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THE CONSTRUCTION AND USE OF COMPROMISE PROGRAMMING MODELS TO MEASURE THE IMPACT OF DEVELOPMENT POLICIES ON THE SUSTAINABILITY OF PEASANT FARMING SYSTEMS IN CENTRAL CHILE

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To my father

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List of acronyms and abbreviations

AHP	Analytical hierarchic process
CA	Cluster Analysis
CBA	Cost-benefit analysis
CIREN	*Centro de Investigación de Recursos Naturales* (Natural Resource Research Centre)
CONAF	*Corporación Nacional Forestal (*National Forestry Corporation)
CP	Compromise programming
CV	Coefficient of variation
DM	Decision maker
DMI	Dry matter intake
DP	Dynamic programming
FAO	Food and Agriculture Organisation
FIA	*Fundación Fondo de Investigación Agropecuaria* (Agricultural Research Fund)
FS	Farming system
FSM	Farming system model
G	Gini coefficient
GM	Gross margin
GP	Goal programming
HIC	High income countries
ID	Income difference
IMGLP	Interactive multiple-goal linear programming
INDAP	*Instituto de Desarrollo Agropecuario* (Chilean Institute for Agricultural Development)
INIA	*Instituto de Investigaciones Agropecuarias* (Chilean Agricultural Research Institute)
LGP	Lexicographic goal programming
LIC	Low income countries

LP	Linear programming
MCDM	Multiple-criteria decision making
MOP	Multiple-objective programming
MOTAD	Minimisation of total absolute deviations
MPM	Mathematical programming models
MRM	Micro-regional model
NPV	Net present value
PCA	Principal Component Analysis
PM	Policy maker
PO	Productive orientation
RIMISP	*Red Iternacional de Metodologías de Investigación en Sistemas de Producción* (International Network on Farming Systems Research Methods)
RUSLE	Revised Universal Soil Loss Equation
SL	Soil loss
TFP	Total factor productivity
TP	Total productivity
TTP	Technology transfer programme
USLE	Universal Soil Loss Equation
WGP	Weighted goal programming

Abstract

This thesis exploits the multiple criteria decision-making paradigm, particularly compromise programming methods, to examine issues related with sustainable agriculture in the Coastal Mountains of the VIth Region of Chile. Agricultural sustainability is analysed using models which are constructed at two interconnected levels; the higher level is the micro-region which in itself is composed of a set of lower level decision-making models representing typical farming systems in the area. The models are then used to assess the impact of different development policies on agricultural sustainability in the area in the light of main economic, environmental and social objectives.

The study has progressed in three logical phases. First the conceptual models are developed to deal with often conflicting objectives of gross margin maximisation, minimisation of economic risk, and minimisation of soil loss, both for the individual farming systems and for the region as a whole. The second phase involves two main activities: (a) construction of a typology of farming systems using factor and cluster analyses, and (b) selection of eight farms representing the most common farming system types, from which data and information is collected. These data are then used to construct eight farming systems models, which are subsequently brought together to form the micro-regional model. Various validation procedures are carried out to establish the applicability of these models. In the third phase the validated models are used to assess the impact of the government's alternative development policies on the sustainability of farming systems in the area. To test the impact of various policies two types of solutions are computed: those where a single objective is optimised and those which seek a compromise among objectives and hence the associated trade-offs between objectives.

The solutions to the base versions of the micro-regional model indicate that the introduction of strawberries produces the best improvement in gross margin and soil loss, followed by planting eucalyptus with yearly cash payments. The policy of introducing artificial pastures has no impact and planting eucalyptus without a yearly income has only a marginal effect. The trade-offs between objectives is analysed to understand the degree of conflict between objectives. At the farm level, it is seen that each policy has different impact on particular farming systems and that frequently the farms with higher incomes make better use of the new policies. Next an extended micro-regional model is constructed after defining maximum levels for the amount of available labour which can be hired

by the farms and for the area under eucalyptus, strawberries, and artificial pastures. This model is used to evaluate the impact of three policies on gross margin, soil erosion, and distribution of income among farms. The policies are the introduction of eucalyptus with cash payments, the introduction of strawberries, and a combined policy including the previous policies in addition to the introduction of artificial pastures. The largest improvements in the objective functions are achieved when the combined policy is introduced. Further, the inclusion of the objective of minimising income differences allowed an improvement in income distribution compared to the base situation.

The conclusions reached in this research highlight the usefulness of multiple-criteria decision making models for the analysis of sustainability in farming systems and the need of considering the heterogeneity among farms when the impact of local development policies on the farming systems is measured.

1. INTRODUCTION

Since the early 80's the concept of sustainability has become part of the agricultural lexicon. It emerged as a response to the fact that agriculture was having a negative impact on the environment. Agricultural development had previously been concerned almost exclusively with improving the economic performance of farms, with little or no regard for environmental externalities of such a development process, but then it was recognised that agriculture, the human activity that makes use of the biggest share of land and fresh water, was having large negative impacts on the environment. Accelerated soil erosion, soil degradation, salinisation, and water logging were reducing soil productivity; fertilisers were leaking to underground reservoirs affecting drinking water quality; the excessive use of pesticides was affecting natural populations as well as becoming a human health problem; extending agriculture towards new lands meant loss of habitats and bio-diversity; sedimentation and eutrophication were affecting rivers and fresh water bodies. Furthermore these impacts were beyond threshold levels which would guarantee the maintenance of the natural resource base in the long term. As a result organisations and individuals concerned with these issues as well as policy makers began to show an increasing interest in stopping or reversing these processes. The concept of sustainability had emerged and started to become more important in the development agenda.

For some groups sustainability meant that the performance of agricultural systems should be evaluated from a purely environmental perspective, suggesting that environmental soundness (or 'neutrality') was a sufficient condition to define a sustainable system. In other words, only that agriculture which does not alter the environment or which improves the natural resource base can be maintained in the very long term and can thus justifiably be called sustainable. The problem of this approach is that it fails to recognise that agriculture is an economic activity which carries many social and cultural values. Sustainable systems have to be not only environmentally sound, but also economically viable and socially acceptable. Of course the environmental, social, and economic problems have different components and determinants, which vary between farms, regions, and countries.

With this background the improvement of sustainability has to be examined within a systems perspective in which the satisfaction of multiple and often conflicting objectives is required. One problem is how to measure sustainability. There are many indicators for measuring economic performance of a farming system (FS), but not for a situation when a mix of economic, environmental and social considerations are taken into account simultaneously. The relevant question is, can sustainability be measured through a single state variable which measures directly the condition of a particular system or is a set of control variables required? Evidently then multi-criteria decision making (MCDM) methods should provide a convenient tool of analysis, as they are able to evaluate explicitly the 'trade-offs' amongst environmental and economic components.

A second problem is the level of resolution for analysis: lower levels, like field or farm level analyses, are usually not able to cope with the larger political, economic and social environment, while higher levels, regional or national, use aggregated data, and fail to consider the heterogeneity of farming realities as they exist on the ground. An intermediate level of analysis would thus overcome some of these conflicting problems.

This thesis presents an approach to the analysis of the sustainability of peasant agriculture in the coastal dryland of Central Chile, an area in which poverty and soil erosion are the two main problems. This takes the FS as the decision making unit, a micro-region as the higher level of analysis, and the MCDM paradigm as the analytical tool. The methodology so developed is then used to evaluate the effect of a set of development policies on the sustainability of the FSs. As such it acknowledges that sustainability is not achievable *per se*, but that policies are able to direct the systems development towards a sustainable state.

The specific objectives pursued in the thesis are:

i. To develop a framework to analyse the sustainability of peasant farming systems.

ii. To analyse how far the ideas of sustainability can be included into agricultural decision-making models.

iii. To develop a methodology to measure sustainability using MCDM models.

iv. To select some quantifiable features that characterise sustainable agriculture and can be used as criteria for farming systems design and evaluation.

v. To construct a typology of peasant FSs for the micro-region and to use this typology to construct farming system and micro-regional MCDM models.

vi. To use these models both to evaluate and to select development programmes for peasant farmers in this micro-region.

vii. To analyse the impact of various development programmes on different FSs in a micro-region of Chile.

viii. To analyse the 'trade-offs' between different determinants of sustainability.

Such a methodological approach has various stages. It starts with the recognition of the problems and the indicators which can be used to evaluate them. Then relevant FSs have to be identified and representative farms within them have to be selected. With data from these farms and from secondary sources individual FS models (FSMs) are constructed. This set of FSMs is then aggregated into a micro-regional model (MRM), which is finally solved by using some of the most commonly used MCDM techniques.

This thesis is divided into three parts (Figure 1.1). Part One analyses the issue of agricultural sustainability (Chapter 2), its measurement (Chapter 3), and presents the theoretical framework which will be used to analyse the sustainability of peasant FSs (Chapter 4). Part Two deals with methodological issues. It starts with a description of the area under study, its agriculture, and its problems related to sustainability (Chapter 5). A FS typology suitable for the evaluations of sustainability is developed in Chapter 6. In Chapter 7 the algebraic structure of both the FS and the micro-regional models are explained with special reference to their objective functions. This is followed by a description of the data and how it was collected, and with FS model construction, calibration and validation (Chapter 8). In Part Three the results of the models are shown and discussed. First for the base micro-regional model (Chapter 9) and then for an extended micro-regional model (Chapter 10). Finally, the main findings, conclusions and areas for future research are highlighted (Chapter 11).

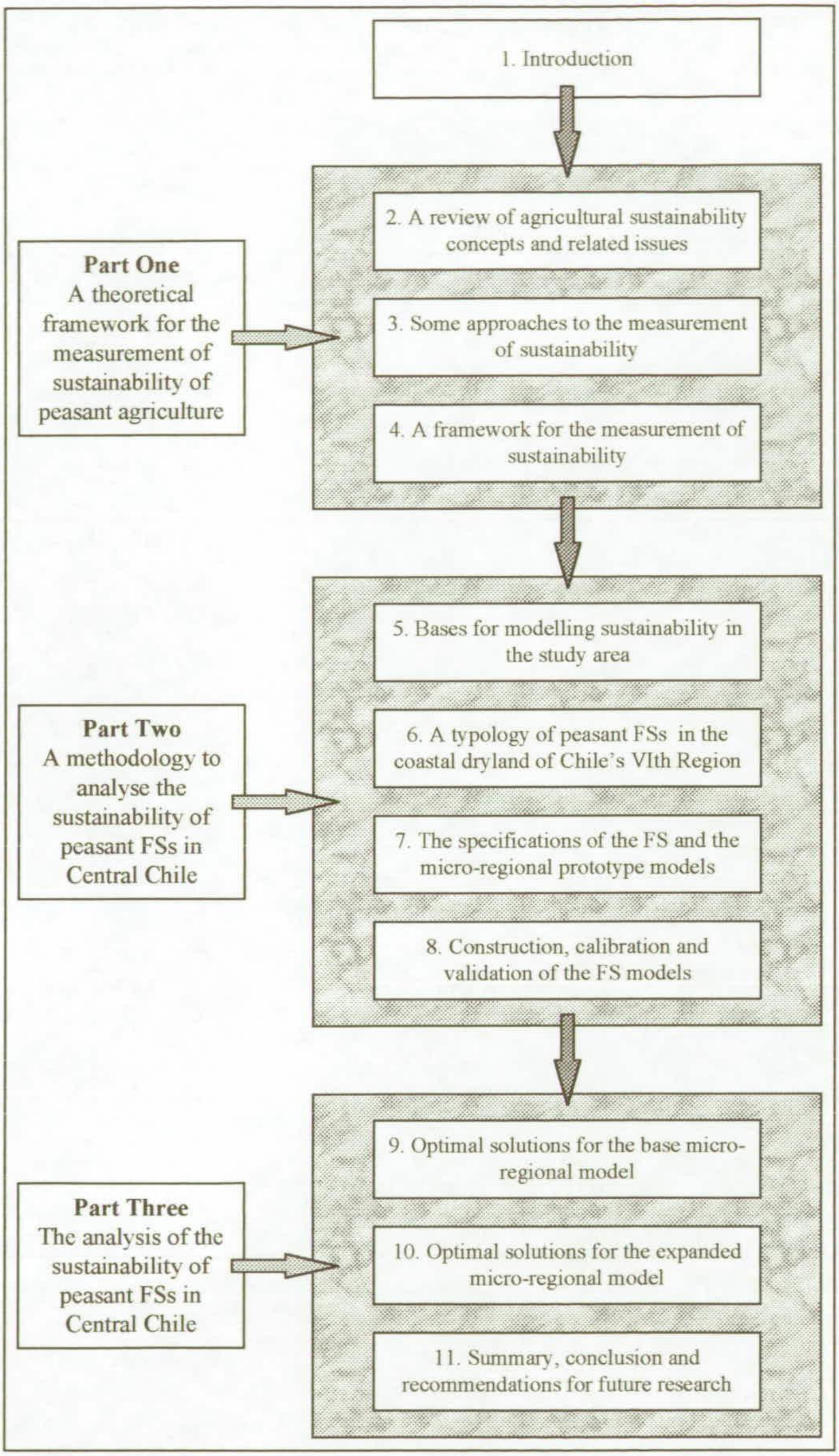

Figure 1.1 Outline and structure of the thesis

PART ONE

A THEORETICAL FRAMEWORK FOR THE MEASUREMENT OF SUSTAINABILITY OF PEASANT AGRICULTURE

2. A REVIEW OF AGRICULTURAL SUSTAINABILITY CONCEPTS AND RELATED ISSUES

2.1 INTRODUCTION

Since the early 80's the concept of sustainability has been increasingly linked to agriculture and its development. It was realised that human activities were reducing the stock of natural resources and as a result the survival of future generations was becoming endangered in both high and low income countries. The emergence of the issue of sustainability produced a paradigmatic shift in the evaluation of agricultural activities. It emphasised that agricultural development could no longer be based solely on one-dimensional economic grounds, but that environmental aspects had to be regarded as equally valid criteria for development.

