	10	64	27	37,800	13	65	22
Of which with buffalo	917		100		917		100		917		100	
Cinnamon	4,953	100			4,904	100			4,946	97	3	
Irrigated paddy using hand labour	7,100	3	79	18	114		100		114		100	
Irrigated paddy using animal traction					4,823		94	6	6,141		79	21
Irrigated paddy using mechanized traction					2,163	9	44	47	845	24	76	
All irrigated paddy	7,100	3	79	18	7,100	3	79	18	7,100	3	79	18
Rainfed paddy using hand labour	9,198	39	52	9	478			100				
Rainfed paddy using animal traction					1,318		71	29				
Rainfed paddy using mechanized traction					7,401	49	51		1,680	100		
All rainfed paddy	9,198	39	52	9	9,197	39	52	9	1,680	100		
Homestead	26,560	28	47	25	26,560	28	47	25	26,560	28	47	25
Forest	28,557	50	42	8	28,969	50	42	8	37,156	43	48	9
Town	1,045	9	12	79	1,045	9	12	79	1,045	9	12	79
Water bodies	960		67	33	960		67	33	960		67	33

The distribution of the tea acreage over the land suitability classes is different for the economic-value added-plan on the one side, and the economic-surplus and the financial-surplus-plan on the other. In the economic-value added-plan there is a trade off between VP tea and coconut on land that is classified as S1 for both. This results in 11,761 ha of VP tea, of which 87 % (10,230 ha) is land that is classified as S1 for tea (see Table 2.5). In Matara district there is a total of 10,865 ha of S1 tea land. Therefore, in the economic-value added-plan a total of 896 ha of S1 tea land is displaced by coconut[23].

In both the economic-surplus and the financial-surplus-plan the (shadow) wage rate is assumed to be Rs. 15 manday^{-1} instead of the Rs. 0 manday^{-1} in the economic-value added-plan. As a result

[23] Note that the land unit in question were the trade off takes place is also S1 for rubber. As mentioned below economic-value added is slightly higher for S1 rubber than for S1 coconut, and therefore one would expect the trade off to take place between VP tea and rubber instead of VP tea and coconut. However, the northern annual labour constraint is binding in the optimal economic-value added-plan. As a result the marginal cost of labour is Rs. 2 manday^{-1} (*i.e.* the *'transportation fee'*) in the economic-value added-plan. This non-zero marginal cost of labour causes the model to prefer the less labour intensive coconut instead of rubber on S1 land in the northern zone.

Table 2.5 *Total acreages of the various LUTs (unit: ha) and the percentage share of each suitability class in the economic-value added, the economic-surplus and the financial-surplus-plan.*

LUT	Economic-value added-plan				Economic-surplus-plan				Financial-surplus-plan			
	ha	S1	S2	S3	ha	S1	S2	S3	ha	S1	S2	S3
VP tea	11,761	87	13		11,549	94	6		11,549	94	6	
Rubber	29,242	93	7	0	7,600	73	26	1				
Coconut	9,419	33	68		30,911	77	21	3	37,800	64	30	6
Cinnamon	4,953	32	66	2	4,904	34	67		4,946	31	69	
Irrigated paddy using hand labour	7,100	33	40	27	114		100		114		100	
Irrigated paddy using animal traction					4,823	26	54	20	6,141	37	42	21
Irrigated paddy using mechanized traction					2,163	48	8	44	845	4	96	
All irrigated paddy	7,100	33	40	27	7,100	33	40	27	7,100	33	49	18
Rainfed paddy using hand labour	9,198		30	70	478			100				
Rainfed paddy using animal traction					1,318		71	29				
Rainfed paddy using mechanized traction					7,401		25	75	1,680		100	
All rainfed paddy	9,198		30	70	9,197		30	70	1,680		100	

labour costs press heavily on the labour intensive tea cultivation which make it more interesting to reduce the tea acreage to the most suitable land units. The trade off between coconut and tea turns in favour of tea and this results in all S1 tea land to be put under VP tea. The remaining tea production that is allowed for by the market constraint takes place on S2 tea land. Total tea acreage is naturally lower under the economic-surplus and the financial-surplus-plan since more tea is produced on S1 land with the same market constraint.

Rubber and **coconut** can best be considered together. Value added at economic prices is very similar for both crops for the different land suitability classes. On land that has an equal suitability for both crops, rubber has a slightly higher value added on S1 land, but coconut has the higher on S2 and S3 land. However, suitability for rubber and for coconut are seldom the same. In the economic-value added-plan for Matara district this results in a large area planted with rubber (23 % of district area) and a considerably smaller area with coconut (7 % of district area[24]).

Rubber, however, requires a substantial labour input (notably harvesting labour, which is considered to be suitability independent) when compared to coconut. Therefore, when the shadow wage rate is assumed to be Rs. 15 manday^{-1} instead of Rs. 0 manday^{-1} labour costs press more heavily on rubber than on coconut. Surplus at economic prices, therefore, is considerably lower for rubber than for coconut for the different land suitability classes. In the economic-surplus-plan this results in a large area planted with coconut (24 % of district area) and a considerably smaller area with rubber (6 % of district area).

Government taxation, moreover, is considerably higher for rubber than for coconut. In addition, rubber makes a relatively limited use of the highly subsidized fertilizer. The difference between coconut and rubber for surplus at financial prices is therefore even more pronounced than the

[24] Coconut acreages always include area under coconut with buffalo, unless otherwise specified.

difference between surplus at economic prices. The balance, therefore, shifts completely in favour of coconut. This results in a financial-surplus-plan where, when compared to the economic plans, rubber has been totally displaced by coconut.

Coconut with buffalo is an interesting LUT, both economically and financially speaking. This LUT, however, only occupies a limited acreage due to the binding market constraint for curd. In all three plans acreage is limited to less than 1,000 ha (0.7 % of district area, see Table 2.4, and confined to the central zone. The buffalo component is considered to be suitability independent. The acreage could, therefore, also be confined to another zone without influencing the return of the optimal solution, as long as:

- the labour constraints remain non-binding in that other zone;
- the coconut acreage is large enough in the other zone to absorb the buffalo component.

In the present situation the LUT coconut with buffalo could therefore also be confined to the southern zone or be spread over the central and southern zone without influencing the return of the optimal solution. The LUT coconut with buffalo could not, however, be moved to the northern zone without influencing the return of the optimal solution. The reason is that the labour constraints are binding in the northern zone. If the LUT coconut with buffalo is taken up in the northern zone, it creates an additional labour demand. This labour demand can only be met by either attracting central labour (at the cost of the so-called *'transportation fee'*) or by displacing labour now used by other LUTs in the northern zone. Whatever the case, this would always have a negative influence on the return of the optimal solution.

Cinnamon also is an interesting LUT as far as value added and surplus are concerned (both at economic and financial prices). However, due to the binding market constraint total acreage can only be limited. The allowable acreage is further reduced by the fact that a considerable share (10 %) of the allowable cinnamon production comes from the homesteads.

Another interesting aspect of cinnamon is its ability to produce on soils that are marginal to other crops. Cinnamon acreage is therefore concentrated in the northern zone on the less suitable soils[25].

The economic-value added-plan places a small share (2 %) of the cinnamon acreage on S3 cinnamon land (see Table 2.5). The economic-surplus (and the financial-surplus-plan), however, place the entire cinnamon acreage on S1 and S2 cinnamon land. Therefore, when assuming the (shadow) wage rate to be Rs. 15 manday^{-1}, it appears to be more interesting to achieve the market constraint on the more suitable S1 and S2 land, leaving S3 land fallow.

Citronella is an uninteresting LUT from both an economic as a financial point of view. In all cases there always appear to be better alternatives. Citronella has a negative surplus for all suitability classes (both at economic and financial prices). It will therefore never be taken up in the basis of a surplus maximizing problem.

In each of the three land use plans the **irrigated paddy** acreage equals 5.5 % of the district area, being clearly limited by the available irrigational infrastructure. In each plan it therefore appears that irrigated paddy is more interesting than rainfed paddy. The preference for irrigated paddy is based on the following:

- irrigated paddy achieves higher yields than rainfed paddy on land that is equally suited for both while the labour and other costs of irrigation are limited.
- irrigation can upgrade land suitability for paddy, *i.e.* land that is only marginally or not suitable for rainfed paddy is normally better suited for irrigated paddy. Consequently most paddy lands are less suited for rainfed than for irrigated paddy.

The **rainfed paddy** acreage occupies about 7 % of the district area in the economic-value added and the economic-surplus-plan. In the financial-surplus-plan rainfed paddy occupies less than 1.5 %

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25 Less suitable is used here in the general sense, *i.e.* marginal for most crops, but not necessarily for cinnamon.

of the district area. The difference in paddy acreages between the two economic plans on the one side, and the financial-surplus-plan on the other, is caused by the severe discrepancy between the economic and the financial price of paddy. As a result the financial-surplus of a rainfed paddy crop is negative on S3 paddy lands. It so happens to be that the largest share of the potential rainfed paddy acreage in Matara district is qualified as S3 land. In the financial-surplus-plan all these S3 rainfed paddy lands will remain fallow, thereby reducing the rainfed paddy acreage considerably when compared to the two economic plans.

In the economic-value added-plan, irrigated paddy using hand labour is the most interesting of the three irrigated paddy based LUTs while rainfed paddy using hand labour is the most interesting of the three rainfed paddy based LUTs (see Table 2.4). They are the more interesting since labour costs are zero (shadow wage rate is Rs. 0 manday^{-1}) while paddy using traction (animal or mechanized) has additional land preparation costs.

In the economic-surplus-plan the division of irrigated and rainfed paddy acreages over the zones and suitability classes is similar to the economic-value added-plan. The types of irrigated and rainfed LUTs taken up, however, are quite different. In the economic-surplus-plan irrigated paddy using hand labour becomes the most uninteresting of the three irrigated paddy based LUTs while rainfed paddy using hand labour becomes the most uninteresting of the three rainfed paddy based LUTs. The substantial labour requirement of land preparation and the shadow wage rate of Rs. 15 manday^{-1} makes the use of traction power interesting.

Some soils, notably the bog and half-bog soils, have a poor bearing capacity and cannot support buffalo or tractors. This part of the paddy acreage (1,770 ha), therefore, has to remain fallow or use hand labour. On the remaining paddy acreage traction power can be used. There is, however, only a limited stock of buffalo available, part of which is used for milk production (see coconut with buffalo above). The remaining buffalo stock can be used for draught power but is not sufficient to prepare all remaining paddy lands with animal traction. Mechanized traction is used to prepare the remaining paddy acreage.

Also in the financial-surplus-plan extensive use is made of traction power. Even though rainfed paddy acreage is greatly reduced when compared to the two economic plans (see above), the buffalo stock remains insufficient to prepare all paddy land with animal traction. Therefore also use is made of mechanized traction power.

Another interesting aspect is the division of the traction power sources over the different zones in the economic-surplus and the financial-surplus-plans. As was just explained, the buffalo stock is insufficient to prepare all paddy lands with animal traction and therefore also use is made of mechanized traction power. Mechanized traction power uses less labour but has higher other costs than animal traction. Labour constraints are, however, binding in the northern zone in the optimal solution in all plans. As a result the marginal cost of labour is increased by Rs. 2 manday^{-1} (the so-called *'transportation fee'*). This causes the model to allocate the allowable animal traction to the central and southern zone, while in the northern zone use is made of the less labour intensive mechanized traction power.

All areas considered for **homestead** based LUTs are placed under homesteads in all three plans. Consequently about 21 % of the district area is under homesteads in each plan. The highest concentration is to be found in the coastal zone (32 % of zone area) and the lowest in the northern zone (16 % of zone area).

All **non-agricultural** LUTs were assumed to be non-optional and therefore to remain on their 1980 acreages. LUs that are considered unsuitable for perennial and annual based LUTs are assumed to be reforested in each plan. Therefore no differences should be expected between the economic-value added, the economic-surplus and the financial-surplus-plan. However, the three different plans allow certain areas of marginal land to remain uncultivated. It is assumed that these will be reforested and consequently forest acreage under the three plans is different (see Table 2.4).

Consequences for production

The consequences of the economic-value added, the economic-surplus and the financial-surplus-plan for district production are presented in Table 2.6. The same table also presents the division of the production over the different land suitability classes under each plan.

The division of production over the suitability classes in the plans is similar to the division of acreages. However, the division is not identical due to the fact that yields are related to suitability classes. The share of S1 lands in a particular crop's production is therefore higher or equal to its share in the crop's acreage. The opposite can be said about the share of S3 lands in a particular crop's production. The situation for S2 lands is dependent on the shares of S1 and S3 lands.

Tea, curd and cinnamon production is clearly limited by the market constraints in each plan, since total production equals allowable production. This also presents the first aggregation problem: in the regional model acreage and therefore production could be limited, thus holding prices for these products constant. But if the total acreage and therefore production is distributed over a number of autonomously producing farms, production is less easily limited. Total district production could exceed the allowable production, thus possibly causing a decline in prices.

In the two economic plans about 80 % of the irrigated paddy production comes from S1 and S2 paddy land, whereas less than 40 % of the rainfed paddy production comes from S1 and S2 paddy land. The reasons for the large share of rainfed production coming from marginal rainfed lands are:

- the marginal suitability of the paddy lands in Matara for rainfed paddy cultivation;
- the lack of alternatives on these paddy lands: most of the paddy lands can only be occupied by paddy based LUT while irrigation facilities are limited.

In the financial-surplus-plan more than 85 % of the irrigated paddy production comes from S1 and S2 land, whereas all rainfed paddy production comes from S2 land. The latter is the result of the negative financial-surplus on S3 rainfed paddy lands and again the lack of alternatives, which causes the model to opt for a land use plan where these soils remain fallow.

For the perennials the case is different: in each of the plans, production comes predominantly (*i.e.* > 85 %) from S1 and S2 lands[26]. The main reason for this is that the different LUs have different suitabilities for the different perennial based LUTs. The model therefore has more possibilities of shifting perennial based LUTs to the LUs most suitable for the specific LUTs. This is off course a notable example of aggregation bias: land use is optimized over the district using allocation possibilities that may not be available to the individual farmers.

Consequences for employment

There is a marked difference in total annual agricultural employment between the three plans. Compared to the economic-value added-plan with an average employment of $22.7*10^6$ mandays $year^{-1}$, employment is reduced by nearly 15 % in the economic-surplus-plan (% based on economic-value added-plan employment). This naturally is a consequence of the assumptions underlying the two different economic plans. In the economic-value added-plan the shadow wage rate is assumed to be Rs. 0 $manday^{-1}$ whereas in the economic-surplus-plan the shadow wage rate is assumed to be Rs. 15 $manday^{-1}$. In a maximization problem this will cause the economic-surplus objective function to choose labour saving LUTs if value added is similar.

Compared to the economic-surplus-plan, employment is further reduced by more than 8 % in the financial-surplus-plan (% based on economic-surplus-plan employment)[27]. The cause of this difference is to be found in the discrepancy between economic and financial prices and the influence this has on the optimal land use, as in both these plans (shadow) wage rates are assumed to be Rs. 15 $manday^{-1}$.

Unemployment, however, remains high in all cases. In the economic-value added-plan nearly 35 % of the agricultural labour force remains unemployed on an annual basis. For the economic-surplus

26 Note that suitability is crop dependent. *E.g.* land classified as S1 for one crop might be S2, S3 or even N for another.

27 Compared to the economic-value added-plan this figure is 21.5 % (% based on economic-value added-plan employment).

Table 2.6 *Total annual production of the various agricultural products (various units) and the percentage share of each suitability class in the economic-value added, economic-surplus and financial-surplus-plan.*

Product	Economic-value added-plan				Economic-surplus-plan				Financial-surplus-plan			
	Matara	S1	S2	S3	Matara	S1	S2	S3	Matara	S1	S2	S3
Tea (10^6 kg made tea)	27.000	90	10		27.000	96	5		27.000	96	5	
Rubber (10^6 kg dry sheets)	26.926	95	5	0	6.626	78	21	1				
Coconut (10^6 nuts)	82.802	39	61		305.861	82	17	1	357.440	72	25	4
Cinnamon[1] (10^6 kg quills)	2.400	35	54	1	2.400	36	54		2.400	34	57	
Irrigated paddy (10^6 kg paddy)	42.702	43	40	18	42.702	43	40	18	43.933	42	47	12
Rainfed paddy (10^6 kg paddy)	33.356		39	61	33.356		39	61	7.938		100	

[1] Suitability classes of the land on which homegarden cinnamon production takes place is unknown. Homegarden cinnamon production accounts for 10 % of total cinnamon production.

and the financial-surplus-plan this figure is as high as 44 % and nearly 49 %.

On a district basis tea is the largest agricultural employer in all plans. In the economic-value added-plan rubber takes a second place, paddy (irrigated and rainfed) a third. In the economic-surplus-plan rubber is displaced by coconut as second largest agricultural employer, while (irrigated and rainfed) paddy remains the third largest. In the financial-surplus-plan coconut remains the second largest agricultural employer, while cinnamon joins (irrigated and rainfed) paddy as being the third largest.

Tea accounts for nearly 41 % of the district agricultural employment in the economic-value added-plan, about 47 % in the economic-surplus and nearly 52 % in the financial-surplus-plan. In absolute terms, however, tea employment is reduced somewhat when going from the economic-value added-plan on the one side, to the economic-surplus and financial-surplus-plan on the other. This is a result of the complete concentration of the tea acreage on the more suitable lands. Since tea acreage is confined to the northern zone in each plan, employment is also largest in this zone.

The displacement of rubber by coconut, which takes place changing from the economic-value added to the financial-surplus-plan, has notable consequences for the employment situation. In the economic-value added-plan rubber and coconut[28] together account for $6.8*10^6$ mandays $year^{-1}$. In the economic-surplus-plan this is reduced to $4.8*10^6$ mandays $year^{-1}$ and in the financial-surplus-plan even to $3.9*10^6$ mandays $year^{-1}$.

The displacement of hand labour by traction power on the paddy lands also has notable consequences for the employment situation. In the economic-value added-plan paddy (irrigated plus rainfed) account for $3.5*10^6$ mandays $year^{-1}$. This is reduced to $2.3*10^6$ mandays $year^{-1}$ in the economic-surplus-plan.

The reduction of the (rainfed) paddy acreage in the financial-surplus-plan when compared to the economic plans has further consequences for the employment situation: in the financial-surplus-plan the employment in paddy account for only $1.6*10^6$ mandays $year^{-1}$.

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28 Including labour related to coconut component in the LUT coconut with buffalo.

Shadow prices

Shadow prices provide valuable information about the scarcity of resources. The **shadow prices of LUs** are however only of limited interest as the differentiated land resource basis is considered to be unchangeable for the time period considered, *i.e.* there is no change in the supply of land nor change in the suitability classes of the various LUs considered.

The shadow price of a LU in the economic-value added-plan represents the value added at economic prices of the best alternative for that particular LU. This is most easily seen when considering LUs that have only limited alternatives:

E.g. 1: LU *'NO01'* (Northern zone, land unit 1) has a shadow price of Rs. 0 ha^{-1} $year^{-1}$. This land unit can only be used for forest. Forest is a non-agricultural LUT and therefore has a value added of Rs. 0 ha^{-1} $year^{-1}$.

E.g. 2: LU *'CE37'* (Central zone, land unit 37) has a shadow price of Rs. 5,662 ha^{-1} $year^{-1}$. This land unit can only be used for rainfed paddy based LUTs due to the limited alternatives available for this LU and the binding central irrigation constraint. As a result rainfed paddy using hand labour is economically speaking the most interesting alternative. An extra ha would therefore be put under this LUT. This gives an extra value added of Rs. 5,662 ha^{-1} $year^{-1}$ (cropping intensity is 175 %, value added per season is Rs. 3,235 ha^{-1}).

But the shadow price of LUs can naturally also be derived when more complicated relationships are considered:

E.g. 3: LU *'NO02'* (Northern zone, land unit 2) has a shadow price of Rs. 7,298 ha^{-1} $year^{-1}$. This land unit can only be used for perennial based LUTs. Suitabilities of this LU for the various perennial LUTs are: (VP or seedling) tea: S1; rubber: N; coconut: S2; cinnamon: S1; and citronella: S1. In the optimal plan market constraints for tea, curd and cinnamon are binding. LUTs producing these products can therefore not be considered as alternatives, unless tea and cinnamon LUTs on other LUs are displaced. This is exactly what happens since the most attractive alternative is to displace 1 ha of tea on LU *'NO19'* (Northern zone, land unit 19) with coconut and plant the extra ha of *'NO02'* with VP tea (Some suitabilities of LU *'NO19'* are: (VP or seedling) tea: S1; rubber: S1 and coconut: S1). Coconut gives a value added of Rs. 7,516 ha^{-1} $year^{-1}$ on S1 land. The northern annual labour constraint, however, is binding in the optimal plan. As a result Rs. 2 $manday^{-1}$ (the so-called *'transportation fee'*) have to be paid for every additional manday used in the northern zone. Since coconut has an average labour use of 109 mandays $year^{-1}$ on S1 land, a total of Rs. 218 $year^{-1}$ transportation costs have to be deducted. This amount deducted from the value added of coconut resulting in a return of Rs. 7,298 ha^{-1} $year^{-1}$, *i.e.* the shadow price of LU *'NO02'*.

The shadow price of a LU in the economic-surplus and the financial-surplus-plan represent respectively the economic-surplus and the financial-surplus of the best alternative for that particular LU in the respective plan. A reasoning similar to the one derived for the economic-value added shadow prices applies for these shadow prices of the LUs.

The central and the southern zone appeared to have a permanent excess supply of labour in each of the three plans, *i.e.* none of the central or southern labour constraints was binding. Consequently the **shadow price of labour**[29] is Rs. 0 $manday^{-1}$ in these zones (on both a monthly as an annual basis).

The northern zone, however, does have a labour shortage in the financial-surplus-plan in the months May, June and October. To ease this shortage, labour can be attracted from the central zone, but at the additional expense of Rs. 2 $manday^{-1}$ (the so-called *'transportation fee'*). Consequently the shadow price of labour is Rs. 2 $manday^{-1}$ in the northern zone in these tight months. The other months have slack labour. Consequently the shadow price of labour is Rs. 0 $manday^{-1}$ in the northern

[29] It should be noted that this shadow price of labour is on top of the labour costs charged in each of the three plans, *i.e.* the assumed shadow wage rate of Rs. 0 $manday^{-1}$ in the economic-value added-plan on the one side, and the Rs. 15 $manday^{-1}$ in the economic-surplus and financial-surplus plan on the other.

zone in these slack months. The annual northern labour constraint is not binding in the financial-surplus-plan.

The two economic plans do have a labour shortage in the northern zone on both an annual basis as in the months May, June and October (as well as in September in the economic-value added-plan). To ease this shortage, labour can be attracted from the central zone, again at the additional expense of Rs. 2 manday^{-1}. Easing the monthly constraints in the tight months, however, has no effect as long as the annual constraint is binding. The shadow price of the northern monthly constraints is therefore Rs. 0 manday^{-1} in the two economic plans. Easing the annual constraint does effect the labour availability. The shadow price of the northern annual labour constraint is therefore Rs. 2 manday^{-1} in the two economic plans.

In the economic-value added-plan buffalo were only used for milk (curd) production. The milk production was limited by the curd market constraint, and not by the stock of buffalo. The buffalo constraint was therefore not binding. Consequently the economic-value added **shadow price of buffalo** is Rs. 0 head^{-1} year^{-1}.

In both the economic-surplus as the financial-surplus-plan extensive use was made of buffalo for both milk (curd) production and draught power. The milk production was again limited by the curd market constraint. The use of draught power, however, was limited by the availability of buffalo. As a consequence use had to be made of mechanized traction, which is in both plans less attractive than animal traction. The extra costs of using mechanized traction are Rs. 130 ha^{-1} season^{-1}. With a cropping intensity of 175 % the extra costs amount to Rs. 227.5 ha^{-1} year^{-1} while each ha requires 1 buffalo. The shadow price of buffalo therefore amounts to Rs. 227.5 head^{-1} year^{-1}.

The irrigation constraint for each zone was binding in each of the three plans. Table 2.7 presents the zonal **shadow price of irrigation** in each plan[30].

Table 2.7 *Zonal shadow prices of irrigation (Rs. ha^{-1} year^{-1}) in the economic-value added, the economic-surplus and the financial-surplus-plan.*

Zone	Economic-value added-plan	Economic-surplus-plan	Financial-surplus-plan
North	7,116	5,165	1,406
Centre	8,137	5,180	282
South	16,020	14,340	6,661

The shadow price of irrigation in the southern zone in the economic-value added-plan can be derived as follows. In the optimal economic-value added-plan only 626 ha of LU *'SO10'* (Southern zone, land unit 10) are occupied by the LUT irrigated paddy using hand labour. The remaining 380 ha of this LU are occupied by the LUT rainfed paddy using hand labour. The LU *'SO10'* is S1 for irrigated paddy and only S3 for rainfed paddy. When the irrigation constraint is eased with 1 ha, 1 ha of rainfed paddy would be replaced with 1 ha of irrigated paddy. The economic-value added of irrigated paddy using hand labour on this LU is Rs. 21,681 ha^{-1} year^{-1} (value added per season is Rs. 12,389 ha^{-1} season^{-1} and cropping intensity is 175 %) and for rainfed paddy this amount is Rs. 5,661 ha^{-1} year^{-1} (value added per season is Rs. 3,235 ha^{-1} season^{-1} and cropping intensity is 175 %). This would therefore give an additional Rs. 16,020 ha^{-1} year^{-1}, *i.e.* the shadow price of irrigation in the southern zone in the economic-value added-plan. The other zonal shadow prices of irrigation in each of the plans can be derived in a similar way.

30 It should be noted that the shadow price of irrigation is net of the original cost of irrigation.

All three market constraints were binding in each of the three plans. Table 2.8 presents the **shadow prices** of the three **products subject to market constraints** in each plan[31].