This chapter aims to give an historic perspective of the issue of agricultural sustainability, to identify its determinants, and to discuss the differences in sustainability issues between high and low income countries. This is followed by a definition of sustainability, highlighting its constituent elements. The chapter ends by discussing the relationship between farming systems and sustainability.

2.2 AGRICULTURAL SUSTAINABILITY

The history of agricultural development, from the point of view of increasing total output, can be divided into two stages. From the moment man domesticated plants and animals, some ten to fifteen thousand years ago, until the end of the past century agriculture had been able to feed and satisfy the needs of an ever growing human population. During this stage as agriculture was essentially a resource-based system the main source for increase in total output was through expansion of the cultivated area (FAO, 1989). Later, as less and less new land was available for agriculture, output could only be increased through higher productivity, i.e. more output using the same amount of land. This required a transformation from a resource-based production system to a science-based system, in which use of external inputs became crucial. This transition began first in high income countries (HICs). In low income countries (LICs) it began as a consequence of the so called Green Revolution of the 1960s and 1970s. At that time, agricultural development thinking was preoccupied with the problem of feeding a rapidly increasing population (Conway and Barbier, 1990). Four elements constitute the Green Revolution (Blake, 1992; Schusky, 1989): use of high yielding varieties obtained through germplasm manipulation, availability of cheap chemical fertilisers, increased use of chemical pesticides, and increased or improved supply of water for agriculture.

The International Agricultural Research Centres engineered the Green Revolution by developing breeding programmes for staple cereals that produced early maturing, day-length insensitive and high yielding varieties, specifically of wheat, maize and rice. These centres also participated in the organisation and distribution of packages of high pay-off inputs, such as fertilisers, pesticides and water regulation. These technical innovations were then implemented in most favourable agro-climatic regions and for those classes of farmers with the best expectations of realising the potential yields (Conway and Barbier, 1990). Its impact on LICs has been phenomenal. From the mid sixties to the mid-eighties, per capita food production in LICs has risen by 7%, and over 27% in Asia alone. Thus the Green Revolution was not only able to respond to the increasing demand for food, but also managed to reduce the gap between demand and supply. As time goes on, these principles become more difficult to achieve. More land is not available, and there is public concern specially in HICs that areas such as the rain-forests of Africa and South America cannot be converted further into arable land. Indiscriminate use of water has increased the salinity of large areas and rivers. The use of chemical pesticides has brought with it the problem of insect resistance and is a threat to human and animal health. Fertilisers can leak into underground waters and run-off towards rivers and streams contaminating drinking water and favouring the eutrophication of water bodies. Finally past genetic improvement cannot be taken for granted to achieve further increases in productivity (Blake, 1992).

Further, it was also realised that this increase in agricultural output produced not only advances in material well being, but has also resulted in degradation of the natural environment and subversion of rural values and institutions (Ruttan, 1990). As an answer to these problems, researchers and developers directed their efforts towards the search for and design of sustainable systems which would not threaten their long term survival. Although these systems should not destroy the limited natural resources, they should also be able to meet an increasing demand for agricultural products[1] (FAO, 1989; Ruttan, 1990; Blake, 1992). These sustainable systems are required for both the modern[2] sector, which can make a disproportionate use of the natural resources if its only objective is profit optimisation, and the traditional sector, which has frequently been forced by external pressures to exploit its resource base in order to survive. For this sector formal and secure property rights as well as institutions, specially those with a traditional base, can be instrumental in promoting the investment in natural resources. Here governments play a major contribution, through the creation of a favourable social and economic climate. But, they have to consider the political cost of lower growth rates and a

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[1] This includes not only demand for food and fibres, but also for clean water and air, and a 'beautiful' countryside.

[2] The modern sector, as opposed to the traditional sector, has adopted capital intensive technologies.

less aggressive modern sector, the effects of liberalisation on both modern and traditional sectors, the fact that policies affect principally the modern sector, actual land tenure system, improvement of rural infrastructure, and the promotion of positive environmental activities and of environmental rehabilitation programmes. Thus from a development point of view, sustainability is not a single sector's problem, but one in which the participation of the modern sector, traditional sector, government and other institutions is essential (Bäck, 1991).

2.3 THE DETERMINANTS OF AGRICULTURAL SUSTAINABILITY

From a purely environmental point of view the problem of agriculture is as old as agriculture itself (Soule, Carré and Jackson, 1990; Cook, 1992). Although the core of the problem has always been soil erosion (and land degradation and sedimentation), new ones have been added. These include problems related to irrigation (salinisation, waterlogging, river and underground aquifers depletion, etc.), chemical contamination (water pollution, food residues, organic waste, etc.), loss of genetic diversity (of wildlife, crops, and livestock), and habitat change (Soule *et al.*, 1990; Tivy, 1990). However, it must be recognised that no agricultural system is inherently either sustainable nor unsustainable; it is the combination of various factors which determine if a system is sustainable or not. Therefore a purely technological focus will not identify why agricultural systems are sustainable (Altieri, 1989; FAO, 1989).

There is a general consensus that the main determinants defining the sustainability of a system are (FAO, 1989; Spencer and Swift, 1992): biological determinants which include conservation of genetic diversity, genetic improvement, pest control, and animal health and nutrition; physical determinants which include soil loss and fertility, irrigation and rainfall, atmospheric pollution, use of agrochemicals, and efficiency in energy use; and social, economic and legal determinants including agricultural development, economic policies for agriculture, infrastructure and markets, inputs and credits, institutions for research, extension and education, land tenure, and laws and regulations affecting the agricultural sector. The relevance of each element depends on local or regional characteristics and thus this concept is likely to be understood in a different way in low and high income countries.

2.4 SUSTAINABLE AGRICULTURE IN HIGH AND LOW INCOME COUNTRIES

There are clear differences when the issue of sustainability in agriculture is analysed from the perspective of high and low income countries (Altieri, 1989; Edwards, 1989). Firstly in HICs it has to deal with the consequences of technologically induced environmental degradation, while in LICs development has not reached resource poor farmers and thus there is a need to match agricultural development with the needs of this sector of society (Altieri, 1989).

In HICs unsatisfied food demand is not a problem, the focus has changed from quantity to quality. There is an increasing demand for food without pesticides, hormones, or other residues, or produced under humanitarian and non polluting systems. In LICs, the main problem is of quantity. Only when an adequate level of production is achieved does some concern for quality arise. LICs have to face the fact that there is a lack of food for the actual population and that this lack will probably increase in the future. This shortage has its roots in the supply as well as in the demand for food (FAO, 1989; Blake, 1992). Three main reasons explain this deficit of food supply. First, more than 60 percent of the population lives in low productivity areas. This has led to deforestation and overgrazing and with it to land degradation and even lower productivity. Second, the surplus production of high productivity areas (i.e. HICs) cannot usually be transferred to other areas, due to its economic and social implications. Third, the continuous urbanisation has led to loss of rural population as well as arable land. In the latter case it quite often happens that this urban nucleus is located precisely on the best arable land. To explain the increase in demand, two main reasons are given. First, the population growth rate is not diminishing, at least in the short and medium term. In fact, the population growth is actually higher than the food production increase. Second, the real increase in income of developing countries is giving rise to a growing middle class, which is continuously increasing its demand for food (Blake, 1992). From the environmental point of view, LICs face the problems of soil erosion, deforestation, salinisation, water logging, etc. In HICs the problems are related to fertiliser and pesticide use, disposal of farm wastes, etc. Also the social dimension is different. In HICs the concern is towards the formulation of policies to keep the countryside as it is, while LICs are mainly concerned with fighting rural poverty and stopping the rural-urban migration.

The research and development consequences of this are that in HICs the search is for neutral technologies, which are assumed to be good for the society and good for the environment. Nevertheless these technologies may be more suitable for the class with capital or political power; they may produce an increased dependence on the private sector; and they may displace small farmers because of the impact of economies of scale (Altieri, 1989). On the other hand, in LICs these technologies have to match the needs of resource poor farmers, as hunger and poverty have been normally perceived more as low production problems than as structural ones. Therefore the approach taken has been to transform the FS into a high production and commercial one, changing first the agronomic practices, then introducing mechanisation and afterwards improved seeds, fertilisers and pesticides (Altieri, 1989).

2.5 AGRICULTURAL SUSTAINABILITY - A WORKING DEFINITION

Sustainability and sustainable agriculture have as many definitions as the number of proponents of these concepts. Economists may define sustainable agriculture as the pursuit of economic growth subject to environmental constraints, whilst for ecologists it is the agriculture that minimises its negative effects on the environment, at a given level of output growth[3] (Ramaswamy and Sanders, 1992). Others call for human activities to be conducted within the limits of environmentally absolute requirements (like water, air, freedom from agro-chemicals), using economics as a tool which helps living within these limits (Hill, 1993). These definitions, despite being conflicting, share the need to minimise the adverse environmental impact of modern agriculture.

Within this variety of definitions and approaches, three broad concepts are discernible. The first concept asserts that agricultural sustainability is the ability to maintain productivity, whether of a field or a farm or a nation, in the face of external forces (or 'resilience' according to Gliessman, 1990), and that agricultural development has to be judged according to the criteria of productivity, stability, equity and sustainability (Conway and Barbier, 1990). The second concept of sustainability, views sustainable agriculture as a production system with 'no-use' or 'low-use' of external inputs (Edwards, 1989; Gliessman, 1990a). These systems have to be able to produce an exportable surplus (i.e. harvested and consumed outside the system) without using large amounts of non-renewable resources. The rationale behind this concept is that every system which uses external inputs in order to be sustainable requires that the resources employed can be maintained in the long run. Modern agriculture, which depends heavily on fossil fuels cannot be sustainable. Organic farming, low-input sustainable

[3] In other productive sectors the definition of sustainability may be quite different. For example for forests sustainability may be measured by the stability of the stand structure and maintenance of a specified residual growing stock (Howard, 1993).

agriculture, agro-ecology, and agro-forestry are all viewed as alternatives to achieve such a sustainability. In this context, the concept of agro-ecosystem has been introduced. It views agriculture as the result of human manipulation and alteration of existing ecosystems. The achievement of sustainable agriculture means developing a sound and a balanced agro-ecosystem. This requires the examination of the interrelationships between structural and functional components, and their restoration if they are unbalanced (Gliessman, 1990a). The third concept looks for practices which reduce the environmental impact of agriculture without necessarily reducing the use of external inputs (Tandon, 1990; Ruttan, 1991; Cook, 1992; Ramaswamy and Sanders, 1992). It recognises the conflict which is central to the issue of sustainability: a reduction of agriculture's environmental impact cannot be achieved without impairing other economic or social objectives. The problem is if sustainable agriculture can have a place where the main concern is food for the next meal, and not the well-being of the next generation (Cook, 1992). This conflict between short and long term objectives is specially important in poorer countries where sustainable agriculture cannot imply subsistence farming or consistently low yields. Instead sound and sustainable high yield systems must be developed (Tandon, 1990), which result from the application of scientific knowledge, technology and good practice (Ruttan, 1990).

It may be argued that during the last years a more consensual view of sustainability has emerged. It recognises that aspects related to plant and animal productivity, environmental quality and ecological soundness, and socio-economic viability have to coincide before sustainable agriculture is possible (Jones, Dyke, Williams, Kiniry, Benson and Griggs, 1991; Neher, 1992). This is precisely the view taken in this thesis: the development of sustainable FSs has to resolve the economic, the environmental, and the social problems. Within this line of thought, the Technical Advisory Committee of the Consultative Group on International Agricultural Research, a group that stems from the Food and Agriculture Organisation (FAO), specified that sustainable agriculture

'... should involve the successful management of resources for agriculture to satisfy changing human needs, while maintaining or enhancing the quality of the environment and conserving the natural resources' (FAO, 1989).

The fact that FAO did not present a precise definition of sustainability, reflects perhaps the problems involved in such a task, when groups of persons, and thus different views, are involved. Although this statement defines a set of necessary conditions to achieve sustainability, it is still an open question what are the sufficient conditions to achieve such a state (assuming that sustainability is an achievable state). According to this approach sustainable agriculture has to address at least three issues: the management of the natural resource, the satisfaction of changing human needs and the intergenerational problem.