The shadow prices that are most easily derived are the ones for curd since curd production is suitability independent and is an additional income to the LUT coconut with buffalo. Economic-value added by the curd component is Rs. 3,303 ha^{-1} $year^{-1}$ while annual milk (curd) yield is 1,200 litres ha^{-1}. Economic-value added on a litre basis is therefore Rs. 2.75 $litre^{-1}$. Loosening the curd market constraint results in an extension of the LUT coconut with buffalo in the central and/or southern zone, at the cost of the LUT coconut. Since curd is an additional income it requires no further sacrifices. The economic-value added on a litre basis is therefore equal to the shadow price of curd in the economic-value added-plan. The shadow price of curd in the economic-surplus and financial-surplus-plan can be derived in a similar way when respectively economic and financial surplus of the buffalo component are used instead of the value added.

Table 2.8 *Shadow prices of the three products subject to market constraints in the economic-value added, the economic-surplus and the financial-surplus-plan.*

Product	Economic-value added-plan	Economic-surplus-plan	Financial-surplus-plan
Made tea (Rs. kg^{-1})	14.62	9.90	2.48
Cinnamon quills (Rs. kg^{-1})	9.08	5.12	5.96
Curd (Rs. l^{-1})	2.75	1.63	1.63

The shadow prices for tea and cinnamon are more complicated since these two products are clearly not additional and thus require sacrifices. The economic-value added shadow price of tea will be derived here. The other shadow prices can be derived in a similar way.

In the economic-value added-plan there is a trade-off between VP tea and coconut on the LU *'NO19'* (Northern zone, land unit 19). This LU is classified as S1 for both LUTs. Value added for VP tea and coconut on this LU is respectively Rs. 43,609 ha^{-1} $year^{-1}$ and Rs. 7,516 ha^{-1} $year^{-1}$. Average VP tea yield on this LU is 2,373 kg made tea ha^{-1} $year^{-1}$. Each extra hectare of VP tea on this LU yields a value added of Rs. 43,609, but at the same time sacrifices the value added by coconut (*i.e.* Rs. 7,516). In addition VP tea annually requires 696 extra mandays. This labour demand can only be met by the central labour force (as the northern annual labour constraint is binding) at the additional expense of the so-called *'transportation fee'* of Rs. 2 $manday^{-1}$ (*i.e.* Rs. 1,392). The net return of an extra hectare of VP tea is therefore Rs. 34,701. The net return of an extra kg of made tea is therefore Rs. 14.62 kg^{-1} (= 34,701/2,373) and this is the economic shadow price of tea.

[31] It should be noted that this shadow price of each product is on top of the original economic and financial prices used in respectively the two economic and the financial plans, *i.e.* it is a scarcity rent.

3 THE REGIONAL MODEL WITH MULTIPLE CRITERIA ANALYSIS

In this chapter we combine the regional model with multiple criteria analysis. The first paragraph will shortly discuss multiple criteria analysis. The second paragraph will present how the multiple criteria analysis was included in the model. The third paragraph will present the results generated by the model.

3.1 Multiple criteria analysis

The traditional framework that is normally used for the analysis of decision making, presupposes the existence of three elements (Romero & Rehman, 1989: 3):

- a decision maker;
- an array of feasible choices; and
- a well defined criterion that can be used to associate a number with each alternative so that the feasible set can be ranked and ordered to find the optimal value.

Mathematical programming can easily be used to solve these decision making problems. The feasible solutions are those that satisfy the constraints of the problem. These feasible solutions are ordered according to a given criterion (*i.e.* the objective function) representing the preferences of the decision maker. The optimum solution is found from the feasible set using a mathematical procedure to find the highest possible value for the objective function (Romero & Rehman, 1989: 4).

In the last chapter we have used this traditional approach to find the optimal land use plan for Matara district for three separate criteria or objective functions, namely maximization of respectively value added at economic prices, surplus at economic prices and surplus at financial prices.

Notwithstanding the fact that this traditional approach is logically sound, most often it does not reflect the real life decision making situations. The decision maker is usually not interested in ordering the feasible set according to just one single criterion alone but seems to be striving to find an optimal compromise amongst several objectives. Multiple objectives are the rule rather than the exception in agricultural decision making (Romero & Rehman, 1989: 3-5).

It is, for example, conceivable that a land use planner, aiming to maximize the benefits for the economy, at the same time wishes to maximize farm level income and agricultural employment. In this study these attributes are approximated in the following way:

- the benefits for the economy are approximated by the value added at economic prices (attribute *'ECOVAL'*);
- the farm level income is approximated by the surplus at financial prices (attribute *'FINSUR'*); and
- the agricultural employment is approximated by the agricultural demand for labour (attribute *'EMPLOY'*).

There is, however, a considerable degree of conflict between these three objectives. This can most easily be investigated in a so-called *'pay-off matrix'*. This is a square matrix that presents the results of optimizing each of the three objectives separately over the efficient set, and then to compute the value of each attribute at each of the optimal solutions[32] (Romero & Rehman, 1989: 69). Table 3.1 presents the *'pay-off matrix'* for the three objectives, maximization of value added at economic prices, maximization of surplus at financial prices and maximization of employment.

The elements of the main diagonal in the *'pay-off matrix'* are referred to as the *'ideal solution'*. The *'ideal solution'* is the utopian solution where all objectives achieve their optimal value (Romero & Rehman, 1989: 70). In our case the *'ideal solution'* (underlined in Table 3.1) is a value added at economic prices of Rs. $1{,}019*10^6$ year^{-1}, a surplus at financial prices of Rs. $320*10^6$ year^{-1} and an employment of $25.8*10^6$ mandays year^{-1}. The *'ideal solution'* is infeasible when the objectives are in conflict, as in our case.

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32 The so-called *'informative rows'* (see preceding chapter) provide this information.

When we take the worst element[33] from each row of the *'pay-off matrix'* then we have what is called the *'anti-ideal solution'*. This is the situation where all the objectives achieve their worst values (Romero & Rehman, 1989: 70).

Table 3.1 *Pay-off matrix for the three objectives maximization of value added at economic prices, maximization of surplus at financial prices and maximization of employment.*

	Objective function		
Attribute	Maximization of value added at economic prices	Maximization of surplus at financial prices	Maximization of employment
Value added at economic prices (Rs. 10^6 year^{-1})	1,019	947	**710**
Surplus at financial prices (Rs. 10^6 year^{-1})	216	320	**24**
Employment (10^6 mandays year^{-1})	21.4	**17.2**	25.8

In our case the *'anti-ideal solution'* (bold in Table 3.1) is a value added at economic prices of Rs. $710*10^6$ year^{-1}, a surplus at financial prices of Rs. $24*10^6$ year^{-1} and an employment of $17.2*10^6$ mandays year^{-1}. The *'anti-ideal solution'* is of importance when normalizing objective functions measured in different units and with different absolute values (see next paragraph).

If objectives are in conflict, as in our case, what approaches do we have if we want to maximize these objectives simultaneously? A clearly different approach is needed than the traditional framework used in the preceding chapter. Romero and Rehman (1989) distinguish the following four different approaches to multiple criteria analysis.

- **Goal programming**: the general aim is the simultaneous optimization of several goals. For that purpose the deviations from the desired targets and what is actually achievable are minimized (Romero & Rehman, 1989: 31). This approach requires a lot of precise information from a decision maker, amongst others the target values, the pre-emptive ordering of preferences, *etc.* (Romero & Rehman, 1989: 101).
- **Multiobjective programming**: the main purpose is to establish the set of Pareto optimal or efficient solutions[34] from the set of feasible solutions (Romero & Rehman, 1989: 63). The only assumption made in this approach is that a decision maker is rational, *i.e.* his choice will belong to this efficient subset, regardless of his preferences. Then, on the basis of the trade-offs between the objectives and his preferences, the decision maker can make his decisions. However, no further guidelines are given for the final choice.
- **Compromise programming**: the main purpose is to establish the optimal set within the set of Pareto optimal or efficient solutions. To determine that optimal set it is necessary to introduce the decision maker's preferences somehow. The basic idea in compromise programming is to identify the *'ideal solution'* and use this as a point of reference for the decision maker. Compromise programming assumes that any decision maker seeks a solution as close as possible

[33] The worst element is naturally dependent on the objective, *i.e.* the maximum element if the objective is minimized and the minimum element if the objective is maximized.

[34] The Pareto optimal or efficient solutions are feasible solutions such that no other feasible solution can achieve the same or better performance for all the criteria under consideration and strictly better for at least one criterion. In other words, a Pareto optimal solution is a feasible solution for which an increase in the value of one criterion can only be achieved by degrading the value of at least one other criterion (Romero & Rehman, 1989: 23).

to the *'ideal solution'*. To achieve this a closeness function is introduced into the analysis. The concept of distance is used here not in its geometric sense, but as a proxy measure for human preferences (Romero & Rehman, 1989: 85).

- **Interactive multiple criteria decision making approaches**: these approaches imply a progressive definition of the decision maker's preferences through an interaction between him and the model. The interaction becomes a dialogue in which the model responds to an initial set of the decision maker's preferences and trade-offs. When this response has been examined by the decision maker, another set of preferences and trade-offs is offered, and so on. Thus the process proceeds in an interactive and iterative way until the decision maker has found a satisfactory solution (Romero & Rehman, 1989: 107). For further details also see Fresco *et al.* (1990) or de Wit *et al.* (1988). For an example of this approach see Ayyad & van Keulen (1987) or Veeneklaas (1990).

There is, however, no definite conclusion about the superiority of one multiple criteria analysis approach relative to others. As Ignizio (as quoted in Romero & Rehman, 1989: 102) says: *'there is not now, and probably never shall be, one single 'best' approach to all types of multiobjective mathematical programming problems'*. In agricultural planning involving multiple criteria decisions, the choice of a given multiple criteria analysis approach as well as the choice of modelling technique will inevitably depend upon several factors (Romero & Rehman, 1989: 102), such as the data availability, the time and resources for (computer) analyses and the nature of the decision making process, including the decision maker.

3.2 Structure of the regional model with multiple criteria analysis

Formulated in a abstract way, decision making requires a *decision maker*. The four mentioned approaches to multiple criteria analysis each involve a decision maker in a different way. However, given the hypothetical nature of the present study and the obsolete data used, it would not make much sense to simulate a 'real live' decision making process. At the same time, given the resources available for the study, it would have been impossible to organise the involvement of a real live decision maker.

In the present study we chose the compromise programming approach for a multiple criteria analysis for Matara district. This choice is related to the *'unavailability'* of a decision maker in our situation. Goal programming, for instance, requires a lot of precise information from the decision maker. However, due to the *'unavailability'* of a decision maker, we are uncertain about both the precise values of the decision maker's targets, as well as the precise specification of the decision maker's preferences with respect to each attribute.

Interactive multiple criteria decision making approaches, on the other hand, initially require less precise information. One of the main advantages of these approaches is the progressive definition of the decision maker's preferences through the interaction between the decision maker and the model. However, in our case there is no *'real'* decision maker and the use of this approach would require many additional assumptions regarding the decision maker's preferences. As a result both multiobjective and compromise programming approaches appeared to be more promising for this study than goal programming and interactive multiple criteria decision making approaches. Note, however, that Table 3.1 could be a starting point for an interactive multiple criteria decision making approach.

Compromise programming was preferred above multiobjective programming as it reduces the efficient set generated by the multiobjective programming to include only the optimal efficient set. It thereby uses an additional assumption concerning the decision maker's preferences that appears to be quite realistic, namely that the decision maker seeks a solution as close as possible to the *'ideal solution'*.

This paragraph presents how compromise programming has been included in the regional model for the example that was given in the previous paragraph. This example concerned the simultaneous maximization of three conflicting objectives, namely of value added at economic prices, surplus at financial prices and employment.

The first step in compromise programming is to identify the *'ideal solution'* (see preceding paragraph). Since the *'ideal solution'* is infeasible, because of the inherent conflict of multiple objectives, it is then necessary to look for compromise solutions. The *'ideal solution'* is thereby used as a point of reference for the decision maker. Compromise programming assumes that any decision maker seeks a solution as close as possible to the *'ideal solution'*. To achieve this a closeness function is introduced into the analysis. This closeness function uses the notion of a family of L_p metrics or a family of distance measures, providing a generalization of the Euclidean distance between two points x^1 and x^2 as (Romero & Rehman, 1989: 86)[35]:

$$L_p = \left[\sum_{j=1}^{n} |x^1_j - x^2_j|^p \right]^{1/p} \tag{1}$$

Obviously, for each value of the parameter *'p'*, a particular distance is obtained between the two points. The parameter *'p'* weights the deviations according to their magnitudes, where as *'p'* increases more weight is given to the largest deviation. If *'p'* equals 1 all individual deviations are summated and therefore L_1 is the largest distance[36]. If *'p'* equals infinity only the largest of the individual deviations is relevant and all the smaller deviations loose relevance[37]. Therefore $L_{infinity}$ is the shortest distance. All the possible distances between two points are bounded by this *'longest distance'*, the L_1 metric, and this *'shortest distance'*, the $L_{infinity}$ metric[38] (Romero & Rehman, 1989: 88-89).