First, it must be recognised that the farmer[4] is probably the principal agent who manages the local natural environment (Bäck, 1991). His decisions are thus fundamental in the 'good' or 'bad' use of the natural resources. These decisions are taken considering his objectives and goals, within the restrictions imposed by his wider environment. As long term objectives are secondary to short term survival, every decision concerning the conservation or improvement of his natural environment is only possible if the short term goals are achieved. Therefore, to improve the sustainability of his farm, he must be motivated to manage his resources adequately, without affecting his subsistence and survival. In other words, it is necessary that he shifts the focus from short to long term considerations (Bäck, 1991). Further, sustainability is a global concept which has to be applied on the field, on the farm, on a region, a country and finally the whole globe. This chain implies that in the end, local impacts have global effects (FAO, 1989). As a result the farmer's individual decisions on how to use the natural resources affect the welfare of people benefiting from them. This is specially relevant in the long term where everyone has to assume the consequences of the farmers' decisions, without having the opportunity to influence them. From the existence of such a multiple level

[4] The word farmer makes no distinction between he, she or a household.

system, the farmer and the public each with different objectives, arises a second conflict central to the issue of sustainability itself. Sustainable agriculture then not only has to resolve the conflict between economic and environmental objectives but also the conflict between the objectives of the farmers and of the rest of the community.

Second, the existence of changing human needs and the need to satisfy them gives sustainability a dynamic characteristic. Population growth, income growth and urbanisation are some of the reasons why the demand for land based products is continuously changing, not only in quantity but also in quality and type. In most parts of the LICs traditional FSs have not been able to respond to growth in food demand while in HICs the demand for 'new' environmental goods like countryside preservation, is putting high pressure on farms. As a result, sustainable systems have been transformed into non-sustainable ones.

Finally, although not explicitly, FAO's definition addresses the intergenerational problem. It states that care has to be taken of the environment and the natural resources so that they can be used by future generations. This is an ethical issue. There should be no doubt that the needs of the present population have to be satisfied, but what should be done with future ones? If past generations also misused the world, why should today's generation assume all the guilt? If in the past nobody took care of our well-being, why should we? The reason to do so arises from the different knowledge and consciousness we have of the problem, compared to our ancestors. We do know that the actual environmental damage is important, we do know that it is irreversible (at least under the existing knowledge and technology), and worst of all we do know that it is increasing over time. One author, on discussing the ideas of economics, ethics and environment, concludes that we have a moral obligation to recognise the inviolable rights of future generations, and that such rights are not to be traded (Spash, 1993). An implication of this is that the economic principle of compensation is no longer a valid argument to justify environmental degradation. This principle states that total economic welfare increases from a change in the economy, if those who gain from the change (present generation) could compensate those who lose from it (future generations) to their mutual satisfaction (Bannock, Baxter and Davis, 1992). Such compensations can be implicit in Pigouvian taxes (based on polluter pays principle) and in discount rates (Section 3.2.3).

2.6 THE FARMING SYSTEM'S APPROACH AND SUSTAINABLE AGRICULTURE

Most of the approaches proposed to analyse agricultural sustainability call for a systems approach. For example, agro-ecology emphasises a systems framework for the transformation of productive potentials into sustainable livelihoods, focusing both on bio-physical and socio-economic constraints on production and using the agro-ecosystem or the region as the basic unit of analysis (Altieri, 1989). Other authors conclude that an integrated approach, based on systems analysis and mathematical programming is a necessary step in the achievement of sustainability (Yin and Pierce, 1993). Further, as the problem of sustainability involves economic, environmental and social aspects, it calls for an interdisciplinary analysis (Neher, 1992), which is also a common feature of FS analysis. It seems reasonable therefore to follow this system's perspective instead of a reductionist or discipline specific approach. In what follows a short introduction to systems thinking is given and its relationship with agriculture is highlighted.

2.6.1 SYSTEMS THINKING AND AGRICULTURE

Systems thinking emerged in the biological sciences during the late 20's with the work of Von Bertalanffy. He suggested abandoning the traditional reductionism in science for a systemic thinking in which organisms had to be seen as entities whose parts interact dynamically. The simple idea behind this change is that the whole is more than the addition of its parts (von Bertalanffy, 1973). However, it should be kept in mind that reductionism is a necessary complement to a systems approach, and that there is a risk that measurable factors are given a greater importance than elements which are difficult to define or value (Beveridge, 1980). Later, and probably as a result of a critical revision of the impact of the Green Revolution on small farmers in Asia, Latin America, and Africa this framework was introduced into agriculture. The Farming Systems' Research and Extension approach tried to overcome the inability of conventional research to develop technologies appropriate to small farmers' economic and social environment (Escobar and Berdegué, 1990). The systems thinking recognised that a FS must be understood before attempting to influence it in a predictable manner (Spedding, 1988). According to the same author,

> *'A system is a group of interacting components, operating together for a common purpose, capable of reacting as a whole to external stimuli: it is unaffected directly by its own outputs and has a specified boundary based on the inclusion of all significant feedback' (p. 18).*

Thus a FS was seen as the totality of production and consumption decisions of the farm-household, including the choice of crop, livestock, off-farm enterprises and food consumed by the household. Such a definition implied that specific production practices were often the result of decisions made for the FS as a whole, and therefore planning technologies for a specific enterprise required knowledge of interactions in the FS which potentially influenced that enterprise (Byerlee, Collinson, Perrin, Winkelmann, Biggs, Moscardi, Martinez, Harrington and Benjamin, 1980). However, the study of the whole system *per se* is not a guarantee for rapid improvement of production or achievement of development objectives. It only attempts to avoid mistakes done by fragmented research and advice (Wadsworth, 1983).

Different frameworks have been developed for the study of systems. One of them, considers that a system has five constituent elements: the resources, the environment (physical, biological, economic, social, etc.), the enterprises or elements, the manager (decision maker) and his objectives (Churchman, 1968). Accordingly a FS has to be viewed as an arrangement of enterprises managed within an environment and in accordance with the household's objectives and resources. This framework recognises that a system has an important non tangible ('soft') component: objectives.

2.6.2 THE FARMING SYSTEM'S MANAGEMENT

In a FS the management is represented by the farmer, who defines the system's objectives and goals, allocating the available resources and controlling the system's performance. Management itself is a process of constant adaptation to its external and internal realities, because the environment as well as the household are continuously changing. It is precisely the need for reducing the environmental impact of agriculture, through the addition of new practices or the modification of existing ones, which is putting an increased requirement for managerial skills on the FSs (Edwards, 1989; Tandon, 1990). For example diversification, which is a common topic in practices linked to sustainable agriculture, like agro-ecology, agro-forestry, or organic agriculture, is one reason why better managerial abilities are required to develop sustainable FSs.

2.6.3 THE FARMING SYSTEM'S OBJECTIVES

Objectives, sometimes also referred to as goals, are 'ends or states in which the individual desires to be or things he wishes to accomplish'. They are based on values, 'a conception of the desirable referring to any aspect of a situation, object or event that has a preferential implication of being good or bad, right or wrong' (Gasson, 1973).

Many authors have studied farmers' values, objectives, and goals, mainly in high income countries, finding that those with an economic basis and those focused on social and lifestyle concerns were predominant (Fairweather and Keating, 1994). But the importance of environmental aspects in this type of study has been changing during the last years. For example Gasson (1973) interviewed groups of English farmers and classified their values according to four orientations: instrumental, when farming is viewed as a means to achieve an end; social, when the importance of farming is given by the interpersonal relationships which can be made; <u>expressive</u>, when it is viewed as a means of personal fulfilment or self expression; or <u>intrinsic</u>, when farming is valued as an activity in its own right. This list includes economic and social aspects, but only the preference for a healthy, outdoor, farming life (intrinsic value) and safeguarding income for the future can be linked in some way with environmental concern. Similarly, another study determined that the short, intermediate, and long run decision making behaviour of Danish farmers was based on economic objectives, without mentioning any environmental aspects (Jacobsen, 1993).

The results of these and other studies encourage the belief that the farmer is not worried about the environmental impact of his activities, but this is not necessarily true, as it is possible that the researcher is biased towards the analysis of economic objectives. In fact some studies on farmers' objectives and goals did not consider environmental issues during data collection (Hatch, Harman and Eidman, 1974; Harper and Eastman, 1980; Kliebenstein, Barrett, Heffernan and Kirtley, 1980; Perkin and Rehman, 1994). Nevertheless more recent studies have found that the farmers show environmental concern. One study grouped New-Zealand farmers into management styles according to the ranking of a set of 45 goal statements, and determined that one style was the environmentalist (Fairweather and Keating, 1994). Another study established that Scottish farmers were primarily concerned with improving the quality of the land, the environment and their way of life (McGregor, Willock, Dent, Deary, Sutherland, Gibson, Morgan and Grieve, 1995).

Finally, objectives have also been classified according to empirical categories. One such study classified the objectives of a FS in four groups (Reijntjes, Haverkort and Waters-Bayer, 1992):

i. *Productivity*: Measures the economic viability, considering market values, and the household's needs for consumption, health, housing, education, etc.
ii. *Security*: Also one of economic viability, it means minimising risk of production or income losses resulting from variations in ecological, economic,

or social processes. This group of objectives is specially important for farmers in LICs, who, lacking alternative activities or sources of income, depend on the survival of their enterprise.

iii. *Continuity*: It reflects the environmental sustainability of the system. To maintain the potential of the farm is a traditional objective, which has changed only due to external or internal pressures.

iv. *Identity*: These objectives relate to social and personal aspects of agriculture, e.g. preferences, status, traditions, norms, and landscape conservation are all part of it.

For the purposes of this study, it can be seen that the first two groups are related to the economic problem of sustainability, the third to the environmental problem and the last one to the social problem. Two difficulties arise from the existence of such sets of multiple objectives. First, some of these objectives are conflicting, and trade-offs or opportunity costs between them exist. Second, only productivity and security objectives are more or less easy to measure or to include into hard system approaches. Continuity and identity objectives are soft objectives and thus complex and difficult to measure or quantify. It is possible to express productivity or security through simple or composite indicators, like total output, or profit and its variance; but this is more difficult for the other groups of objectives.

2.6.4 THE FARMING SYSTEM'S ENVIRONMENT AND RESOURCES

The natural, political, legal, economic, social, and cultural environment define the system's fixed constraints. The characteristics of the natural environment determine the space and production boundaries within which the manager has to produce (Andreae, 1981). The economic environment affects prices and thus income and costs, as well as the availability of capital. The political and legal environment affect the economic environment, the development opportunities and sometimes the productive structure. The social and cultural environment have a great effect upon the households' structure, values, norms and traditions. Finally, the resources available to the system, i.e. land, labour, and capital, are very important when the question is asked how the sustainability of a FS will be improved. For resource poor farmers the only factor available for soil conservation is labour, because access to capital, additional land, or technology is normally limited. As a result the effectiveness of soil conservation programmes will depend heavily on labour availability. The technical appropriateness of these programmes has to consider labour requirements and availability, while their economic appraisal has to establish social and private trade-offs using cost-benefit analysis on return to labour, capital and land (Stocking and Abel, 1992).

2.7 Summary

In this chapter general aspects related to sustainability were discussed. It was shown that two conflicts were central to it. The first is the conflict between economic, environmental, and social aspects. The economic problem is related to the provision of food, fibre, wood, fuel, and all sorts of agricultural products. It aims to satisfy not only the needs of the farmer and his household, but also those of urban dwellers and other rural communities. The environmental problem arises from the fact that agriculture is an activity based on the use of natural resources. Thus, it has impacts on the environment as has the environment on agriculture. These impacts are not confined to the farm or local level, they also have regional and global implications. Finally, the social problem considers all human aspects related to living on the farm and the values represented by rural life. It has to do with agriculture or farming as a way of life, its cultural and traditional values and norms. The simultaneous consideration of these three problems limits the possibilities of improving productivity to satisfy increasing human needs. This can only be achieved if the resources are used together with science, technology and good practice (Ruttan, 1990). There is also no prejudice against the use of external inputs or high input technology, as long as it respects the long term objective of being sustainable. It agrees with the view that for many farm-households (especially resource poor) the phrase Low-Input, Sustainable Agriculture, frequently translates into High-

Cost, Unsustainable-Livelihoods (Low, 1993). The second conflict originates from the existence of two levels which take decisions on how the natural resources are used. At the higher level, policy makers representing the wider public define or affect the economic and legal environment within which the farmers (the second and lower level) take their decisions on how to use the natural resources. The objectives of both groups are not necessarily the same, and frequently trade-offs between these objectives exist.

Therefore, the development of sustainable agriculture needs to resolve or at least consider these conflicts, as a balance between these aspects has to be reached if any new, different or improved production systems have any chance of succeeding. It was further shown, that this resolution can only be achieved within a farming systems perspective, in which the combination of farm and household constitute the basic unit of analysis, instead of just any particular activity. The systems approach recognises that the relationships between parts of a farm are as important as the parts themselves; therefore, the measurement and analysis of the impact of development policies on the sustainability of a given area has to be based on a FS, as the modification of any constituent element has far reaching consequences within it. This three dimensional (economic, environmental, social) and bi-level (farmer-policy maker) framework will be used throughout this thesis to analyse the problem of sustainability in peasant farming systems.

In the next chapter the problem of measuring sustainability will be discussed, making special reference to methods which try to take into account the multiple factors which affect sustainability.

3. SOME APPROACHES TO THE MEASUREMENT OF AGRICULTURAL SUSTAINABILITY

3.1 INTRODUCTION

One important issue related to sustainability is how to measure it, i.e. how shall a value or a set of values be constructed or calculated to determine the sustainability of a system. The purpose is to determine if a system is sustainable, which system is more sustainable, what are the trade-offs between alternative practices, if sustainability is changing, and what is its sensitivity to changes in its determinants (Harrington, 1992). Even FAO (1989) after defining sustainability and its determinants, fails to provide an indicator or even a procedure to be used to determine if a FS is sustainable.

There are many indicators to measure economic performance of a FS, like profit, gross margin, net farm income, and management or investment income. From a mixed economic and environmental point of view, this issue is more complex because of the different definitions of sustainability. It can for example refer to an increase in production together with resource maintenance (sustainability in its widest sense), the availability of natural resources and their change over time (environmental sustainability), or the resilience of the system (agro-ecological sustainability). For any of these views the question arises if there is any single measure for sustainability, or if a set of measures has to be used. This is the question of measuring sustainability by means of a single state variable or a set of control variables (Harrington, 1992).

A state variable measures directly the condition or state of the parameter (i.e. sustainability). Now, as sustainability was defined in Chapter 2 as being built upon three components (production, environment, society) it is necessary that the state variable includes them all. But, it is difficult to visualise a single variable which enables the measurement of the condition of all three components. The alternative of using a state variable which is a composite of variables measuring each component raises further problems. First how is each of the components measured, considering that it also has multiple determinants, that these differ between FS, and that they change over time. Second if a value for each component is found, how will they be combined to obtain a single value for sustainability, i.e. which is the function with the best fit between sustainability and the three components.

As these two problems have not been overcome, an estimate of sustainability has been made through the use of control variables. In agriculture the variables that have been used frequently are: gross margin (GM) and its variation to measure economic performance; soil loss, use of agro-chemicals and Nitrogen leakage to measure the impact on the environment; and a wide range of qualitative variables to characterise the social problem.

Further decisions that have to be taken when measuring sustainability are if the measurement will be discreet or continuous, if the indicator will be qualitative or quantitative, and if the sustainability will be analysed for part or the whole of the system (Harrington, 1992).

Some major methods for evaluating sustainability such as productivity, cost-benefit analysis and mathematical programming models (or MPMs) and the problem of time when measuring sustainability are discussed in this chapter.

3.2 METHODS USED TO MEASURE SUSTAINABILITY

Any method aiming to measure the sustainability of a given system needs to specify the system level, to define the outputs, and to define the time period of concern (Lynam and Herdt, 1989). During the last decades much effort has been put into developing or modifying procedures to evaluate systems from a mixed economic and environmental (and sometimes social) point of view. Their main shortcoming is that although they can be used to measure the sustainability of a given system, frequently they were not developed for that purpose and do not give a precise and unambiguous definition of sustainability. Some of these methods are discussed below.

3.2.1 TOTAL FACTOR PRODUCTIVITY AND RELATED MEASURES

These approaches relate sustainability with the systems' output over time, i.e. input/output coefficients are used as sustainability estimators. Under these approaches a sufficient condition for a system to be sustainable is that it has a non-negative trend in factor productivity over the period of concern.

One such input/output coefficient is total factor productivity (TFP) which is defined as the total value of all output produced by the system during one cycle, divided by the total value of all inputs used by the system during that cycle (Lynam and Herdt, 1989). The theoretical basis of this concept is that sustainability is understood as the capacity of a system to maintain output at a level approximately equal to or greater than its historical average. Total output should include also by-products.

A more general measure is total productivity or TP (Harrington, Jones and Winograd, 1994), which differs from TFP in that the denominator includes both off-farm and environmental costs and benefits.

$$TP = Y / (C + F + X + E)$$

where Y is the total value of outputs, including by-products; C are the short term economic costs, including opportunity costs of the farmer's own resources; F are the long term economic costs, including user costs; X are the off-farm economic costs; and E are the environmental costs. All these values should be expressed in terms of social costs, i.e. excluding any price distortion induced by current policies (Spencer and Swift, 1992).

Other indicators derived from TFP are inter-temporal TFP and inter-spatial TFP (Ehui and Spencer, 1993). In this case TFP includes the unpriced contributions from natural resources and their unpriced production flows. The former evaluates changes in one system between periods of time and the latter compares one system over another at a given period of time.

Drawbacks of these approaches are the enormous amount of information required, the overestimation of sustainability when there is a quick technological change, the assumption that environmental values may be compared to economic ones, and that past trends do not necessarily reflect future ones (Harrington *et al.*, 1994).

TFP should also be able to distinguish between yield change due to change in input use, yield change due to technological change, and reductions in TFP due to resource degradation (Harrington, 1992). If TFP is linked to a production function, it will be able to account for the effects of increased input levels on output.

3.2.2 Sustainability Indicators

One of the most common ways of measuring sustainability is through the use of a set of indicators or control variables, i.e. measurable variables which are related to the system's sustainability, or through the development of a function which computes a state variable (i.e. sustainability) from a set of control variables. Both of them evaluate and monitor the performance of a given system.

Examples of indicators used as control variables are:

i. Indicators of environmental quality and ecological soundness, productivity, and socio-economic level (Neher, 1992)

ii. Agro-environmental indicators to evaluate trends of environmental importance, agriculture-environment impacts, and agricultural and environmental policy and market interactions (Parris, 1994)
iii. Indicators of ecosystem characteristics, like nutrient cycling, energy flow, population dynamics, species interactions, and habitat modification (Gliessman, 1990a; Gliessman, 1990b; Trenbath, Conway and Craig, 1990)
iv. Ecological, social/cultural/political, and economic indicators of sustainability at household and community levels (FARM, 1996)

The problem of these control variables is that only when one system dominates another in the Paretian sense (i.e. equally 'good' in all indicators and 'better' in at least one of them), is it possible to say that the sustainability of a system has been improved. Further, the use of a set of indicators allows the reduction of the information on any of the determinants of sustainability to a few values, but these will continue to be conflicting and trade-off between them will exist. The only way to deal with the trade-off between any pair of indicators is given by MCDM methods.

To overcome the problem of comparability, a function can be developed which transforms the set of control variables into a single state variable. For example:

i. Approximated sustainability index, based on the aggregation of indicators of productivity, equity, resilience and stability (Gutierrez-Espeleta, 1993)
ii. Index of ecological sustainability which is a function of external inputs, energy ratio, power equivalents, efficiency of solar flux use, and residence times of soil and biota (Senanayake, 1991)
iii. Sustainability coefficient which is a function of the output per that unit input which maximises the per capita productivity or profit, of the output per unit decline in the most limiting or non-renewable resource, and of the minimum assured output (Lal, 1991)
iv. Environmental sustainability index defined for a homogenous management unit and based on the aggregation of indicators on productivity, stability and

degradativity[1], integrated over a particular increment of time (Sands and Podmore, 1994)

Such an approach still has some drawbacks. The first is to establish the function which gives the best fit between the control variables and the unknown state variable. Second, the aggregation of values in a single indicator can hide extreme values in one component, unless threshold levels are used. And third, the trade-offs between determinants are not made explicit and can therefore not be considered in the analysis of sustainability.

Considerable effort has been put into the development of indicators of sustainability, but the multi-factor causality behind sustainability determines that their use is limited to the circumstances and area for which it was developed. The literature on indicators of sustainability may help to establish guidelines for the construction of indices or the selection of variables, but would probably not be able to provide the answer appropriate for a specific problem. It is not possible to use a universal function to measure sustainability.

3.2.3 COST-BENEFIT ANALYSIS

Cost-benefit analysis (CBA) is a tool frequently used to asses the economic performance of systems (farms) or sub-systems (crops, livestock). CBA computes the difference between all measurable and relevant costs and benefits of a given decision over a specific planning horizon. CBA is one of the most used discounting techniques which, using the concept of economic efficiency, searches for a maximum difference between benefits and costs (Pearce, Barbier and Markandya, 1990). Probably the most powerful argument for its use is that the discounting process can handle quite easily the timing of the cost and benefit flows. Four economic arguments are usually given to justify discounting (Pearce *et al.*, 1990):

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[1] The degree to which the agricultural system reduces or potentially reduces the quality of the surrounding environment.

i. Due to pure time preferences people prefer today's certain consumption or money to future expectations. But, this is not necessarily true if we consider the objective of lifetime welfare maximisation. It also does not have implications for policies because real needs matter, and not future or expected ones.

ii. Risk and uncertainty reduce the value of future benefits, principally due to the risk of death and change of needs. But, society is not mortal in the same sense and the fundamental basic needs (housing, food, etc.) do not change. Also, the use of a compounded discounting procedure suggests that uncertainty increases exponentially with time, but there is no reason to believe that the risk factor takes this particular form.

iii. Due to diminishing marginal utility of consumption, which only holds if there is a sustainable increase in consumption. Usually a vicious circle exists, by which poverty induces a high time preference, favouring environmental degradation, and with it bringing more poverty.

iv. Due to the opportunity cost of capital, assuming that it can be reinvested and that it is possible to compensate the future sufferers of the environmental damage.

Biases in the estimation of the net present value (NPV) may arise from using expected values of stochastic variables to calculate an expected NPV, valuation biases caused by failing to consider potential bankruptcy effects, failing to consider embedded risk, and neglecting consideration of the possible irreversibility of investment decisions and the option to postpone decisions until more information is available (Hanf and Collins, 1996).

Although CBA is not a method to measure sustainability itself, during the last years it has been extended to include considerations of environmental costs and benefits (Pearce *et al*., 1990; Bojö, 1992; Johnsen, 1993; de Janvry and Santos, 1994; Hughes, Butcher, Jaradat and Penaranda, 1995). From this environmental perspective, a general cost/benefit rule is (Pearce *et al*., 1990):

$$\sum_{t=1}^{n}\left[(B_t - C_t - E_t) * d^{-t}\right] > 0$$

where B_t are the benefits on period t; C_t are the costs on period t; E_t are the environmental costs in period t; and d is the discount rate.

This means the sum of discounted benefits less its costs (i.e. NPV) has to be positive. By using discount rates, both consumers and producers treat the future as less important than the present. This means that the distant future is almost valueless. To avoid environmental degradation under this setting, two positions exist. First a sustainability constraint is included in the rule (Pearce *et al.*, 1990):

i. Strong sustainability: In every period the environmental costs have to be positive,

   $E_t > 0$ for every t

ii. Weak sustainability: The sum of the environmental costs over all the periods is greater than zero. Thus some periods can have damage, provided there are some which compensate for it,

   $\sum E_t > 0$

As any of these is difficult to achieve, they can be modified to represent a portfolio of projects, with some compensating the damage made by others.

The second is to adjust the discount rate, but, if any adjustment is made, then it has to deal with the problems of (i) environmental risk, for which certainty equivalents can be used; (ii) irreversibility of the development actions, but no-development is reversible; (iii) justice with future generations, not discriminating against them; and (iv) the intergenerational problem (Pearce *et al.*, 1990).

There are many arguments against the use of CBA for the evaluation of the impact of any activity on the environment. The most important is that unless sustainability constraints are included into the rule, a positive NPV does not mean that the environmental costs are minimal, nil or even negative (i.e. environmental benefit). It only implies that the benefits are enough to pay for this impact. But, the fact that the damage done is less than the compensation made, does not license society to infringe this damage (Spash, 1993).

The second argument relates to the selection of the discount rate[2] which determines the present value of future money flows. Its selection is not only an economic question, but also a philosophical one, in which four attitudes exist (Spash, 1993):

i. *There is no moral obligation beyond the immediate future*, thus the social discount rate is infinite and the present value of future flows of money is zero.

ii. *There is a moral obligation towards future generations, but the future is less important than the present*. Accordingly, the social discount rate is greater than zero but lower than infinite, and the present value of future money decreases with time. Such a discount rate implies that the future matters, but the degree of concern is indirectly proportional to the discount rate used, i.e. a higher rate means less importance. Some justifications for using this type of discount rate are that the temporal location of our descendants disqualifies them from equal treatment with the current generation; that we should restrict our attention to the aspects of our actions for which preferences are known and exclude unknown future preferences; that because the human race will at some stage become extinct, more consumption today prevents potential resource wastage tomorrow; and that we cannot be sure that people in the distant future will want or need the resource we have saved for them.

iii. *The rights and claims of the future and the present are the same*, and the discount rate must be zero. It implies that the future and present value of any fund flow is the same.

[2] Almost as a rule, when some discounting technique is used little justification of the selection of the discount rate is given by the authors. This fact was also found in the mathematical programming models reviewed in the next section which have used discounting techniques.

iv. *The moral obligation with the future is even more important than with the present.* In this case the discount rate is negative, and the present value of future flows increases as time increases.

Other arguments against the use of CBA are that monetary measurement is unethical, because money is considered as an end; monetary measurement is not practical, but possible; CBA poses the risk of overemphasising the quantifiable; CBA can hide conflicts, because it aggregates across individuals; and that results can be manipulated (Bojö, 1992). Also, CBA does not consider non-use value, thus it underestimates the benefits of natural capital preservation (Pearce *et al.*, 1990).

From a practical point of view, CBA requires the establishment of a 'with the project' versus a 'without the project' situation, which requires substantial knowledge of the relation between resource base and output. This weakness can be overcome through the use of sensitivity analysis (Bojö, 1992).

3.2.4 MATHEMATICAL PROGRAMMING MODELS FOR ECONOMIC AND ENVIRONMENTAL EVALUATION

During the last years a number of studies have used MPMs to solve problems related to natural resource management (Romero and Rehman, 1987) or related to environmental quality control (Greenberg, 1995). In these models a set of linear equations is used to characterise the relationships between elements of the system. The model is then optimised according to one criterion as in Linear Programming (LP) or a set of normally conflicting criteria as in MCDM models, and using a given resolution algorithm[3].