These L_p metrics can be used to calculate *'distances'* between solutions belonging to the efficient set and the *'ideal solution'*. It has been proved by Yu (1973 & 1985: 76-77) that the minimization of the L_1 and $L_{infinity}$ metrics define a subset of the efficient set, the so-called *'compromise set'* (Zeleny, 1973). All the other best-compromise solutions fall between the solutions corresponding to the minimization of the L_1 and $L_{infinity}$ metrics. It is therefore sufficient to calculate these two solutions to know the boundaries of the *'compromise set'*. To calculate these two solutions we have to construct two LP models, one minimizing the L_1 metric and the other minimizing the $L_{infinity}$ metric. In both cases the minimization is subject to all the other constraints imposed to the regional model. Furthermore, in both cases the measures of the objectives need to be normalized as:

- the units used to measure various objectives may be different;
- to avoid solution bias towards those objectives that can achieve higher values.

The normalized degree of closeness are bounded between 0 and 1, *i.e.* when an objective achieves its *'ideal solution'* then the degree of closeness is 0. On the contrary, when an objective achieves its *'anti-ideal solution'* then the degree of closeness is 1. Consequently, the degree of closeness now measures the fractional deviation of one objective with respect to its ideal value (Romero & Rehman, 1989:90).

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35 According to the Pythagoras theorem the distance $\underline{d}$ between two points, $x^1=(x^1_1,x^1_2)$ and $x^2=(x^2_1,x^2_2)$, defined in a Cartesian plane would be:

$$\underline{d} = [(x^1_1 - x^2_1)^2 + (x^1_2 - x^2_2)^2]^{1/2} \tag{F1}$$

This concept can easily be extended to a n-dimensional space and the formula (F1) becomes:

$$\underline{d} = \left[\sum_{j=1}^{n} (x^1_j - x^2_j)^2 \right]^{1/2} \tag{F2}$$

Although this is the best known measure of proximity between two points, it is not necessarily the only one. A further generalization of the Euclidean distance gives us the family of L_p metrics presented in formula (1). The Euclidean distance is a particular case of the family of L_p metrics, namely when p=2 (Romero & Rehman, 1989: 86).

36 The L_1 distance between the two points $x^1=(0,0)$ and $x^2=(3,4)$ defined in a two dimensional space would be:

$$L_1 = |0 - 3| + |0 - 4| = 7$$

37 The $L_{infinity}$ distance between the two points $x^1=(0,0)$ and $x^2=(3,4)$ defined in a two dimensional space would be:

$$L_{infinity} = \text{Max}\,[|0-3|, |0-4|] = 4$$

38 This distance is also known as the *'Chebysev'* distance.

The L_1 metric model

For the L_1 metric model the sum of the individual deviations is minimized. That is, when *'p'* equals 1, each deviation counts. For this metric, the best compromise solution is obtained by solving the following LP problem (Romero & Rehman, 1989: 93):

$$\text{Min } L_1 = \sum_{j=1}^{n} W_j * \frac{Z^*_j - Z_j(x)}{Z^*_j - Z_{*j}} \qquad (2)$$

subject to all other constraints imposed on initial model.

and where:

W_j : weight attached to j-th objective;
Z^*_j : value of objective Z_j in *'ideal solution'*;
$Z_j(x)$: actual value of objective Z_j;
Z_{*j} : value of objective Z_j in *'anti-ideal solution'*.

Applying this to our example gives:

$$\text{Min } L_1 = W_1 * \frac{1019\text{-'}ECOVAL\text{'}}{1019 - 710} + W_2 * \frac{320\text{-'}FINSUR\text{'}}{320 - 24} + W_3 * \frac{25.8\text{-'}EMPLOY\text{'}}{25.8 - 17.2}$$

subject to all other constraints imposed on regional model.

and where:

W_1 : weight attached to the maximization of *'ECOVAL'*;
W_2 : weight attached to the maximization of *'FINSUR'*;
W_3 : weight attached to the maximization of *'EMPLOY'*.

The L_1 metric LP model differs from the original regional model in the following aspects:

- the entire objective function.
- an additional variable, namely the constant in the L_1 metric objective function.
- an additional row to force the model to take up the constant in the solution basis.

The $L_{infinity}$ metric model

For the $L_{infinity}$ metric model the maximum deviation from among the individual deviations is minimized. That is, when *'p'* equals infinity, only the largest deviation counts. For this metric, the best-compromise solution is obtained by solving the following LP problem (Romero & Rehman, 1989: 94):

$$\text{Min } L_{infinity} = d \qquad (3)$$

subject to:

$$W_1 * \frac{Z^*_1 - Z_1(x)}{Z^*_1 - Z_{*1}} \leq d$$

$$\vdots$$

$$W_n * \frac{Z^*_n - Z_n(x)}{Z^*_n - Z_{*n}} \leq d$$

all other constraints imposed on initial model.

and where:

d : the largest deviation among the individual deviations;

W_j : weight attached to j-th objective;
Z^*_j : value of objective Z_j in *'ideal solution'*;
$Z_j(x)$: actual value of objective Z_j;
Z_{*j} : value of objective Z_j in *'anti-ideal solution'*.

Applying this to our example gives:

$$\text{Min } L_{infinity} = d$$

subject to:

$$W_1 * \frac{1019\text{-'}ECOVAL\text{'}}{1019 - 710} \leq d$$

$$W_2 * \frac{320\text{-'}FINSUR\text{'}}{320 - 24} \leq d$$

$$W_3 * \frac{25.8\text{-'}EMPLOY\text{'}}{25.8 - 17.2} \leq d$$

all other constraints imposed on regional model.

and where:

d : the largest deviation among the individual deviations;
W_1 : weight attached to the maximization of *'ECOVAL'*;
W_2 : weight attached to the maximization of *'FINSUR'*;
W_3 : weight attached to the maximization of *'EMPLOY'*.

The $L_{infinity}$ metric LP model differs from the original regional model in the following aspects:

- the entire objective function.
- two additional variables, namely the constant in the $L_{infinity}$ metric additional rows and the variable *'d'* representing the largest deviation.
- four additional rows, namely one row to force the model to take up the constant in the solution basis and the three constraints used to identify the maximum deviation from among the individual deviations.

3.3 Results of the regional model with multiple criteria analysis

In this paragraph the results of the regional compromise programming model are presented. Firstly the L_1 and $L_{infinity}$ metric solutions are presented. Secondly the consequences of these solutions are presented.

The L_1 and $L_{infinity}$ metric solutions

The minimization of the L_1 metric under the regional constraints (see chapter 2) gives us one boundary of the *'compromise set'*. The minimization of the $L_{infinity}$ metric under the same regional constraints gives us the other boundary of the *'compromise set'*. Table 3.2 presents the solution values of the three relevant attributes in the L_1 and $L_{infinity}$ metric solutions assuming each of the three attributes to be equally important (*i.e.* $W_1 = W_2 = W_3 = 1/3$). For comparison the *'ideal solution'* and *'anti-ideal solution'* values of these three attributes are mentioned as well.

All the other best-compromise solutions (for the same three attributes and the same weights) fall between the solutions of the L_1 and $L_{infinity}$ metrics. Therefore, if we:

- aim to simultaneously maximize these three attributes under the constraints given;
- find each of the attributes equally important;
- are willing to approximate the *'ideal solution'*;

we will always achieve:

- a value added at economic prices that lies between Rs. 1,017*10^6 and 920*10^6 $year^{-1}$;
- a surplus at financial prices that lies between Rs. 295*10^6 and 205*10^6 $year^{-1}$;
- an employment that lies between 22.5*10^6 and 19.9*10^6 mandays $year^{-1}$.

The *'ideal solution'* is clearly not part of the *'compromise set'*, as could be expected due to the conflicting objectives.

Table 3.2 *The value of each attribute in the ideal, the anti-ideal, the L_1 metric and $L_{infinity}$ metric solutions.*

Attribute	Ideal solution Z^*_j	Anti-ideal solution Z_{*j}	L_1 metric solution	$L_{infinity}$ metric solution
Value added at economic prices (Rs. 10^6 $year^{-1}$)	<u>1,019</u>	710	1,017	920
Surplus at financial prices (Rs. 10^6 $year^{-1}$)	<u>320</u>	24	295	205
Employment (10^6 mandays $year^{-1}$)	<u>25.8</u>	17.2	19.9	22.5

Table 3.3 presents the same *'compromise set'*, but now expressed as the percentage deviation of each attribute with respect to the ideal value. Again, all other best-compromise solutions[39] have deviations (with respect to the ideal) that fall between the L_1 and $L_{infinity}$ deviations.

At one extreme, the L_1 metric provides us with the minimum sum of the weighted individual deviations (*i.e.* 1/3*[0.6 + 8.4 + 68.6] = 1/3*77.6). It appears that the objectives that are most in conflict with each other are employment on the one side, and economic value added and financial surplus on the other. This can be seen by the extreme high deviation of the employment attribute with respect to the two other attributes in the L_1 metric solution.

At the other extreme, the $L_{infinity}$ metric provides us with relatively similar individual deviations. This naturally is the consequence of minimizing the maximum deviation from among the individual deviations, which causes the deviations to converge to similar levels.

39 For the same three attributes and the same weights.

Table 3.3 *The percentage deviation of each attribute with respect to the ideal value in the ideal, the anti-ideal, the L_1 metric and $L_{infinity}$ metric solutions.*

Attribute	Ideal solution Z^*_j	Anti-ideal solution Z_{*j}	L_1 metric solution	$L_{infinity}$ metric solution
Value added at economic prices	0	100	0.6	32.0
Surplus at financial prices	0	100	8.4	38.9
Employment	0	100	68.6	38.4

Note that the *'compromise set'* changes if we change the weights attached to each of the three attributes, or if we want other combinations of attributes. Each set of weights and/or combination of attributes therefore asks for a new calculation of the *'compromise set'*.

For different sets of values of weights W_1, W_2 and W_3 the structure of the *'compromise set'* can thus be modified. A sensitivity analysis with the weights can furnish the decision maker with worthwhile information related to the stability of the solution and the range within which the *'compromise set'* can be defined (Romero & Rehman, 1989: 95). This has, however, not been done in this study.

The differences between the L_1 and $L_{infinity}$ metric solutions can be explained by the different acreages of LUTs in each case. These different acreages of LUTs influence production and the use of labour, fertilizer and other inputs.

Consequences of the L_1 and $L_{infinity}$ metric solutions

The minimization of the L_1 and $L_{infinity}$ metric LP models results in two different land use plans for Matara district. The two land use plans are presented in Table 3.4.

On the one hand, at an aggregated level, the differences are not very large, except with regard to tea. On basis of the acreages occupied, the five most important land uses in the L_1 metric plan occupy 89 % of total district area. These land uses are: 1. coconut (24 % of district area); 2. forest (22 %); 3. homestead (21 %); 4. paddy (13 %); and 5. VP tea (9 %). The five most important land uses in the $L_{infinity}$ metric plan occupy 90 % of total district area. These land uses are: 1. forest (21 %); 2. homestead (21 %); 3. coconut (20 %); 4. VP tea (14 %); and 5. paddy (14 %).

On the other hand, at a more disaggregated level, there are large differences between the two plans. In the first place, the distribution of the different crops over the zones is completely different comparing the two solutions (Table 3.4). In the second place, the suitability classes on which each LUT is cultivated, are different. Table 3.5 presents this division of the LUTs over the suitability classes in the two extreme plans. In the third place, the introduction of a 'new' crop (citronella) in the $L_{infinity}$ metric plan, not cultivated at all in the L_1 metric plan.

It should be remembered that these are the two extreme land use plans of the *'compromise set'*. All the other best-compromise land use plans (for the same three attributes and the same weights), fall between the L_1 and $L_{infinity}$ metric land use plans. The fact that these really are extreme land use plans can easily be illustrated with some examples.

E.g. 1: The LUT citronella: on one side of the *'compromise set'* citronella is not part of the land use plan, on the other side it is.

E.g. 2: The LUT coconut with buffalo: on one side of the *'compromise set'* this LUT is entirely allocated to the central zone, on the other side it is entirely allocated to the southern zone.

E.g. 3: The LUT VP tea: on one side of the *'compromise set'* VP tea is concentrated on the more suitable lands (S1 and S2), on the other side it is concentrated on the less suitable lands (S2 and S3).

The differences between the two extremes are not elaborated any further. They are only meant to illustrate the fact that it is possible to visualize the scala of consequences of adhering to a set of objectives. On basis of these data it is then possible to decide whether to adhere to one's objectives, or whether it is necessary to adjust the weights related to each objective or even to adjust the objectives themselves.