The extent of the use of MPMs for the analysis of economic-environmental issues was also appreciated at the VIIIth Congress of the European Association of Agricultural Economists (Edinburgh, Scotland, 1996). Of over 20 studies which

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[3] A review of MCDM methods used in agricultural decision making can be found in Romero and Rehman (1985).

used such models twelve (57%) dealt with economic-environmental issues. These 12 studies were part of a total of 29 presentations which analysed in some way the environmental impact of agriculture.

MPMs are well suited for environmental-economic research, because many activities and restrictions can be considered simultaneously, an explicit and efficient optimum seeking procedure is involved, results from changing variables (parameters) can be calculated, and new production techniques can be incorporated (Wossink, de Koeijer and Renkema, 1992).

3.2.4.1 Linear programming models for economic and environmental evaluation

Within a single criteria framework LP models have been used to analyse the impact of technological and institutional changes at both the farm and the regional level (Table 3.1). Technological change may arise from the introduction of new or the modification of existing production activities (crops or livestock), while institutional change affects principally available resources and the wider environment.

LP has been used to establish optimal farm plans, i.e. the combination of activities which gives the optimal value for the given objective function. One paper used such an LP model of Nepalese hill farmers (Shakya and Leuschner, 1990). In this model four productive objectives and one environmental objective were weighted into a single composite objective function to determine the optimal farm plan.

One of the most frequent uses of farm level LP models is for the analysis of the effect of agricultural policies. Examples include a model of a specialised arable farm in North Eastern Polder, Holland to analyse the effects of levies on the use of chemicals (Wossink *et al.*, 1992); a model of a Dutch specialised dairy farm used to analyse the effect of policy scenarios and technological change on N, K and P loss to the environment (Berentsen and Giesen, 1995; Berentsen and Giesen, 1996); a multi-period LP model to analyse the use of natural resources and the impact of alternative agricultural policies in the Alentejo region of Portugal (Ferro, 1996); and a model to analyse response of European dairy farms to policies aiming at reducing water pollution (Hellegers, 1996).

Farm level LP models have been used to analyse the impact of environment protecting technologies (e.g. soil conservation practices) on the performance of farms. One model was used to analyse the managerial implications of alternative tillage systems on crop rotation and weed management systems for East Central Corn Belt farms, USA (Martin, Schreiber, Riepe and Bahr, 1991). The effect of maximum soil loss levels on farm income was studied for farms in North-Central Dominican Republic through an LP model which considered the introduction of soil conservation practices (Hwang, Alwang and Norton, 1994). LP models have also been used to analyse the effect of changes in the external environment on the farm. One study analyses the effect of reduced access to bush-fallow land (as a response to increasing population pressure) in the Central Plateau of Burkina Faso using a one year LP model of a representative farm (Ramaswamy and Sanders, 1992)[4].

Trade-off between economic and environmental issues can be determined using LP models. One such model of a hillside farm near Tegucigalpa, Honduras used parametric variation of maximum soil loss to analyse the trade-off between income and soil loss. Parametric variation of income and/or soil loss was used to analyse the trade-off between risk and income. The effect of varying the repayment time (and thus cost) of soil conservation devices and the optimal soil erosion considering productivity loss induced by it was also analysed (Cárcamo, Alwang and Norton, 1994).

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[4] Although the paper's title includes the words land degradation and sustainability, no attempt is made to quantify these concepts.

Table 3.1 Features of LP models used for the joint evaluation of economic and environmental issues in agriculture

Author	Purpose	Objective function	Environment expressed as	Level
(Shakya and Leuschner, 1990)	Optimise management strategy	Food, fuel production, and fodder production, soil loss, cost	Objective function	Farm
(Deybe and Flichman, 1991)	Study effects of economic changes on income and soil loss	Regional net farm income	A result of the model	Region with three farm types
(Martin *et al.*, 1991)	Optimise management system under three tillage systems	Net income	Activities	Three representative farms
(Turvey, 1991)	Study effect of maximum soil loss levels	Profit	Parametric variation of soil loss	Watershed
(Ramaswamy and Sanders, 1992)	Predict technology uptake and income change	Profit	Different levels of bush-fallow land	Representative farm
(Wossink *et al.*, 1992)	Analyse alternative environmental policy instruments	GM	Parametric chemical and N discharge	One farm of certain type (cluster analysis)
(Hwang *et al.*, 1994)	Analyse the cost of soil loss reduction		Maximum level of soil loss	Average farm
(Cárcamo *et al.*, 1994)	Analyse trade-offs and optimal level of soil loss	GM	Parametric variation of soil loss	One average farm
(Berentsen and Giesen, 1995; Berentsen and Giesen, 1996)	Impact of institutional and technical change on farm and environment	Net farm income	Rows accounting for N, P_2O_5, K_2O loss	Farm based on data from various sources
(Wossink *et al.*, 1996)	Identify the best nature conservation and restoration methods	GM	Environmental cost in objective, and population level restraints	Region

At a regional level, a model of a Southern Ontario watershed maximised profit subject to a maximum level of soil loss, determined by public policies (Turvey, 1991). The model was optimised to determine the marginal cost for the environmental quality constraint, and the effect of maximum soil loss policies on farm profit. The marginal cost of soil loss, estimated from the foregone profits, was then compared with assumed social marginal costs to determine the pros and cons of each policy.

Finally, only one of the models used dynamic programming to determine the optimal decision sequence. Specifically the model intends to identify the best nature conservation and restoration methods at a regional level in The Netherlands (Wossink, Buys, Jurgens, Snoo and Renkema, 1996).

3.2.4.2 Multiple criteria decision making models for economic and environmental evaluation

Under the paradigm of MCDM each criterion or combination of criteria used to find the optimal may yield a different solution. Thus no single optimal solution can exist and the concept of efficient solutions is introduced. The efficient or Pareto optimal 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 (Romero and Rehman, 1989).

Within the MCDM framework a large number of methods have been used to solve agricultural decision problems (Romero and Rehman, 1989), most of which have also been used to analyse agricultural economic-environmental problems (Table 3.2). Goal programming (GP), and variations of it, like lexicographic GP (LGP), weighted GP (WGP), interactive multiple-goal linear programming (IMGLP) and multiple goal programming (MGP), are commonly used.

Table 3.2 Features of MCDM models used for the joint evaluation of economic and environmental issues in agriculture

Author	Method	Purpose	Objective functions	Environment expressed as	Level
(Lonergan and Cocklin, 1988)	LGP	Study effects of forest plantations on development goals	Economic and energy efficiency goals, regional labour and income, environmental goals	Goals	Twenty-seven townships in one region
(Schans, 1991)	IMGLP	Determine optimum management strategies	GM, pesticide use, N leaking, product quality	Objective	Region
(Zekri and Romero, 1991)	LGP and WGP	Study effects of incentives on irri-gation systems	NPV, labour use, labour variation, water use, energy use	Goal	One typical hectare
(Fernández-Santos *et al.*, 1992)	NISE	Study trade-offs between objectives	GM, fertiliser use, fertiliser leaking, irrigation water loss	Objectives	One simulated farm
(Holden, 1993)	WGP	Predict peasant ability to meet basic needs under varying scenarios	Labour, income and leisure	Technological and population scenarios	One average farm
(van Duivenbooden and Veeneklas, 1993; van Duivenbooden, 1993)	IMGLP	Explore impact of fertiliser availability on land use and farm production	Physical product, monetary goals, risk in dry year, and employment and emigration	Nutrient and forage restraints, stable herds	Eleven agro-ecological zones
(Yin and Pierce, 1993)	LGP	Evaluate land use policies and impact of land use change	Economic return, resource production, habitat protection, soil loss, and forest cover	Goals	Three sectors and 55 territorial sections
(Zekri and Romero, 1993)	CP	Predict optimum allocation of irrigation systems and agricultural enterprises	NPV, seasonal labour, energy use, water consumption, employment	Objective	Micro-region
(Zhu *et al.*, 1993)	MODP	Simulate restricted use of N	NPV, N leaking, soil loss	Objective and as model's parameter	Representative farm
(Fiske *et al.*, 1994)	Integer WGP	Identify optimal system	Profit, risk, and soil loss	Goal	One farm with seven management systems
(Niño de Zepeda *et al.*, 1994)	MOP	Optimise management system	GM, environmental impact	Objective	One real farm
(Zekri and Herruso, 1994)	NISE	Analyse impact of prices and taxation on farm planning	GM, N leakage, N use, and water use	Objectives	Average farm

Table 3.2 Continued

Author	Method	Purpose	Objective functions	Environment expressed as	Level
(de Koeijer *et al.*, 1995)	MGP	Evaluate economic and environmental effects of mixed farming	Labour income, chemical input, and N surplus	Objectives	One hypothetical farm
(Mimouni *et al.*, 1996)	NISE	Optimise water use	GM, Nitrate leaching and run-off, soil loss	Objectives	One farm

Notes : LGP - lexicographic GP; WGP - weighted GP; MGP - multiple goal programming; IMGLP - interactive multiple-goal linear programming; CP - compromise programming; NISE - non-inferior set estimation method; MOP - multi-objective programming; MODP - multiple-objective dynamic programming; GM - gross margin; NPV - net present value.

MCDM models have been used to determine efficient farm plans using different sets of criteria. For example, an integer WGP model of a West Virginian cattle farm was constructed using experimental data, and the best management system obtained for different scenarios, i.e. weight combinations and goal targets (Fiske, D'Souza, Fletcher, Phipps, Bryan and Prigge, 1994). A CP model was used to find the optimal water use in the micro-region of Tauste, Spain, under three different decision making scenarios. Each scenario was constructed by attaching different weights to farmers' objectives (NPV and seasonal labour), environmentalists' objectives (energy used for irrigation, and water consumption), and trade unions' objectives (level of employment) (Zekri and Romero, 1993).

A frequent aim of these types of models is to establish the trade-off between economic and environmental objectives, allowing the exploration of the economic losses associated with a reduced environmental impact. Three MGP models of Dutch farms (dairy, arable, and mixed) were developed to analyse the trade-off between labour income and chemical input and nitrogen surplus (de Koeijer, Renkema and van Mensvoort, 1995), while a CP model identified the possible trade-offs between the aesthetic value of landscape and the economic equilibrium of farms in North East Italy (Marangon and Tempesta, 1996). One model used MOP to find the set of efficient solutions and the trade-off between objectives. It analysed the trade-off between private economic and public environmental objectives in a peasant agricultural system in Chile's VIIIth Region (Niño de Zepeda, Maino, Silvestre and Berdegué, 1994). In this model one decision making level was given by a gross margin (GM) maximising farmer and the other by the policy makers, who want to reduce soil erosion and improve the balance of organic matter in the soil. To include both environmental objectives into his model, the authors construct a weighted goal which then acts as an indicator of environmental impact. Three models used the NISE method to generate the extreme efficient solutions and the trade-off between objectives. One analysed the trade-off between GM and fertiliser use, fertiliser leakage, and water percolation in the Guadalquivir watershed in Spain (Fernández-Santos, Zekri and Herruzo, 1992), while the other analysed the effects of nitrogen price and drainage water taxation on the adoption of management practices by farmers of Córdoba, Spain (Zekri and Herruzo, 1994). The third one determined the trade-off between GM, soil erosion and N loss for a Tunisian farm (Mimouni, Zekri and Flichman, 1996).

The impact of technological and institutional change at the farm level has also been explored using MCDM models. For example, both LGP and WGP have been used to analyse the use of irrigation water in Zaragoza, Spain (Zekri and Romero, 1991). These GP models, reflecting private (e.g. maximise net present value) and public objectives (e.g. minimise water use and minimise energy use), were used to compare the impact of five irrigation systems. Another set of WGP models analysed the evolution and sustainability of farms in Northern Zambia (Holden, 1993). These models were built for both traditional and modernised farms, and the impact of different population pressures (threats to sustainability) examined.

At a regional level, efficient plans have been obtained through MCDM models. For example, an IMGLP model was used to generate optimal potato production systems for the Dutch Flevopolders, based on a blend of economic, quality and environmental objectives (Schans, 1991). A compromise solution was reached by imposing relative restrictions on different goals, and analysing its effects on the others.

Regional MCDM models have also been used to quantify the impact of technological and institutional change, and to analyse the trade-off between objectives. The impact of the introduction of forest energy plantations in Eastern Ontario, Canada, was analysed using LGP models (Lonergan and Cocklin, 1988). The criteria used to optimise these model were economic efficiency in biomass production, economic efficiency in energy conversion, regional employment generation, regional income generation, energy efficiency, environmental quality-biomass production, and environmental quality-energy conversion. By parametric variation of the target value for one goal the trade-offs between it and other goals were established. Another study analysed the land use of a region in British Columbia, Canada, using an LGP model constructed by the aggregation of an agricultural, a forestry and a wetland sub-model (Yin and Pierce, 1993). Minimum output targets were set for each sub-model and the model was then optimised under six different scenarios, computing the required land conversion from one type to the other. A GP model was used to identify the key social, environmental and economic impacts of apple development projects at European level (Quin, Albin and McGregor, 1996).

An IMGLP model analysed the effect of three levels of inorganic fertiliser availability on land use and production in the Fifth Region of Mali (van Duivenbooden and Veeneklas, 1993; van Duivenbooden, 1993). From an initial set of 20 goal variables, nine were used to specify four objectives (physical production, monetary goals, risks in a dry year, and employment and emigration), while the remaining goals were used to set threshold levels. The authors modelled sustainability of cropping systems through N, K and P supply-demand restraints, while stable herds (total flock size in relation to fodder availability) and prevention of the degradation of natural pastures (apparently through adequate stocking rates) were defined as conditions for sustainability in the livestock sub-sector.