Table 3.4 *Total acreages of the various LUTs (unit: ha) and the percentage share of each zone in the L_1 and $L_{infinity}$ metric solution.*

	L_1 metric solution				$L_{infinity}$ metric solution			
LUT	ha	North	Centre	South	ha	North	Centre	South
VP tea	11,761	100			18,124	45	37	18
Rubber	7,600	23	77	0	940	2	98	
Coconut	31,061	9	64	27	25,653	9	71	20
Of which with buffalo	917		100		917			100
Cinnamon	4,953	100			4,566	100		
Citronella					6,093	100		
Irrigated paddy using hand labour	7,100	3	79	18	7,100	3	79	18
Irrigated paddy using animal traction								
Irrigated paddy using mechanized traction								
All irrigated paddy	7,100	3	79	18	7,100	3	79	18
Rainfed paddy using hand labour	9,198	39	52	9	10,956	33	57	11
Rainfed paddy using animal traction								
Rainfed paddy using mechanized traction								
All rainfed paddy	9,198	39	52	9	10,956	33	57	11
Homestead	26,560	28	47	25	26,560	28	47	25
Forest	28,557	50	42	8	26,798	53	39	8
Town	1,045	9	12	79	1,045	9	12	79
Water bodies	960		67	33	960		67	33

Table 3.5 *Total acreages of the various LUTs (unit: ha) and the percentage share of each suitability class in the L_1 and $L_{infinity}$ metric solution.*

	L_1 metric solution				$L_{infinity}$ metric solution			
LUT	ha	S1	S2	S3	ha	S1	S2	S3
VP tea	11,761	87	13		18,124		51	49
Rubber	7,600	73	26	1	940	2	90	9
Coconut	31,061	80	21		25,653	98	2	
Cinnamon	4,953	32	66	2	4,566	59	40	1
Citronella					6,093	99		1
Irrigated paddy using hand labour	7,100	33	36	32	7,100	28	20	52
Irrigated paddy using animal traction								
Irrigated paddy using mechanized traction								
All irrigated paddy	7,100	33	36	32	7,100	28	20	52
Rainfed paddy using hand labour	9,198		30	70	10,956		25	75
Rainfed paddy using animal traction								
Rainfed paddy using mechanized traction								
All rainfed paddy	9,198		30	70	10,956		25	75

4 THE REGIONAL MODEL WITH FARMING SYSTEMS

In an attempt to make the regional model more realistic we can differentiate the so-called supply sources. In the original regional model the supply sources were called zones, but they could as well be farm size classes, irrigated versus non-irrigated farms, or other categorizations. Now suppose large and small farms are distinguished within the northern zone. Even if the available technologies of production were the same for the two size classes, a representative small farm could be expected to produce a different output mix than a representative large farm. This would be the result of the fact that the relative resource endowments (ratios of land to family labour) differ between the two farms. Therefore, it often is useful to introduce farm size distinctions to enhance the realism (predictive ability) of the model (Hazell & Norton, 1986: 151).

In the present study we chose to differentiate the supply sources in the northern zone. The supply source was only differentiated in one zone in order to keep the model within reasonable proportions. The differentiation could, obviously, also be build in for the other zones. The northern zone was chosen as this is the most *'interesting'* zone, as it produces the lion's share of the two most profitable products (both from an economic as a financial viewpoint), namely tea and cinnamon.

In the first paragraph of this chapter we describe the farming systems present in the northern zone. The second paragraph presents how these farming systems were build into the regional model. The last paragraph presents the results generated by the model.

4.1 Farming systems in the northern zone

The 1980-studies describe the various farming systems that were found in Matara. The different farming systems were typified by using a number of farm types. In the northern zone these farm types can be divided as belonging to either[40]:

- the private small farm sector;
- the state plantation sector;
- the settlement scheme.

Polman, Samad & Thio (1982) distinguish four types of farms in the **small farm sector** of the northern zone, namely:

- micro holdings;
- small holdings;
- medium sized holdings;
- small estates.

The main criterion used in this classification of farms is the ability to generate an income level above or below the official poverty line of the country[41] (Polman, Samad & Thio, 1982: 101). This ability is closely related to the farm size class. Table 4.1 presents the farm size distribution of the distinguished farm types. The average family labour available for agricultural work is 2.5 man equivalents for each farm type.

Farming systems in the small farm sector are closely related to the traditional three-way pattern of land use in Sri Lanka. The first element of this land use pattern is the cultivation of valley bottoms, usually referred to as *'lowland'*. Paddy is customarily cultivated on these lands under water-logged conditions and is ecologically the most suited crop for such land. The second element is the cultivation of the slopes and the ridges, referred to as *'highland'*. The highland is further subdivided physically into the highland proper and the *'homestead'*. The latter is the third element of the three fold system of land use. The homestead contains the dwelling and a small area under *'mixed crops'*, characteristically referred to as *'homegarden'* crops (Fresco *et al.*, 1990: 73).

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40 The first two are actually existent, the latter has been made up for this study. This settlement scheme comprises lands that are neither part of the private small farm sector nor of the state plantation sector and that are suitable for cultivation.

41 In the 1980-studies the poverty line was considered to be a family income of Rs. 3,600 year^{-1}. Families could make use of the *'food stamp scheme'* if family income was lower (Fresco *et al.*, 1990: 76).

Table 4.1 *Size, number and area of farms per farm type of the small farm sector in the northern zone (Fresco et al., 1990: 74-75).*

Farm class	Size class (ha)	Average size (ha)	Number of holdings no.	%	Total acreage ha	%
Micro holding	0 - 0.5	0.22	1,750	10	380	1
Small holding	0.5 - 2	1.12	13,000	76	14,520	57
Medium holding	2 - 4	2.70	2,000	12	5,400	21
Small estates	4 - 20	13.95	380	2	5,300	21
All classes		1.49	17,130	100	25,600	100

Traditionally, a farm consisted of all three types of components, *i.e.* lowland, highland and homegarden. However, due to an increasing pressure on the land, farms are becoming smaller and some have lost one or two components (Fresco *et al.*, 1990: 73). Table 4.2 presents the land use composition of the distinguished farm types of the small farm sector.

Table 4.2 *Land use composition per farm size class of the small farm sector in the northern zone (Fresco et al., 1990: 75).*

Farm class	Lowland ha	Highland ha	Homestead ha	Total acreage ha
Micro holding	100		280	380
Small holding	2,800	6,100	5,620	14,520
Medium holding	600	3,800	1,000	5,400
Small estates		4,700	600	5,300
All classes	3,500	14,600	7,500	25,600

The **state plantation sector** in the northern zone consists of 14 plantations, totalling an acreage of 2,600 ha. The state plantations are found on the highlands. Tea and rubber are the most common crops. The state plantations are managed by a plantation manager. As a result no family labour is available for agricultural work on the plantation. All labour is supplied by off-plantation sources.

The **settlement scheme** occupies a total acreage of 4,316 ha. It consists of 1,439 settlement holdings of 3 ha each. These holdings are relatively large compared to the *'normal'* size of settlement holdings in Sri Lanka, which is 2 acres (*i.e.* 0.81 ha). However, this *'normal'* size is based on settlement holdings in irrigation schemes while this scheme is rainfed. Moreover, the scheme is comprised of very marginal soils. The settlement scheme consists of both lowland and highland. The average family labour available for agricultural work is 2.5 man equivalents.

4.2 Structure of the regional model with farming systems

In this paragraph we shortly describe how the farming systems were included in the regional model. The regional model with farming systems assumes an aggregate farm approach for the northern zone and an aggregate zonal approach for the other zones. In the northern zone we distinguish six farm type classes. The homogeneous land units of all the farms belonging to a farm type class are aggregated over all farms belonging to that farm class. The same applies to all other relevant resources.

For the central and southern zone the resources within each of the two zones are aggregated over all farms in the zone. There is therefore no difference in the way in which the central and southern zone are incorporated in the regional model and the way they are incorporated in the regional model with farming systems (in the northern zone)[42]. All the changes discussed in this paragraph therefore refer to the northern zone only. The model is developed for the situation in the year 2000.

An overview of the regional model with farming systems is presented in Table 4.3 (pages 42-43). This table attempts to summarize the relationships that exist between the variables, the constraints and the objective function.

Variables

The model consists of 866 variables, being 90 output variables, 30 input variables, 276 labour source variables, 398 land use variables and 72 off-farm labour supply variables.

The **output variables** are again used as pricing activities (see paragraph 2.2). The **input- and labour source variables** are again used as costing activities. Both the pricing and costing activities, however, now distinguish an extra level next to the zonal and regional level, *i.e.* the farm level. This implies that output production and input use is also accounted at the aggregate farm level, *i.e.* for each farm type separately.

The **land use variables** need to be adapted for the incorporation of farming systems. Each LU is considered as a separate resource at the zonal level. However, at the farm level, one particular LU is normally a shared resource by two or more farm types. Therefore, we have to apply a lower aggregation level than the LU level. For this purpose we introduce the *'farm unit'* (FU). A farm unit is considered to be a farm type's share of a particular LU. A particular LU therefore equals the sum of the respective FUs. Each possible combination between a FU and a LUT must be distinguished as a separate activity in the model. Such a combination will from here on be referred to as a *'FULUT'*, *i.e.* a particular FU in combination with a particular LUT.

The land use (or FULUT/LULUT) variables are used as production activities. As such they are the backbone of the model, using inputs (which draw on the regional resources) and producing outputs. The actual costing of inputs and pricing of outputs, however, is again performed by the costing and the pricing activities respectively.

The **off-farm labour supply variables** are an entirely new set of variables that was not included in the regional model. They are used as exchange activities, *i.e.* to allow for labour movement between farm types. They could be used as costing activities, like the labour source variables. However, in our model we assume labour to be mobile within each zone without extra costs.

Constraints

The model consists of 514 constraint rows, being 204 *'balance'* rows, 60 *'informative'* rows and 250 *'real'* constraints.

The *'balance'* rows are again used as accounting rows to equate and transport model components. As such balance rows are required for each component at each level. Distinguishing an extra level (*i.e.* the farm level) therefore requires additional balance rows for each component at that level (*i.e.* for each farm type).

As before, the *'informative'* rows are included in the model only for informative reasons. The informative rows, however, now distinguish an extra level next to the zonal and regional level, *i.e.* the farm level. This implies that the various attributes are also accounted at the aggregate farm level, *i.e.* for each farm type separately.

The *'real'* constraints pose constraints to the model, *i.e.* they limit the allowable space in which the solution is to be found. These *'real'* constraints can be divided into constraints concerning:

- availability of land;

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42 The only exception is the buffalo stock constraint which is set at the regional level in the regional model and at zonal level in the regional model with farming systems.

- availability of labour;
- availability of buffalo;
- availability of irrigation;
- limited markets;
- production quotas.

The aggregate farm approach implies that the constraints concerning the availability of agricultural resources are set at the farm level. The market constraints are again set at the regional level.

In the original regional model we use market constraints to limit production to such a level that the production can be absorbed by the market at a fixed price. The introduction of the farming systems in the regional model, however, presents the problem of how to divide the marketable production over the various farm types. As the model uses exogenously determined fixed prices we cannot use the price mechanism for this purpose. Instead, we make use of artificial interventions in the form of **production quotas**. These production quotas divide the *'allowable'* production for the northern zone over the distinguished farm types. They therefore only apply to those products that are subject to market constraints and are produced in the northern zone, *i.e.* to tea and cinnamon.

'Allowable' zonal production of a product is here considered to be the amount of that product produced in that zone in the regional financial-surplus-plan (see paragraph 2.3). The aggregate zonal production of the product generated by the different farm types may not exceed this allowable zonal production. To achieve this use is made of production quotas. A production quota is here considered to be the allowable farm production of a product on a specific farm type. The sum of all production quotas of a product equals the allowable zonal production.

The problem then still remains how to determine the size of the individual production quotas of both tea and cinnamon for each of the farm types. To calculate the tea production quotas use was made of the following formula:

$$PQ_i = QF * RP_i$$

where:

PQ_i : tea production quota for farm type i;
QF : tea quota factor;
RP_i : *'financially unconstrained'* tea production for farm type i.

The *'financially unconstrained'* tea production of a certain farm type is the amount of tea that specific farm type would produce if:

- all its tea can be marketed without limits at the actual financial farm gate tea price, and
- the sole objective of the farmer in question is the maximization of surplus at actual financial prices.

The *'financially unconstrained'* tea production of each farm type was calculated by solving the actual regional model with farming systems for each individual farm type, however, without the production quotas[43].

The tea quota factor is defined as:

$$QF = \frac{AP}{\Sigma RP_i}$$

where:

QF : tea quota factor;
AP : *'allowable'* zonal tea production;
RP_i : *'financially unconstrained'* tea production for farm type i.

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43 Note that the same regional model (with farming systems) can be used as a zonal model or even as a farm model. This is the result of distinguishing pricing and costing activities at three levels, *i.e.* farm, zone and region. Therefore only the objective function needs to be changed when modelling a lower level than regional. This can easily be done since it only requires placing the prices under the relevant level of pricing and costing activities.

Table 4.3 Overview of the regional model with farming systems.

			Input/output-variables							FULUT-variables			LULUT-variables			Labour source-variables													Off-farm lab. supply-var.			RHS
																MH			...	SS			CE			SO					
			X1	X13	X25	X37	X49	...	X99	X109	...	X246	X299	X304	X444	X507	X519	X531	... ...	X687	X699	X711	X723	X735	X747	X759	X771	X783	...	X843	
			MA	NO	CE	SO	MH	...	SS	MH	...	SS	NO	CE	SO	MH	NO	CE	... ...	SS	NO	CE	CE	NO	SO	SO	CE	MH	...	SS	
Objective function	Y0	Return	PR															-2	...			-2		-2	-2		-2				Maximize
Informative rows	Y1	?????	PR															-2	...			-2		-2	-2		-2				Free
	Y7	NO??????		PR														-2	...			-2									Free
	Y13	CE??????			PR																			-2	-2						Free
	Y19	SO??????				PR																					-2				Free
	Y25	MH??????					PR											-2													Free
	...	....						...											...												...
	Y55	SS??????							PR													-2									Free
Input/output balance	Y61	???CN	-1	1	1	1																									= 0
	Y73	NO???CN		-1			1	...	1																						= 0
	Y85	CE???CN			-1									AN																	= 0
	Y97	SO???CN				-1									AN																= 0
	Y109	MH???CN					-1			AN																					= 0
	....	....						...			...																				... ...
	Y159	SS???CN							-1			AN																			= 0
Land unit constraints	Y169	MHNO??								1																					≤ ?????
	....	......									...																				... ...
	Y214	SSNO??										1																			≤ ?????
	Y230	NO??											1																		≤ ?????
	Y235	CE??												1																	≤ ?????
	Y265	SO??													1																≤ ?????
Labour balance	Y283	MHMD??A								AV						-1	-1	-1													= 0
	....	....									...								...												... ...
	Y343	SSMD??A										AV								-1	-1	-1									= 0
	Y355	CEMD??A												AV									-1	-1	-1						= 0
	Y367	SOMD??A													AV											-1	-1				= 0
Labour constraints	Y379	MHMD??														1												1			≤ ?????
	....	......																	...										...		... ...
	Y444	SSMD??																		1										1	≤ ?????
	Y457	NOMD??															1		...		1			1				-1	...	-1	≤ ?????
	Y470	CEMD??																1	...			1	1				1				≤ ?????
	Y483	SOMD??																							1	1					≤ ?????

		Input/output-variables (MA NO CE SO MH ... SS; X1 X13 X25 X37 X49 ... X99)	FULUT-variables (MH ... SS; X109 ... X246)	LULUT-variables NO X299	LULUT-variables CE X304	LULUT-variables SO X444	Labour source-variables: MH (MH NO CE; X507 X519 X531)	Labour source-variables: ... (... ...; ... ...)	Labour source-variables: SS (SS NO CE; X687 X699 X711)	Labour source-variables: CE (CE NO SO; X723 X735 X747)	Labour source-variables: SO (SO CE; X759 X771)	Off-farm lab. supply-var. (MH ... SS; X783 ... X843)	RHS
Buffalo constraints	Y496 CEBUF				1								≤ 5.758
	Y497 SOBUF					1							≤ 1.300
Irrigation constraints	Y498 CEIRRAR				1								≤ 5.600
	Y499 SOIRRAR					1							≤ 1.300
	Y500 MHTEAQT		AV										= 0
	....		...										... ...
Production quotas & market constraints	Y505 SSTEAQT		AV										= 1.493
	Y506 TRAMARK		AV ... AV		AV	AV							≤27.000
	Y507 MHCINQT		AV										= 0.004
	....		...										... ...
	Y512 SSCINQT		AV										= 0.615
	Y513 CINMARK		AV ... AV		AV	AV							≤ 2.400
	Y514 CURMARK				AV	AV							≤ 1.100

Legend:
- PR: matrix containing prices
- AN: matrix containing annuities
- AV: matrix containing averages
- '1': matrix composed of '1' and '0' elements
- '-1': matrix composed of '-1' and '0' elements
- '-2': matrix composed of '-2' and '0' elements
- ?: wild character ('joker'), meaning that it can take on a certain value (letter or number)
- 'X?': column number of first column of matrix
- 'Y?': row number of first row of matrix

The farm specific tea production quotas are set as equality constraints in order to prevent the model from shifting *'allowable'* production between farm types and/or zones.

The cinnamon production quotas were calculated in a similar manner. There are, however, two major differences.

1. Cinnamon is partly produced in homesteads (*i.e.* by mixed cropping) while all tea is produced in pure stands. This presents a problem in the cases where a farm type produces all its cinnamon by mixed cropping, as is the case for micro holdings. If we apply the cinnamon quota factor to this farm type we would not only reduce its cinnamon production, but at the same time reduce its homestead area. Homestead, however, is a non-optional LUT. As a result the farm type would have no other alternative than leaving part of his homestead area fallow, a clearly unacceptable proposition. To prevent this we spare the micro holdings by using a cinnamon quota factor of unity. The micro holding cinnamon production, however, is still considered to be part of the allowable production. The cinnamon quota factor for the other farm types is thus slightly reduced.
2. Cinnamon production quotas only become relevant once the tea production quotas have been established. Tea is, in the financial-surplus context, the more interesting crop on the good soils. On the marginal soils, unsuitable or only marginally suitable for tea cultivation, cinnamon is the more interesting crop. As long as tea is not subject to production quota, cinnamon remains the *'second best'* crop on the more suitable soils. As a result, the sum of the *'financially unconstrained'* cinnamon production is less than the *'allowable'* production, and hence no quota are required. However, once the tea quota have been established, cinnamon becomes the *'first best'* crop on the more suitable soils. As a result, the sum of the *'financially unconstrained'* cinnamon production rises above the *'allowable'* production, and hence cinnamon production quotas are required.

Objective function

The objective function is the maximization of the surplus at financial prices. This is assumed to generate the regional optimal land use plan as seen in the *'super'*-farmers context. It thereby uses the financial farm gate prices and the actual wage rate. The objective function row is formulated identically to the private-financial objective function of the regional model.

4.3 Results of the regional model with farming systems

In this paragraph the results of the regional model with farming systems are presented. Firstly the return of the optimal solution is presented and disaggregated. Secondly the consequences of the optimal solution for land use, production and employment in the northern zone are presented. Finally various shadow prices are presented.

Optimal solution

The optimization of surplus at financial prices under the constraints given results in an optimal land use plan as seen in the *'super'*-farmers context when considering farm level constraints in the northern zone. The return of this financial-surplus-plan is Rs. $316*10^6$ year^{-1}. The maximization of financial-surplus in the original regional model (*i.e.* without farming systems in the northern zone) led to a return of Rs. $320*10^6$ year^{-1} (see paragraph 2.3). Introducing the farm level constraints in the northern zone therefore has decreased the return with Rs. $4*10^6$ year^{-1}.

Table 4.4 presents the regional and zonal returns of the maximization of financial-surplus in the original model and the model with farming systems. The data clearly show that it is the northern zone that causes the difference between the two plans, as could be expected. The exchange of Rs. $1*10^6$ year^{-1} between the central and the southern zone in the two solutions is the result of a different allocation of the allowable curd production over the two zones. But as curd production is suitability independent this is of no real importance.

Table 4.4 *Regional and zonal returns of the maximization of financial-surplus in the original regional model and the regional model with farming systems.*

	Original regional model Rs. 10^6 year^{-1}	Regional model with farming systems Rs. 10^6 year^{-1}
At the regional level:		
Matara district	320	316
At the zonal level:		
Northern zone	163	159
Central zone	116	115
Southern zone	41	42

The difference of Rs. $4*10^6$ year^{-1} in the northern zone financial-surplus return can be explained by the different acreages of LUTs in this zone in each case. These different acreages of LUTs influence production and the use of labour, fertilizer and other inputs in the northern zone. The consequences of including farming systems for land use, production and the use of labour in the northern zone are discussed hereafter. However, before doing so, we shortly present the financial-surplus return at the farm level, *i.e.* we disaggregate the return of the northern zone to the farm level. Table 4.5 presents the returns of the maximization of financial-surplus in the model with farming systems at the farm level. The same table also gives an indication of the size and composition of the average (agricultural) household income in the optimal plan. The average household income for each farm type lies above the 1980 poverty line of Rs. 3,600 year^{-1} (see footnote 41)[44].

The (agricultural) household income consists of the financial-surplus and the labour income. The labour income, in turn, consists of the on-farm and off-farm labour income. The off-farm labour income is of great importance for the micro and small holdings. These holdings have relatively low land to labour ratios. The off-farm employment provides an attractive alternative to apply the *'slack'* labour.

Consequences of optimal solutions

The optimization of financial-surplus in the original model and the model with farming systems results in two different **land use** plans for the northern zone. These two land use plans are presented in Table 4.6. The same table also presents the division of the LUTs over the different land suitability classes under each plan.

On basis of the acreages occupied, the five most important land uses in the northern zone land use plan **without** farming systems occupy 96 % of total zone area. These land uses are: 1. forest (34 % of zone area); 2. VP tea (25 %); 3. homestead (16 %); 4. coconut (11 %); and 5. cinnamon (10 %). On the other hand, the five most important land uses in the northern zone land use plan **with** farming systems occupy 95 % of total zone area. These land uses are: 1. forest (35 %); 2. VP tea (25 %); 3. homestead (16 %); 4. cinnamon (10 %); and 5. coconut (9 %).

The inclusion of the farming systems in the regional model results in a slight increase in the **VP tea** acreage. The market constraint was however binding in the solution of the original regional model. An increase in the VP tea acreage is therefore only admissible by displacing VP tea from the more suitable lands and cultivating more of the less suitable lands. This is exactly what happens as can be

[44] It should however not be forgotten that the northern zone is the more *'promising'* zone of Matara district, as it produces the lion's share of the two most profitable products and consequently has relatively good employment opportunities. The situation in the two other zones is clearly less *'promising'*.

Table 4.5 *Farm level returns of the maximization of financial-surplus in the regional model with farming systems.*

	Aggregate financial surplus return Rs. 10^6 year^{-1}	Number of holdings	Return per household Rs. year^{-1} Financial surplus return	On-farm labour income	Off-farm labour income	Total income
At the zonal level:						
Northern zone	158.8					
At the farm level:						
Micro holdings	0.4	1,750	217	256	8,201	8,675
Small holdings	58.6	13,000	4,507	4,842	4,533	13,875
Medium holdings	22.3	2,000	11,140	9,375		20,515
Small estates	41.8	380	109,932	9,375		119,307
State plantations	23.9	14	1,709,497			1,709,497
Settlement scheme	11.8	1,439	8,206	8,884		17,090

seen from Table 4.6: the fraction of the total tea acreage that is grown on S2 lands is higher in the regional model with farming systems than in the original model.

This increase in the total tea acreage is a result of the tea production quotas that have been allocated to the various farm types. The use of production quotas reduces the model's ability to move LUTs over the different LUs of the northern zone. Instead the model now can only move LUTs over the different FUs available to each (aggregate) farm type, while being subject to market constraints and production quotas. As a result, in some farm types some of the S1 tea land is used for other purposes than tea cultivation, as the farm types in question have already achieved their tea production quota. On the other hand, in other farm types relatively a lot of S2 tea land is used for tea cultivation, as the farm types in question need to achieve their tea production quota but have no better land available. For the northern zone as a whole the production quotas result in an increase of the tea acreage and a shift of tea to the less suitable S2 soils. The use of production quota therefore allows the approximation of optimal land use plans at the farm level, instead of one optimal land use plan at the zonal level.

A similar reasoning applies to **cinnamon**. The consequences for cinnamon, however, are different: the total cinnamon acreage actually declines as a result of the inclusion of farming systems. The cinnamon market constraint was binding both prior and after the inclusion of the farming systems. The decrease in the cinnamon acreage is therefore a result of displacing cinnamon from the less suitable lands and cultivating more of the better suitable lands. That this is what happens can be seen from Table 4.6: the fraction of the total cinnamon acreage that is grown on S1 lands is higher in the regional model with farming systems than in the original model.

In the original regional plan cinnamon was mainly allocated to the more marginal lands, *i.e.* lands which are marginal to most crops. However, when we distinguish farm types and apply production quotas things start to change. As was already stated in paragraph 4.2, cinnamon can be considered to be the *'second best'* crop, after tea. But after applying tea production quota cinnamon becomes the *'first best'*. If there is no cinnamon market constraint, most lands would be planted with cinnamon. However, there is a market constraint and we apply the cinnamon production quotas to allocate a market share to each of the farm types. As cinnamon is now *'first best'*, all farm types are willing to cultivate cinnamon and they receive a production quota on basis of their *'financially unconstrained'* cinnamon production. But once that these cinnamon production quotas are imposed, the individual farm types are free to determine on what kind of farm land the production quota is produced. As a result, farm types with little marginal land[45] will cultivate cinnamon on these, and only afterwards cultivate cinnamon on the better land until the production quota is reached. They do so since most marginal land is only suitable (in the financial-surplus sense) for cinnamon, *i.e.* not cultivating these

[45] Marginal in the general sense, *i.e.* marginal for most crops and not necessarily for cinnamon.

Table 4.6 *Total acreages of the various LUTs in the northern zone (unit: ha) and the percentage share of each suitability class in the financial-surplus solutions of the original regional model and the regional model with farming systems.*

LUT	Original regional model				Regional model with farming systems			
	ha	S1	S2	S3	ha	S1	S2	S3
VP tea	11,549	94	6		11,806	86	15	
Coconut	4,962	10	56	34	4,386	19	40	41
Cinnamon	4,777	32	68		4,691	38	62	
Irrigated paddy using hand labour								
Irrigated paddy using mechanized traction	200	18	83		200	11	47	42
All irrigated paddy	200	18	83		200	11	47	42
Rainfed paddy using hand labour								
Rainfed paddy using mechanized traction	1,680		100		1,797		100	
All rainfed paddy	1,680		100		1,797		100	
Homestead	7,500				7,500			
Forest	16,122				16,410			
Town	95				95			

lands with cinnamon would leave these lands fallow, while the better lands normally do have other more worthwhile alternatives than leaving the land fallow.

Farm types with a lot of marginal land will also cultivate cinnamon on these. However, the cinnamon production quota is too small to cultivate all the marginal land. Since most marginal land is only suitable (in the financial-surplus sense) for cinnamon this forces them to leave part of these lands fallow.