Finally, a MODP (multi-objective dynamic programming) model was used to determine optimum agricultural management systems, and to compare the effects of unrestricted and restricted Nitrogen use in Richmond County, Virginia (Zhu, Taylor and Sarin, 1993). Fourteen management systems were included in the programme, to obtain a sequence of optimal decisions. The objectives of this model were productive and environmental. The model's decision variable were the management systems and the state variable, the potential mineralisable Nitrogen (the Nitrogen carry-over from one season to the next).

3.2.4.3 Some observations on the use of mathematical programming models for economic and environmental evaluation

As seen in the previous section, a large number of models has been used to examine the relationship between economic and environmental issues in agriculture. From these applications the following observations can be made:

i. Both LP and MCDM models have been used. No rule exists for the selection of any of these techniques, because the superiority of any of them over any other depends on the characteristic and nature of the specific problem (Rehman and Romero, 1993).

ii. The models can represent both the farm and the regional level.

iii. Only one of the reviewed papers used a mixed farm and regional model based on the aggregation of different farms.

iv. Farm level models are usually based on typical or average farms, or based on compiled or simulated data. As a result model validation becomes difficult or is not done[5].

v. Regional models are normally based on the aggregation of farm data and not on the aggregation of farm level models, which would seem to be reasonable as two decision levels are involved.

vi. The aim of these models is either establishing optimal/efficient plans, determining trade-offs, or analysing the impact of technological or institutional changes.

vii. As the trade-offs between objectives can be made explicit and evaluated, the ecological effects can be quantified in terms of economic effects on a continuous scale between a minimum and a maximum attainable level (Schans, 1991). These trade-offs can then be used to find 'the best' solution considering the economic and the environmental objectives.

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[5] Berentsen and Giesen (1996) even set some activities at fixed level to overcome problems of lack of information and risk aversion, and later conclude that the differences between the fixed model and the non-fixed model can be overcome by education and extension.

viii. The assessment of the effect of policies on the farms' production or the FSs' environmental impact can help the policy maker to select the appropriate ones.

ix. The environmental concern can be included in the model as an objective, as a constraint, as a decision variable, as a parameter, or affecting the quotient of an objective, goal, or constraint.

x. Although a great number of different objective functions are used as optimisation criteria, the most frequent are related to profit (GM and NPV), and soil loss and nutrient loss. The difficulty of constructing appropriate objective functions may be overseen as only a few papers deal with this issue.

xi. The time frame[6] of the models is essentially one period (usually one year); only two models are dynamic. Although some models consider various periods, this is not in the sense of considering the problem as a sequence of interrelated problems. Dynamic programming does this as it searches for an optimal policy (sequence of decisions) such that '... whatever the initial state and the initial decision are, the remaining decisions must constitute an optimal policy with respect to the state which results from the initial decision' (Cooper and Cooper, 1981).

3.2.5 OTHER METHODS USED TO MEASURE SUSTAINABILITY

Although most of the methods to measure productive and environmental performance of FSs are quantitative, qualitative measurements also exist. One example are directional measurements, which can determine the direction of the change but not its magnitude (Harrington, 1992). Other quantitative measures include aggregate trends in outputs and yields, trend in per capita production, yield trend in relation to applied input, sustainability quotient measured as the proportion of income which would remain if environmental costs had been met,

[6] The problem of time in the evaluation of sustainability will be discussed in Section 3.3.

and natural resource accounting techniques (Harrington, 1992; Van Der Pol, 1992; Faeth, 1993).

Dynamic stochastic programming, a method which takes into account the sequential nature of decision and risk, as well as farmers' risk aversion, has also been used for these sorts of problems. One such model of a hillside farm in Southern Honduras, was used to analyse the effect of three scenarios on the expected utility of distribution of wealth for various levels of risk aversion. One scenario corresponded to the base situation, the second introduced soil conservation technologies, and the third introduced soil conservation and new crop technologies (López-Pereira, Sanders, Baker and Preckel, 1994).

Within the MCDM paradigm, the analytic hierarchic process (AHP) has also been used to analyse environmental issues, although no application of this method in the agricultural sector was found. AHP has for example been used to construct indicators of environmental impact on road planning (Garuti and Spencer, 1994), to set the priorities of economic and environmental objectives in strategic forest management planning (Kuusipalo and Kangas, 1994), and to identify and specify regional policy concerns relating to climate change (Yin and Cohen, 1994).

Simulation models have been developed to quantify the costs and benefits of certain practices. One such model is EPIC (Erosion-Productivity Impact Calculator), which has been used to evaluate crop productivity, risk of crop failure, degradation of the soil resource, impacts on water quality, response to different input levels and management practices, response to spatial variation in climate and soils and sensitivity to long term changes in climate (Jones *et al.*, 1991). The data generated through such crop growth models has also been used to construct linear optimisation models (Deybe and Flichman, 1991; Turvey, 1991; Faeth, 1993; Hughes *et al.*, 1995). Other models like CREAMS (Chemical, Runoff, and Erosion from Agricultural Management Systems) and GAMES (Guelph model for evaluating effects of Agricultural Management systems on

Erosion and Sedimentation) have also been used for this purpose (Turvey, 1991; Zhu *et al.*, 1993).

3.3 The Problem of Time in the Measurement of Sustainability

One of the major issues which has not been discussed up to this stage is how should time be considered in the evaluation of sustainability. The problem of time has two dimensions. The first is how shall the present generation deal with the damage (or benefits) being left for future generations - an inter-temporal issue involving the balance between the consumption of environmental goods by present and future generations. Secondly how should 'today' define what will be sustainable in the future.

From a purely environmental point of view, a dogmatic answer can be given to the first problem. The resource base has to be maintained; thus any damage to it is not allowed and the practice leading to it must be forbidden. So the problem of the future is resolved. But, as discussed in Chapter 2, from the social and economic points of view, this is neither feasible nor reasonable as it endangers the survival of the farming system. Trade-offs between the economic, social, and environmental determinants of sustainability exist, and some compromise has to be found which involves a reduction in the achievement level of all three of them.

From an operational point of view, two approaches can be made: static or dynamic. In a static approach the effect of the system on the environment is measured period by period and a decision is taken based on the current states of the system. In contrast, a dynamic approach considers the cumulative effect of the FS on the environment, giving more flexibility to the decision maker, because he can adapt his decisions according to the current states. It seems obvious that the latter is more appropriate for dealing with long term issues, but despite the problems of complexity, there are other reasons determining caution when using dynamic analyses.

Two important implications arise from the fact that inter-temporal trade-offs are involved. It is necessary to know first the extent to which present income is preferred to future income (i.e. the time preference) and second the effect of the current income generating activity on the future output of the natural resource base (Pandey and Hardaker, 1995). The first is the problem of the discount rate (Section 3.2.3) while the second reflects productivity change of the resource base.

A restricted version of such an inter-temporal choice problem can be written as (Pandey and Hardaker, 1995):

$$Max\ J = \sum_{t=0}^{T} \frac{B(S_t, X_t)}{(1+\alpha)^t} \qquad [3.1]$$

Subject to

$$S_{t+1} - S_t = G(S_t, X_t)$$
$$S_0 = \overline{S}$$
$$S_T = \overline{S}_T$$

where J is the discounted sum of the performance measure evaluated over the planning horizon of T time periods; B is a function measuring the farm's performance; S_t is the stock of natural resources in period t; X_t are the farmer's management decisions in period t; α is the appropriate discount rate; G is a function measuring the change in the stock of natural resources over time; $\overline{S}$ is the initial stock of natural resources; and $\overline{S}_T$ is the minimum level of stock at the end of the planning period.

As previously stated, a major problem of such an approach is the specification of the performance and stock dynamic functions. Other problems arise from the definition of the discount rate, the large amount of data requirements, the validation of the model, and the model's size and complexity (the 'course of dimensionality') which may threaten its usability and understanding. When these problems are overcome simulation models, MPMs, dynamic modelling, or a combination of the three can be used to generate the solutions (Pandey and Hardaker, 1995).

Most of the methods used to measure sustainability shown in Section 3.2 have a static nature. Indicators measure the actual or past performance of the system and thus can only determine the future state of the system if it continues to behave as it has done during the previous years. MPMs can consider the problems of time preference and productivity change of the resource base, but doing so implies increasing considerably the size and the complexity of the models. Dynamic programming and quadratic programming are better suited as standard LP or linear MCDM models to deal with such problems, as they generate the optimal sequences of decisions, but again the data requirements and the size of the problem make them difficult to solve and analyse with the available hard and software. Serious efforts have been made to improve CBA including environmental issues, but the results are still far from satisfactory. Finally, simulation models are able to include time preference and productivity changes (when the data is available), but with whole farm models of great size and complexity, and with no optimisation method associated with them.

3.4 SUMMARY

This chapter has reviewed the issues connected with various methods to measure and model sustainability or, in a more restricted sense, the economic and environmental impacts of agriculture.

The first method calls for the definition and measurement of indicators, which monitor the state of the system. Such indicators are well suited for determining quantitative and/or qualitative measures of all three determinants of sustainability. They are also easy to determine and measure. Their problem arises when the future has to be considered. Their incapacity to predict future states of the FS limits their applicability for the evaluation of technological and institutional changes. Their utility in measuring trade-offs between determinants is also rather limited.

CBA has become a standard procedure to deal with time preferences from an economic point of view, as it allows the comparison of flows of costs and benefits over a long period of time. Nevertheless it has problems as it requires the valuation of the environmental costs or benefits, unless environmental thresholds levels are set in which case traditional CBA is done. Social aspects are also very difficult to include. Although it can value the benefits of technical or institutional changes, it cannot establish optimal solutions from a FS perspective. When coupled with simulation models it can generate large sets of possible solutions, but this does not guarantee that the optimal solution has been found. From the set of possible solutions, trade-offs between determinants may be computed.

MPMs are of great value measuring the trade-off between economic and environmental variables or the effect of technological and institutional changes in the short term. As optimisation procedures are involved, the optimal solution or a set of efficient solutions can be generated. Of great advantage is their flexibility in data requirement (although less data may involve less validity of the results) and the simplicity of model construction. Despite this the complexity and size of the models dealing with larger time frames limits considerably their use when a dynamic approach to the problem is taken. Non-quantitative aspects are also difficult to incorporate.

Finally simulation models are able to deal with the problems of time preference and productivity changes, when these data are available. These models can be used to measure the effect of technological and institutional changes on whole FS. But as no optimisation procedure is attached, only a large set of feasible solutions can be generated. Nevertheless, from this set the trade-off between economic and environmental variables can be obtained. As with most quantitative methods, it has great difficulties in dealing with social variables.

In the next chapter a methodology is proposed to construct MPMs to measure the sustainability of peasant systems using mathematical programming models and considering the definition of sustainability given in Chapter 2.

4. A FRAMEWORK FOR THE MEASUREMENT OF SUSTAINABILITY

4.1 INTRODUCTION

In the previous chapters issues related to sustainability and its evaluation were analysed. The following issues were stressed and became central in the construction of a framework for the evaluation of sustainability in peasant farming systems in Central Chile:

i. Sustainable systems have to address the economic problem, the environmental problem and the social problem.
ii. The sustainability of any system depends on local or regional characteristics, and no system is *per se* sustainable or unsustainable.
iii. The farming systems approach is a valid framework for the study of sustainability due to its multi-factor causality phenomenon and the issues involved in its achievement, and due to the structure of farms.
iv. Any approach to the measurement of sustainability needs to specify the level of analysis and the time period of concern.
v. Mathematical programming and MCDM models are very convenient and useful tools for evaluating sustainability.

With these propositions as the background, a framework was developed for the analysis of the impact of development policies on the sustainability of peasant agriculture in the coastal dryland of Central Chile. It takes the FS as the decision making unit, a micro-region as the unit of analysis, and the MCDM paradigm as the analytical tool. The framework has a single decision making period, although it may be based on expected returns or impacts relevant to a longer period.

It is envisaged that such a framework can direct the development of the FSs along sustainable pathways (Figure 4.1). Such pathways 'should maintain, and hopefully increase, the adaptability[1] within a given production system, maintaining a direction which can fulfil both short term needs and long term objectives (i.e. sustainable)' (Park and Seaton, 1996). This approach establishes a compromise between an uncertain future, in terms of what will be considered sustainable, and a certain present, i.e. the actual performance (economic, environmental and social) of the FS.