For the northern zone as a whole the production quotas result in a decrease of the cinnamon acreage (and a shift of cinnamon to more suitable soils) and an increase in the fallow acreage. The latter can be seen in Table 4.6 by the increase in the area under forest (all fallow is assumed to be reforested).

The decrease of the **coconut** acreage is a combined result of the tea and cinnamon production quotas. Coconut can be considered to be the *'third best'* crop in the financial-surplus sense, after tea and cinnamon. As a result, coconut becomes *'interesting'* only after that the production quotas have been imposed on the two *'best'* crops. All suitable coconut lands (*i.e.* S1, S2 or S3 for coconut) will then be planted with coconut. However, the remaining acreage that is suitable for coconut has decreased (when compared to the original regional model) as a result of the increased tea and cinnamon acreage on the better lands. For the northern zone as a whole the production quotas for tea and cinnamon therefore result in a decrease of the coconut acreage.

The inclusion of the farming systems in the regional model results in an increase in the rainfed paddy acreage, while the irrigated paddy acreage is apparently undisturbed. There is, however, a shift in the **irrigated paddy** acreage towards the less suitable soils (see Table 4.6).

In the original regional model there was an irrigation constraint at the zonal level. The model was free to move the available irrigation facilities over the northern LUs. As a result, when maximizing financial-surplus at the regional level, the irrigation facilities were placed on the better soils. When we introduce farming systems, however, irrigation facilities are not freely moveable over the LUs. At the farm level, irrigation facilities are considered to be a fixed resource of the various farm types, and as such are considered to be part of the FUs. The inclusion of irrigation facilities in the FUs reduces the model's ability to move the irrigated paddy based LUTs over the northern LUs. Instead the model now only can decide whether or not to cultivate the irrigated FUs as they stand.

The increase in the **rainfed paddy** acreage is the result of the shift in the irrigated paddy acreage towards the less suitable soils. This shift *'frees'* some S2 rainfed paddy lands, which were under irrigated paddy in the original regional model. These *'freed'* S2 lands are placed under rainfed paddy in the regional model with farming systems, thereby causing the increase in rainfed paddy acreage[46].

The inclusion of the farming systems in the regional model has no influence on the acreage with **homesteads**. All areas considered for homestead based LUTs are placed under homesteads in both plans.

The inclusion of the farming systems in the regional model causes a slight increase of the area under **forests** (see Table 4.6). This increase of 288 ha is caused by the reforestation of the increased acreage of uncultivated land. This reforestation is the net result of:

- an increase of 372 ha in the marginal highland that lies fallow (see discussion on perennials above), and
- a decrease of 84 ha in the marginal lowland that lies fallow (see discussion on paddy above).

The inclusion of the farming systems in the regional model has no influence on the other non-agricultural LUTs.

The inclusion of the farming systems in the regional model has no consequence for the total annual **production** of the products with market constraints (*i.e.* tea and cinnamon). Tea and cinnamon are the most profitable products (in the financial-surplus sense) and total production is achieved through production quotas.

The inclusion of the farming systems in the regional model does have consequences for the total annual production of the products without market constraints, *i.e.* those products that can be marketed without limits. The inclusion has a negative influence in the case of coconut: total annual coconut production decreased with 11% as result of the reduced coconut acreage. The influence is however positive in the case of paddy: total annual paddy production increased with 4%. This increase is the net result of:

- a 2% decrease in total paddy production due to reduced irrigated production (as a result of the shift to the less suitable lands), and
- a 6% increase in total paddy production due to an increased rainfed production (as a result of the increase in rainfed acreage).

The inclusion of the farming systems in the regional model has a slight positive influence on **employment** in the northern zone. The employment is increased with 47,000 mandays year^{-1} or 0.4 % of the original zonal employment. This increase is the net result of:

- an increase in tea labour demand with 94,000 mandays year^{-1} (as a result of the increased tea acreage),
- an increase in rainfed paddy labour demand with 14,000 mandays year^{-1} (as a result of the increased rainfed paddy acreage),
- a decrease in cinnamon labour demand with 8,000 mandays year^{-1} (as a result of the decreased cinnamon acreage),
- a decrease in coconut labour demand with 50,000 mandays year^{-1} (as a result of the decreased coconut acreage), and
- a decrease in irrigated paddy labour demand with 4,000 mandays year^{-1} (as a result of the shift of irrigated paddy towards less suitable lands).

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46 Note that any *'freed'* S3 rainfed paddy lands would remain fallow in a financial-surplus maximizing problem as result of the negative financial-surplus on S3 rainfed paddy lands.

Shadow prices

The **shadow price of a FU** in the financial-surplus solution of the regional model with farming systems represents the surplus at financial prices of the best alternative for that particular FU. These alternatives are dependent on the alternatives available to the farm type to which the FU belongs. Consequently, FUs that belong to the same LU, and therefore have the same physical suitabilities for the different crops, may still have different shadow prices.

E.g.: FU *'SHNO06'* (Small holders northern zone, farm unit 6) has a shadow price of Rs. 2,448 ha^{-1} $year^{-1}$. FU *'MENO06'* (medium holders northern zone, farm unit 6) has a shadow price of Rs. 1,057 ha^{-1} $year^{-1}$. Both these FU are part of the LU *'NO06'* (Northern zone, land unit 6), and therefore have the same physical suitabilities for the different crops. The LU is only suited for perennial crops. Some suitabilities of this LU for the various perennial LUTs are: tea: S2; coconut: S3; and cinnamon: S1. Tea and cinnamon are subject to farm production quota. LUTs producing these two products can therefore in principle not be considered as alternatives, unless tea and cinnamon LUTs on other FUs are displaced.

For the small holdings farm type the most attractive alternative is to displace 1 ha of cinnamon on FU *'SHNO20'* (Small holders northern zone, farm unit 20) with coconut and plant the extra ha of *'SHNO06'* with cinnamon (Some suitabilities of FU *'SHNO20'* are: tea: S2; coconut: S2 and cinnamon: S1). Coconut gives a financial-surplus of Rs. 2,495 ha^{-1} $year^{-1}$ on S2 land. The small holdings monthly labour constraints, however, are binding in the months May, June and October. As a result Rs. 2 $manday^{-1}$ (the so-called *'transportation fee'*) have to be paid for every additional manday used in this period. Since coconut uses 23.3 mandays in these months, a total of Rs. 46.5 $year^{-1}$ transportation costs have to be deducted. This amount deducted from the financial-surplus generated by coconut gives a return of Rs. 2,448 ha^{-1} $year^{-1}$, *i.e.* the shadow price of FU *'SHNO06'*.

For the medium holdings farm type the most attractive alternative is to plant the extra ha of *'MENO06'* with coconut. Coconut gives a financial-surplus of Rs. 1,095 ha^{-1} $year^{-1}$ on S3 land. The medium holdings monthly labour constraints, however, are also binding in the months May, June and October. As a result Rs. 2 $manday^{-1}$ have to be paid for every additional manday used in this period. Coconut uses 18.8 mandays ha^{-1} in these months. A total of Rs. 37.5 $year^{-1}$ transportation costs have to be deducted. This amount deducted from the financial-surplus generated by coconut gives a return of Rs. 1,057 ha^{-1} $year^{-1}$, *i.e.* the shadow price of FU *'MENO06'*.

The micro and small holdings have a permanent excess of on-farm labour. All other farm types, however, have a shortage of labour in at least a couple of months. Casual labour is used to ease this shortage. This casual labour mainly comes from slack labour from the micro and medium holdings and the zonal labour force. However, casual labour sources in the north are insufficient to ease all shortages within the northern zone. As a result central labour has to be attracted in the months May, June and October at the additional expense of Rs. 2 $manday^{-1}$ (the so-called *'transportation fee'*). As a consequence the **shadow price of labour** is also Rs. 2 $manday^{-1}$ in these months for each farm type and the northern zone as a whole.

The central and the southern zone appeared to have a permanent excess supply of labour, *i.e.* none of the central or southern labour constraints was binding. As a consequence the shadow price of labour is Rs. 0 $manday^{-1}$ in these zones (on both a monthly as an annual basis).

All three market constraints are binding in the optimal plan. However, only tea and cinnamon are produced within the northern zone. The inclusion of farming systems in the regional model therefore only influences **the shadow prices of tea and cinnamon**. The shadow price of curd remains uninfluenced (see Table 4.7).

The inclusion of farming systems reduces the alternatives available for tea and cinnamon cultivation. This is a result of the use of production quotas which limit the amount of production in the northern zone. Relaxing the tea or cinnamon market constraint would therefore have no influence on the tea and cinnamon production in the northern zone. Instead, relaxing the market constraints now only influences the production in the central and southern zone. The alternatives available for tea and

Table 4.7 *Shadow prices of the three products subject to market constraints in the financial-surplus solution of the original regional model and the regional model with farming systems.*

Product	Original regional model	Regional model with farming systems
Made tea (Rs. kg^{-1})	2.48	1.95
Cinnamon quills (Rs. kg^{-1})	5.96	3.89
Curd (Rs. l^{-1})	1.63	1.63

cinnamon cultivation in these two zones are however less profitable than those originally available in the northern zone. As a result the shadow prices are lower in the regional model with farming systems than in the original model (see Table 4.7).

The shadow price of tea can be derived as follows. Relaxing the tea constraint would result in a displacement of coconut by VP tea on the LU *'CE04'* (Central zone, land unit 4). This LU is classified as S2 for both LUTs. Financial-surplus for VP tea and coconut on this LU is respectively Rs. 5,969 ha^{-1} $year^{-1}$ and Rs. 2,495 ha^{-1} $year^{-1}$. The net return of an extra hectare of VP tea is therefore Rs. 3,474 ha^{-1} $year^{-1}$. Average VP tea yield on this LU is 1,779 kg made tea ha^{-1} $year^{-1}$. The net return of an extra kg of made tea is therefore Rs. 1.95 kg^{-1} and this is the shadow price of tea. The shadow price of cinnamon can be derived in a similar way.

The production quotas are set as equalities and therefore always are binding. Table 4.8 presents the **shadow prices of the production quotas**. The shadow price of a constraint is based on the consequences of relaxing the constraint in question with one unit. In order to derive the shadow price of the tea production quota[47] we can relax the tea production quotas and analyze what will happen. It is however impossible to increase the tea production quotas under the same market constraint, as this would result in an infeasible problem. It is feasible to reduce the production quotas. Reducing a production quota *'frees'* the same amount of tea from the binding market constraint. This *'freed'* tea can than be taken up for tea cultivation in the central and southern zone. The *'freed'* tea can not be taken up in the northern zone as all tea production in this zone is already subject to tea production quota. The alternatives available for tea cultivation in the central and southern zones, however, are in general less profitable than those originally available on the different farm types. Consequently, moving tea from the northern to the central zone would have a negative impact on the aggregate return.

The shadow price of the tea production quota for the small holdings can be derived as follows. Decreasing this tea production quota would result in a displacement of VP tea by coconut on the FU *'SHNO18'* (Small holders northern zone, farm unit 18). This FU is classified as S1 for both LUTs. Financial-surplus for VP tea and coconut on this FU is respectively Rs. 11,523 ha^{-1} $year^{-1}$ and Rs. 3,895 ha^{-1} $year^{-1}$. The displacement would therefore cause a loss of Rs. 7,628 ha^{-1} $year^{-1}$. The small holdings monthly labour constraints, however, are binding in the months May, June and October. As a result Rs. 2 $manday^{-1}$ (the so-called *'transportation fee'*) are saved for every manday not used in these months. VP tea uses 289 mandays while coconut uses 23.8 mandays in these months. Consequently a total of Rs. 531 $year^{-1}$ transportation costs are saved. For the small holdings the displacement therefore results in a net loss of Rs. 7,097 ha^{-1} $year^{-1}$. Average VP tea yield on this FU is 2,373 kg made tea ha^{-1} $year^{-1}$. The net loss of the deduction of one kg of made tea for the small holdings is therefore Rs. 2.99 kg^{-1}, *i.e.* the small holding shadow price of tea.

However, the reduction of the tea production quota for the small holdings *'frees'* the same amount of tea from the binding market constraint. This *'freed'* tea yields Rs. 1.95 kg^{-1}, *i.e.* the shadow price of the tea market constraint. Consequently, for the region as a whole the shadow price of the

[47] A similar reasoning applies to the shadow price of cinnamon production quotas.

Table 4.8 *Shadow prices of the production quotas in the financial-surplus solution of the regional model with farming systems.*

Farm type	Shadow price tea production quota (Rs. kg^{-1})	Shadow price cinnamon production quota (Rs. kg^{-1})
Small holdings	1.04	-0.56
Medium holdings	0.53	2.33
Small estates	1.04	2.07
State plantations	1.63	-0.56
Settlement scheme	-1.04	2.33

small holdings tea production quota equals Rs. 1.04 kg^{-1} (*i.e.* the farm level shadow price minus the regional shadow price).

Most shadow prices of the tea production quota have a positive value. This implies that the farm level shadow price of tea is higher than the regional shadow price of tea. This is a result of the location of the farm types in the northern zone which in general is more profitable for tea cultivation than the central zone. A notable exception, however, is the settlement scheme. The farm level shadow price is actually lower than the regional shadow price as a result of the relatively marginal soils available to this farm type.