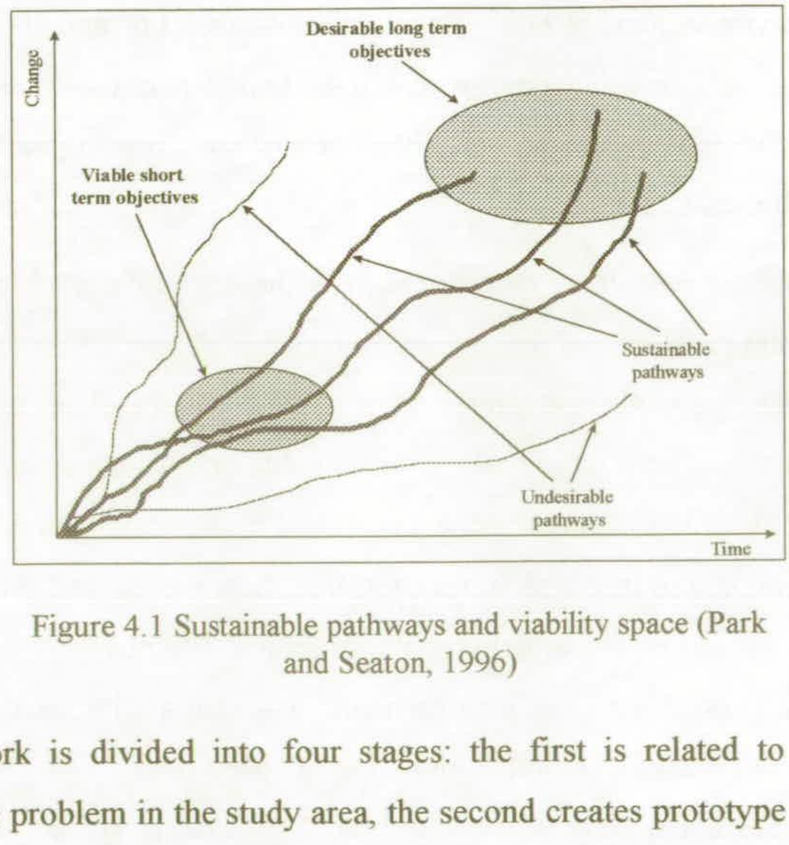

Figure 4.1 Sustainable pathways and viability space (Park and Seaton, 1996)

Such a framework is divided into four stages: the first is related to general definitions of the problem in the study area, the second creates prototype models, the third transforms these prototype models into operative models, the last uses these models to measure the impact of development policies on the sustainability criteria.

[1] Park and Seaton (1996) view sustainability as the maintenance of the adaptive capacity of a FS, so that there is no reduction of the options available for future generations to utilise the land for productive purposes.

4.2 PHASE I: DEVELOPMENT OF A CONCEPTUAL MODEL

The purpose of the first phase is to define what are the main issues involved in analysing sustainability and using these definitions to develop a model which addresses these issues. As observed earlier two definitions have to be dealt with at the beginning of any study of sustainability: first what is understood under this term; secondly the level at which analysis will be conducted (Figure 4.2).

Sustainability is seen as one of the properties of a FS, and thus the level of analysis has to be a farm unit. Nevertheless as the purpose of the proposed framework is to evaluate the impact of development policies on the sustainability of FSs, from a practical point of view the unit of analysis has to be the area where such policies are applied. Within such an area many FSs exist. Some of them may

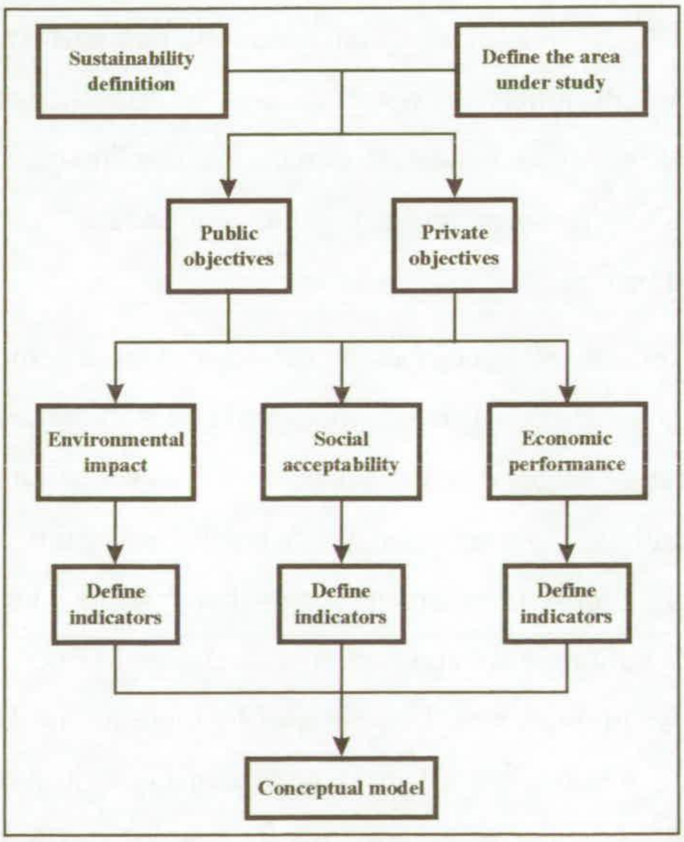

Figure 4.2 Phase I of the framework for the measurement of sustainability: Development of a conceptual model

have similar features and be categorised as 'recommendation domains', a concept developed during the late 70's by researchers of CIMMYT[2] and defined as

> *'A group of roughly homogenous farmers with similar circumstances for whom we can make more or less the same recommendation. Recommendation domains may be defined in terms of both natural (e.g. rainfall) and economic factors (e.g. farm size)'. (Byerlee et al, 1980 p. 71)*

Farmer's circumstances include those factors which affect his decisions with respect to the use of crop technologies, explaining both his current technology as well as his decisions about changes in that technology. They can be natural (climate, biological factors, soils and topography) and socio-economic. The latter may be internal (farmers' goals and resource constraints) or external (markets, institutions and national policies). Byerlee *et al*. (1980) recognise that 'knowledge of farmer circumstances and how they affect crop technologies will be a necessary element in defining these recommendation domains' (p. 11), leaving a leeway for bias through subjective appreciation of the relevance of certain factors in the definition of the recommendation domain. Agro-climatic, socio-economic, and resource availability seem to be the most important factors determining recommendation domains.

From these two definitions a series of objectives can be determined so that an improvement in their values will mean an improvement along a sustainable path (Figure 4.1). It acknowledges that sustainability is a dynamic concept and therefore it is not possible to determine today what will be sustainable in the future. Past history of agricultural development shows that systems which were sustainable in the past are no longer so, and nothing has changed to persuade us that this will not be the case in the future. In other words, there are no known sufficient conditions which determine that a system is sustainable, but there are necessary conditions to achieve such a state; thus, the aim of policies is to ensure that a

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[2] International Centre for the Improvement of Maize and Wheat or "Centro Internacional para el Mejoramiento del Maiz y el Trigo".

system develops along pathways which are both within the viability and sustainability space of that system (Park and Seaton, 1996). The set of objectives (or goals if a target has been attached to them) represent such necessary conditions.

Objectives can be classified broadly as public or private (see also Section 2.6). Public objectives are defined by the wider population and policy makers (PMs) implement policies, establish institutions, or set the legal environment to achieve them. Private objectives are set by the decision maker or DM (i.e. the farmer or household).

As a sustainable system has to be economically feasible, environmentally sound and socially acceptable, the objectives can also be classified as economic, environmental and social. Although economic objectives have basically a private nature, it is also in the public interest to improve the welfare of the population which is usually related to the achievement of economic growth.

From an agricultural point of view environmental objectives in LICs are mainly public. Many reasons explain such a belief. First the individual contribution of each farm to the overall problem is small (e.g. habitat loss, or N leaking); second, the problem is not perceived at the farm level or is even unknown to the farmer (e.g. river eutrophication, or sedimentation); third there is no point in reducing his impact if other farmers do not do the same (e.g. overgrazing of common lands, or salinisation due to lowering of the water table); and fourth, there is nothing the farmer can do as the short term survival is far more important than the long term environmental impact.

Finally, social objectives are both public and private. Many studies have shown the importance of social objectives at the farm level (Fairweather and Keating, 1994). Nevertheless from a public point of view agriculture as a way of life is becoming increasingly important, not only in HICs but also in LICs.

For each of the previously defined objectives indicators have to be defined. These indicators measure the change in the objectives, and thus indicate if the systems under study are increasing or decreasing their sustainability. These indicators will be associated with optimal values (the more or less the better), or targets (satisfactory values).

The previous definitions and assumptions establish the structure of the conceptual model. The proposed model has a bi-level structure, as the unit of analysis is a micro-region composed by a multiplicity of FSs. Both PM (micro-regional level) and DM (FS level) pursue a set of objectives (economic, environmental, and social), whose level of achievement is measured through the use of indicators. The optimisation of these objectives will then be a step forward towards the achievement of sustainable FSs.

4.3 Phase II: Development of prototype models

The purpose of the second phase is to define the FSs within the area under study and to transform the conceptual model into prototype models for those FSs and for the micro-region as a whole. These prototype models facilitate the definition of the data requirements, the design of the data collection tools and the construction of the operational models.

Two main steps have to be completed during this stage: definition of representative farms for a typology of farming systems and construction of their associated prototype models (Figure 4.3). The construction of this typology is needed to capture various degrees of similarities and dissimilarities amongst farms in the micro-region. As the number of farms is expected to be large, some method of classifying them into specific farming systems has to be used. In this thesis multivariate analyses are used to define the FSs, using both primary and secondary data related to farms in the area.

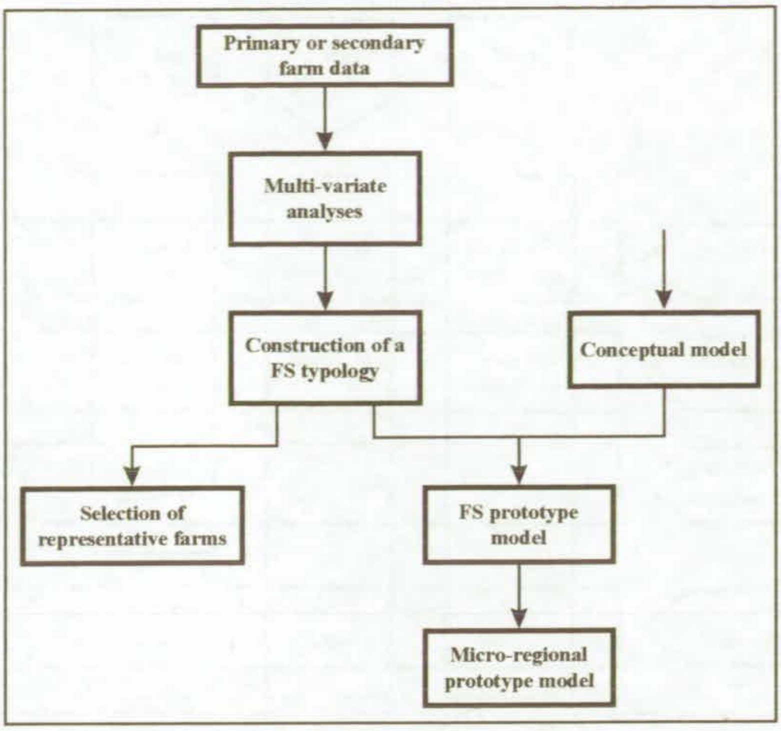


Figure 4.3 Phase II of the framework for the measurement of sustainability: Construction of the prototype models

The use of multivariate analyses rather than treelike hierarchical classification schemes generates classifications based on simultaneous consideration of multiple variables. Based on this FSs typology representative farms are selected and prototype models are constructed. From the representative farms farm data will be collected on the next stage. The prototype models are the algebraic formulation of the mathematical models. A schematic representation of such a prototype model is shown in Figure 4.4. The columns represent sets of cropping and livestock activities, while the rows agricultural, economic and labour restraints. The intersection between both contain the input/output coefficients. The set of activities limits the possible combination of enterprises, while the restraints define the use of resources and its availability (RHS column in Figure 4.4). The objective functions are constructed by a combination of an objectively measurable attribute and a direction of improvement. Objective functions are transformed into goals when a target value is attached to them (as shown in Figure 4.4).

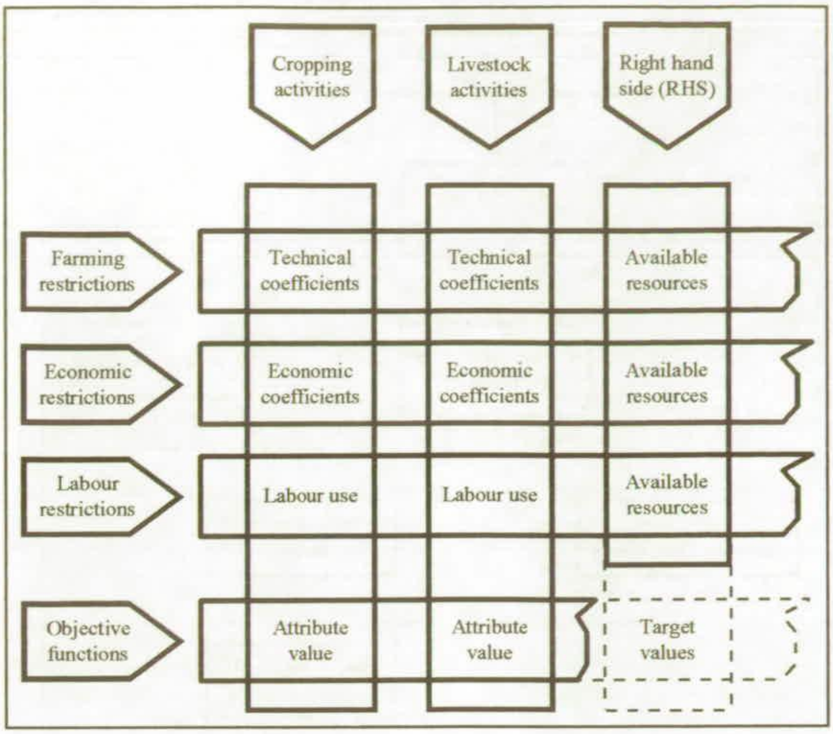


Figure 4.4 General schematic representation of the prototype models (based on a scheme by Wossink and de Koeijer, 1992)

As the micro-region covers a homogenous agro-climatic unit, it is expected that only a few prototype models would suit the whole range of FSs. The major differences between farms will be given by the input or output coefficients and by the level of available resources.