5 CONCLUSIONS

The regional agricultural planning models presented in this study can provide us with *'optimal'* land use plans for the Matara district in Sri Lanka. These land use plans were dependent on the objectives of the planner and the level of analysis. The present study presented three different models:
- a regional model;
- a regional model with multiple criteria analysis; and
- a regional model with farming systems.

An important feature of these models is the inclusion of a differentiated land resource base (79 land units, each with different qualities and different suitabilities, and thus yields, for each crop). The main results of the models will be summarized first. Thereafter, the use of the presented models in land use planning will be discussed, as well as the limitations of these models.

Regional model

The regional model provides us with the *'optimal'* land use plan for Matara district as a whole when the lowest level of analysis is the zone. The *'optimal'* plan is naturally dependent on the objectives of the planner.

Two types of objective function are considered, namely national-economic and private-financial. The national-economic objective function calculates the regional optimal plan as seen in the national-economic context. It thereby uses the economic farm-gate prices and a shadow price of labour. The precise value of the latter is however unknown. Therefore two versions of the national-economic objective function are presented, one assuming the shadow wage rate to be Rs. 15 manday^{-1}, the other assuming it to be Rs. 0 manday^{-1}. These two versions are considered as the maximization of respectively surplus at economic prices and value added at economic prices.

The private-financial objective function calculates the regional optimal plan as seen in the *'super'*-farmers context. It thereby uses the financial farm-gate prices and the actual wage rate. This objective function is considered as the maximization of surplus at financial prices.

The optimization of these objective functions generated three clearly different optimal land use plans. These plans indicate that while optimizing land use, the land use type with the highest gross margin per hectare or with the highest biophysical suitability is not always the *'best'* use of a certain land unit. The *'best'* land use is dependent on the objectives and the constraints imposed.

The difference between the three plans can be explained by considering the differences between the three objective functions. These differences are related to the following factors.

a. The prices used: on the one hand there are the national-economic objective functions which use economic prices, on the other hand there is the private-financial objective function which uses financial prices. There is a clear divergence between economic and financial prices of both inputs and outputs. The divergences are, however, not the same for all inputs and outputs. This causes considerable differences between what is considered to be optimal in the two economic plans and the financial plan.

b. The labour costs charged: on the one hand there is the economic-value added objective function where no labour costs are deducted, on the other hand there are the economic-surplus and the financial-surplus objective functions where all labour costs are valued against the (shadow) wage rate of Rs. 15 manday^{-1}. The maximization of the former objective function clearly will generate a land use plan that is relatively more labour intensive than the land use plans that are generated by the maximization of the latter two objective functions.

The economic-value added objective function gave a return of Rs. 1,019*10^{6} year^{-1} (value added in economic prices, see Table 2.3. Compared to the economic-value added-plan, the economic-surplus and the financial-surplus-plans cause a loss to the economy of respectively Rs. 16*10^{6} year^{-1} and Rs. 72*10^{6} year^{-1} (value added in economic prices).

The financial-surplus objective function, however, gives a return of Rs. 320*10^{6} year^{-1} (surplus in financial prices). This surplus is Rs. 104*10^{6} year^{-1} and Rs. 20*10^{6} year^{-1} higher than the financial-surplus of respectively the economic-value added and the economic-surplus-plans.

The economic-surplus-plan always takes an intermediate position between the economic-value added and financial-surplus-plan, since it uses economic prices (as in the economic-value added-plan) but also assumes a (shadow) wage rate of Rs. 15 manday^{-1} (as in the financial-surplus-plan).

The most striking differences between the economic-value added and the economic-surplus-plan are caused by the following factors.

a. The substitution of rubber by coconut on a large acreage in the economic-surplus-plan, compared to the economic-value added-plan. This change is related to the relatively high labour input for rubber.
b. The substitution of hand labour by animal and mechanized traction power during land preparation in the paddy based LUTs in the economic-surplus-plan, compared to the economic-value added-plan. This change was related to the assumed shadow wage rate. The shadow wage rate of Rs. 15 manday^{-1} in the economic-surplus-plan makes it attractive to use traction power.
c. The withdrawal of LUTs from the more marginal lands in the economic-surplus-plan, compared to the economic-value added-plan.

The differences between the economic-surplus and the financial-surplus-plan are related to the following elements.

a. The complete substitution of rubber by coconut in the financial-surplus-plan, compared to the economic-surplus-plan. This change is related to the more severe taxation of rubber.
b. The considerable reduction of rainfed paddy acreage in the financial-surplus-plan, compared to the economic-surplus-plan. This change is a result of the severe discrepancy between the economic and the financial price of paddy.

Regional model with multiple criteria analysis

In this study we applied a special form of multiple criteria analysis, namely compromise programming. An important reason for this choice was the *'unavailability'* of a decision maker. Compromise programming requires the least assumptions with regard to preferences of a decision maker.

The regional compromise programming model provides us with a range of *'optimal'* land use plans for Matara district as a whole. This range of plans, the so-called *'compromise set'*, is based on the simultaneous maximization of three conflicting attributes, namely:

- value added at economic prices;
- surplus at financial prices; and
- employment.

All the other best-compromise solutions (for the same three attributes and the same weights) fall within this range. As a result, if we:

- aim to simultaneously maximize these three attributes under the constraints imposed by the regional model; and
- find each of the attributes equally important;

we will always achieve:

- a value added at economic prices that lies between Rs. 1,017*10^6 and 920*10^6 year^{-1};
- a surplus at financial prices that lies between Rs. 295*10^6 and 205*10^6 year^{-1}; and
- an employment that lies between 22.5*10^6 and 19.9*10^6 mandays year^{-1}.

The regional model with multiple criteria analysis is especially useful to visualize the scala of consequences of adhering to a set of objectives. On basis of this visualization it is then possible to decide whether to adhere to one's objectives, or whether it is necessary to adjust the weights attached to each objective, or even to adjust the objectives themselves.

It would therefore be worthwhile to experiment further in this regard, *e.g.* by assuming different weights for the different objectives. But it would also be worthwhile to experiment with other forms of multiple criteria analysis. This especially applies to interactive multiple criteria analysis, which opens the possibility of a meaningful interaction between the analyst/planner and the decision maker.

Regional model with farming systems

The regional model with farming systems provides us with the *'optimal'* land use plan as seen in the *'super'*-farmers context when considering farm level constraints in the northern zone.

The return of this plan was Rs. 316*10^6 year^{-1} (surplus in financial prices). The maximization of financial-surplus in the original regional model (*i.e.* without farming systems in the northern zone) led to a return of Rs. 320*10^6 year^{-1}. Introducing the farm level constraints in the northern zone therefore has decreased the return with Rs. $4*10^6$ year^{-1}. This decrease is caused by differences in the land use plan for the northern zone.

The most important differences between the land use plans for the northern zone are the following.

a. An increase in the tea acreage in the with farming systems plan, compared to the original plan. This change is related to the use of tea production quotas, which cause a shift of tea to the less suitable soils.
b. A decrease in the cinnamon acreage in the with farming systems plan, compared to the original plan. This change is related to the use of cinnamon production quotas, which cause a shift of cinnamon to the more suitable soils (associated to the shift of tea to the less suitable soils).
c. A decrease of the coconut acreage in the with farming systems plan, compared to the original plan. This change is related to the use of tea and cinnamon production quotas, which reduce the area available for coconut.
d. An increase in the rainfed paddy acreage in the with farming systems plan, compared to the original plan. This change is related to the shift of the irrigated paddy towards less suitable lands and the *'freeing'* of suitable rainfed paddy soils. The shift is related to the *'fixation'* of the irrigation resource to land units.

The farm types were included to enhance the realism of the model. A major consequence of splitting the northern zone up into six separate farm types is the reduction of resource mobility. Consequently LUTs will be placed not necessarily on the most suitable lands of the region, but on the most suitable lands of a farm.

The labour mobility, however, remains largely present in the present formulation of the model. This is a consequence of allowing inter-farm movement of labour and working with one wage rate within the northern zone. As a result, all slack labour on one farm type can be applied on another without extra costs.

The realism of the model could further be improved by using differentiated farm gate prices instead of the actual pan-regional farm gate prices. The model coefficients now only include the physical land qualities in the form of land suitability evaluation classes. Accessibility, *i.e.* the ability to supply required inputs and to transport output from the cultivation site, is not included. Accessibility can be accounted for in the farm gate price of inputs and outputs. The farm gate price of inputs is than based on the price at some standard supply or sale market location to which is added the cost of movement from that market to the field. The farm gate price of outputs is based on a similar standard price from which is subtracted the cost of movement from the field to the market (Diltz, 1980: 14). These data were however not available for Matara district.

On the use of land use planning models

The land use planning models presented in this study generate optimal land use plans under the variables, the constraints and the objective functions included in each model. But even if each model is formulated conform reality, it will remain impossible to achieve these optimal plans in the real world. This is mainly related to the fact that we can reduce some of the aggregation problems through the way we formulate the model. It is however impossible to eliminate all aggregation problems.

The land use planning models are only meant as an aid to agricultural development planning. The solutions should therefore never be taken too literally. The solutions are meant to indicate the direction of the principal options, as well as their possible consequences for the use of land. They aim to make explicit the kind of major options that exist. Once these options are explicit, they can be used to show the different categories of land users, planners and decision makers what the consequences of their objectives and priorities are. It thereby hopes to improve the quality of the regional planning process.

On the limitations of the models presented

Last but not least, we would like to refer to some additional limitations of the here presented models. Overcoming each of these limitations offers the possibility to improve the present models. This will be attempted in future research.

- Demand for agricultural products and prices

In the present models it is assumed that there is no relation between the quantity of production and the product prices. For most products it is assumed that there is an unlimited demand at a fixed exogenously determined price. However, for three products (tea, cinnamon and curd) demand is strictly fixed. Up to the market limitation the production is absorbed by the market at a fixed price. Above this limitation the production can not be sold. Although there are plausible reasons for modelling the demand side - as a first approximation - in this fashion (see paragraph 2.2), from a theoretical point of view, it would be better to model the demand side with downward slopping curves and with endogenous determined prices. Hazell & Norton (1986, chapters 7, 8 & 9) treat this aspect of sector models extensively, both from a theoretical point of view, as well as providing practical solutions to build such an approach into linear programming models. Incorporation of downward slopping demand curves in the present model will be attempted in a later stage.

Apart from the product prices, the input (fertilizer) and factor prices are also kept constant. In a later stage, model runs will be executed with changing input and factor prices to study the effect of those changes on the use of land, but also in relation to issues of factor substitution (see below).

- Risk

Risk is an important aspect of agricultural production. This especially applies to yields and prices, but also the availability of factors of production is uncertain. The omission of risk is likely to overstate supply responses of farmers as well as the returns to investment, especially in the context of low income agriculture (Hazell & Scandizzo, 1983: 203). Methods to incorporate risks in linear programming models are treated in Hazell & Norton (1986), both under conditions of exogenous determined prices, as well as in the case of downward slopping demand curves. To keep the model simple, no attempt has been made to incorporate risk in the present model. However, this will be done in a later stage.

- Factor substitution

Another important aspect of agricultural production is the use of different technologies for the production of commodities. In practice, each commodity is produced in many different ways. This applies both to the use of inputs and factors of production, as well as to cultivation and husbandry methods. A conventional way of treating different technologies in linear programming models is to define for each technology a separate activity. However, as an important objective of the present study is to model a very differentiated land resource base (79 land units, each with different qualities and different suitabilities, and thus yields, for each crop), it was desirable to limit the number of different technologies to one for each crop (except in the case of tea where two technologies are distinguished and in the case of paddy where six technologies are distinguished). The reason is that for each different land unit a different activity has to be defined for each crop with a specified technology. Therefor, to keep the model small, it was decided not to distinguish different technologies per crop. Nevertheless, because of the different suitabilities with its associated yields for each crop on each of the land units, implicitly, the supply curves are increasing as more land is devoted to a certain crop, reflecting increasing costs per unit of output.

Recently, Celis (1989), in the context of a sector model in Costa Rica, developed a new approach for modelling the substitution of factors of production, for example between labour and capital goods, at an aggregated level. The demand for two factors of production is aggregated over the producers (or a group of producers) of a certain crop. The demand of both factors is then linked to a step-wise linear approximation of a continuous isoquant. If an estimated isoquant is available, Celis (1989: 58-66) designed a procedure to incorporate this isoquant into a linear programming model. If such an isoquant is not available, as would be the case in the present study, a hypothetical isoquant can be generated. Celis (1989: 35-42) also elaborated an algorithm for generating such isoquants. A key aspect of this technique is that it requires only information of the elasticity of factor substitution, the factor use ratio and the factor prices observed at a single point on the hypothetical isoquant (Celis, 1989: 4). If successful, the proposed way of incorporating factor substitution in linear programming models avoids the need to introduce separate activities for each different technology, keeping the size of the model within manageable limits. However, it has to be seen whether this method can be applied under the circumstances of the present case study. This will be researched in the future.

In any case, it will be important to introduce more possibilities in the model for choices between different technologies ('production methods' or 'production techniques') within a land use type. In that way, the model would approach decisions with regard to technical options for the production of a commodity more conform reality.

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