Although any of the proposed models can consider variations in the time of resource input or output (e.g. cash flow or labour), it considers a single year as the decision making period, because:

i. Sustainability has a dynamic nature and thus future determinants of this phenomenon are uncertain.
ii. This uncertainty increases when larger time frames are considered.
iii. The increase in the accuracy of results and the predictive power of a model are probably outweighed by the increased data requirements and dimensions of the decision making model.

Finally the micro-regional prototype model is constructed by the aggregation of the FS prototype models plus additional rows constraining certain activities at this level. Its objective function is given by the aggregation of the FS's objectives plus the public objectives.

4.4 PHASE III: DEVELOPMENT OF OPERATIONAL MODELS

During this phase the prototype models are transformed into operational models (Figure 4.5). This means that activities and constraints are modified to suit each FS. Also the parameters and the values of both the coefficient matrix and the available resources are replaced with the observed values.

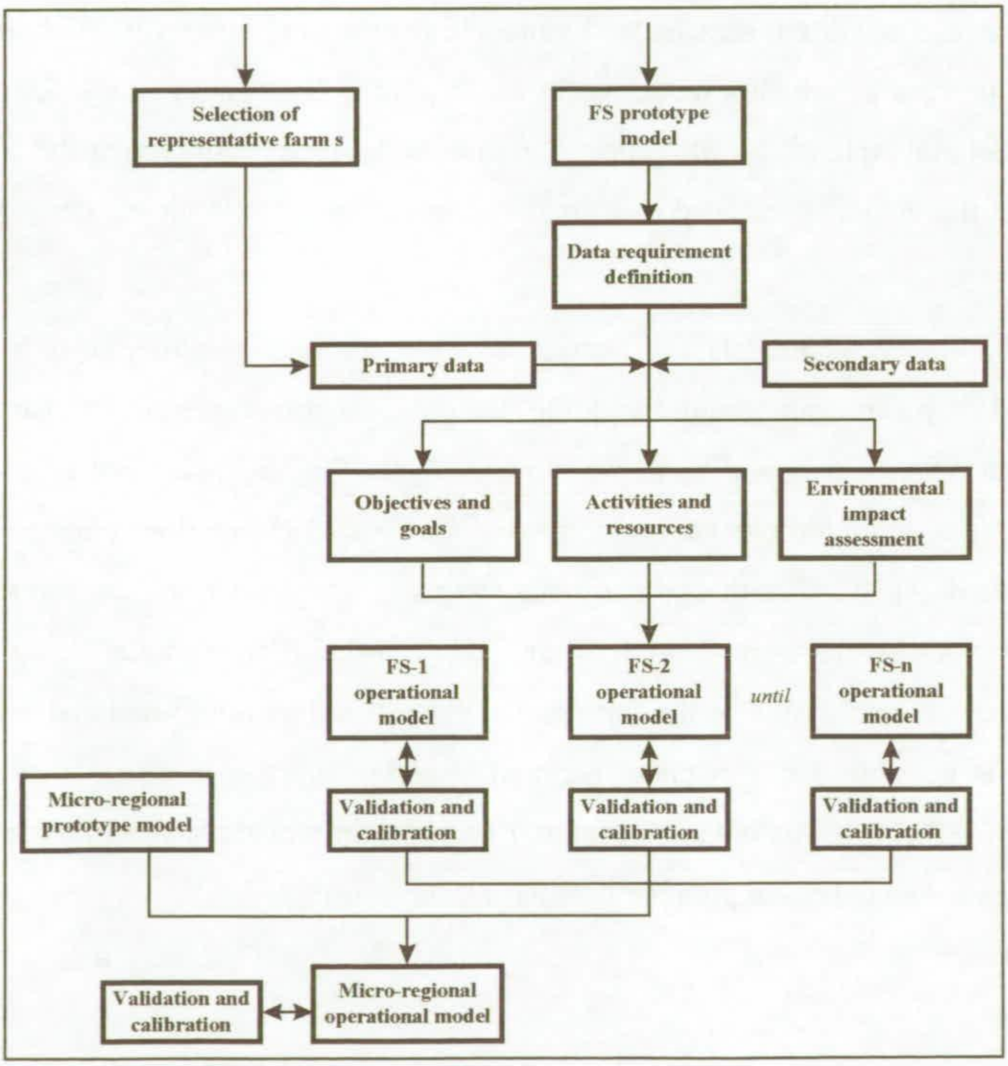


Figure 4.5 Phase III of the framework for the measurement of sustainability: Development of the operational models

The prototype model helps to determine what data are required and from which source. Surveys are prepared to collect primary information from representative farms. This data is then used to construct the coefficients of the objective functions, the input-output relations, and the resource availability. Although the environmental impact is one of the model's objective, it is shown as a separate issue in Figure 4.5 as it represents one of the essential parts of the proposed framework. Only when primary data are not available should secondary data be used. These can be obtained from other sources at both national and regional level.

As a result, one farm level operational model is constructed for each FS. These FS models or FSMs need to be individually validated and calibrated to ensure that the results will not be affected by modelling or assumption errors. Validation is the process by which a model is shown to portray the system being modelled (McCarl and Apland, 1986) while calibration is the process by which the structure of the model is changed to increase its accuracy. Thus both are concurrent processes.

Finally the FSMs models are aggregated into a single micro-regional model (MRM), by aggregating and weighting objective functions, merging constraints sets, and if necessary adding new restraints. Again the micro-regional prototype model is used as the basis for such a process. This MRM is also validated and calibrated. Although mathematically this merger is straightforward, the economic assumptions behind it must be stated and kept in mind. For example, changes in resource use and output at the farm are unlikely to affect micro-regional prices, but it is possible that at a micro-regional level the aggregated effect is able to influence them. If this is the case partial equilibrium models have to be used or aggregate demand or supply restraints have to be considered.

4.5 PHASE IV: POLICY EVALUATION

In the final stage the MRM is used to evaluate development policies, by measuring their impact on the objectives at both the micro-regional and the farm level (Figure 4.6). First the set of policies to be evaluated is defined and then transformed into meaningful constraints and activities. These are then constructed into the existing MRM. The policies can include new activities, changes in input/output relationships, new restraints or relaxation/tightening of existing restraints. Examples are the introduction of new technologies or crops, changes in marketing channels, change in the availability of capital, limits to the use of chemical fertilisers, and maximum permissible levels of soil loss. This is any action which can modify the actual productive structure of a FS and is suitable for modelling.

These models are then optimised using any of the available MCDM techniques. An ideal solution, composed of the best achievement levels for each objective

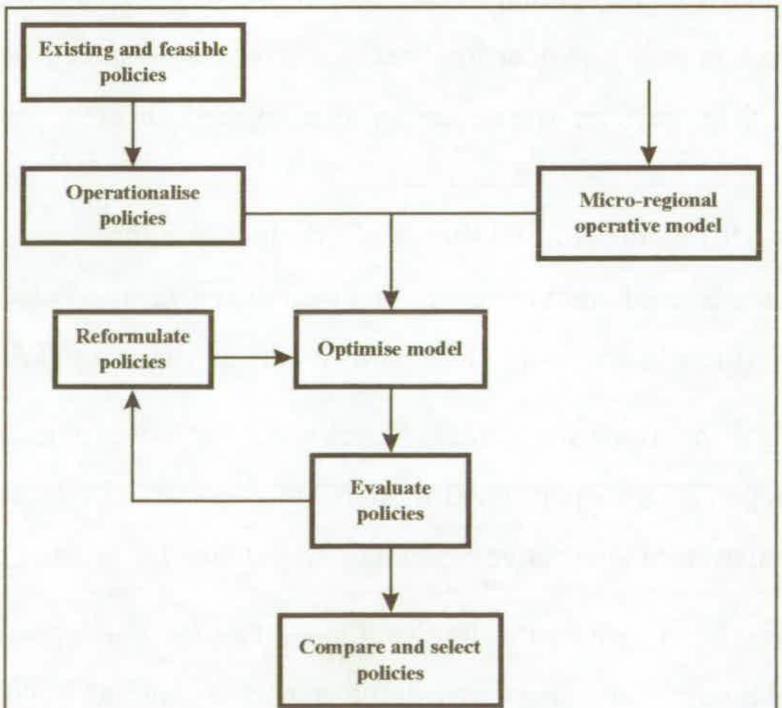


Figure 4.6 Phase IV of the framework for the measurement of sustainability: Policy evaluation

function, can be obtained and the results attained by each policy compared with that ideal. If necessary policies can be reformulated and reanalysed. The comparison of alternative solutions for each policy should help the policy maker to choose the policy whose overall performance best meets his own goals.

4.6 SUMMARY

In this chapter a framework for the evaluation of sustainability has been presented. This framework has the following features:

i. It uses a bi-level multiple-criteria single period model, considering the FS as the decision making unit and the micro-region as the basic unit of analysis.
ii. As such it has to consider multiple independent FSs, whose aggregation constitutes the micro-regional level.
iii. A typology of farming systems in the study area which is suitable for this particular purpose is constructed using multivariate analyses.
iv. It allows consideration of private and public objectives representing the economic, environmental and social issues.
v. As it considers only one decision making period, it assumes that the improvement of the objectives is a necessary step towards the achievement of sustainability.
vi. It uses MCDM models to find the set of efficient solutions.
vii. The policies to evaluate are operationalised at the farm level, and as such should provide a better insight into their impact on the whole FS.

Methodologically the framework starts developing the conceptual model, and then the prototype and the operational models are constructed. The latter is then used in the evaluation of alternative development policies for peasant farms.

Part Two of this thesis deals with the development of the conceptual, prototype and operational models for peasant FSs in the coastal dryland of Central Chile.

PART TWO

A METHODOLOGY TO ANALYSE THE SUSTAINABILITY OF PEASANT FARMING SYSTEMS IN CENTRAL CHILE

5. BASES FOR MODELLING SUSTAINABILITY IN THE STUDY AREA

5.1 INTRODUCTION

Chapter 4 presented a theoretical framework for the evaluation of FSs' sustainability with special reference to LICs. The four stages which made up such a framework were presented and their aims and activities described. This chapter deals with the first stage of such a process, the development of a conceptual model based on the definition of sustainability and taking into account the particular features of the area under study.

First a general description of the problem is given, and some definitions are stated; then the area under study, part of the coastal dryland of Chile's VIth Region is described. Next the threats to sustainability in that particular area and the indicators to be used in the measurement of sustainability are discussed. The chapter concludes with a description of the conceptual model for the analysis of sustainability in this area.

5.2 THE PROBLEM AND ITS GENERAL SETTING

Despite the fact that Chile is a country with a low population density, due to a large area (over 75 mill ha) and a relatively small population (around 13.5 million), the available agricultural land per capita is low, 0.12 ha. As a result marginal land is under intense pressure, and soil degradation and erosion are observed in most of parts of the country. According to the only major study on soil erosion 46% of the country had been subject to some degree of erosion (IREN, 1979). Despite this, these problems have received little attention during the last decades.

As the issue of environmental soundness begins to be important for the policy makers and the wider population, the issue of sustainability in its wider sense is becoming more important to the formulation of local and national agricultural policies. The problem of sustainability has to be analysed in its wider sense, as poverty is still a problem despite Chile's economic growth during the last 15 years. At national level over 32% of the population is considered to be poor, a figure which rises to 34.3% in rural areas.

This research analyses sustainability in its wider sense. The framework developed in the previous chapter was used to analyse the sustainability of peasant agriculture in an area of Central Chile and to evaluate the impact of local development policies on these FSs. Sustainable agriculture is that agriculture which is able to solve the economic, the social, and the environmental problem, as described in Chapter 2. Such a definition is in accordance with Chile's Environmental Base Law[1] which defines sustainable development as 'the process of continuous and equitable improvement of people's quality of life, based on appropriate environmental conservation and protection measures, in such a way that the expectations of future generations are not compromised'.

The reason for working with peasant farmers is that they represent the poorer sector of rural society and because frequently rural poverty and soil degradation are closely correlated.

In Chile, agricultural development policies for peasant agriculture are normally implemented through the Chilean Institute for Agricultural Development INDAP ('Instituto de Desarrollo Agropecuario'). At present the principal activities of INDAP are technology transfer programmes and short term loans. According to

[1] 'Ley de Bases del Medio Ambiente', 9 March 1994. Law No. 19,300, Republic of Chile.

INDAP's mandate a peasant farm when expressed in terms of irrigated area is less than 12 ha in size.

Lately INDAP has changed its administrative units from 'Comunas' or Counties to micro-regions, which may include parts of different Counties. A micro-region is defined as a geographic planning area which has (INDAP, 1993):

i. Similar agro-ecological features, i.e. soil and climate
ii. Similar water availability, i.e. irrigated land or dryland
iii. A given pattern of farming systems, defined according to their productive orientation
iv. A recognisable unit of socio economic integration in terms of access to markets, agro-industries and roads

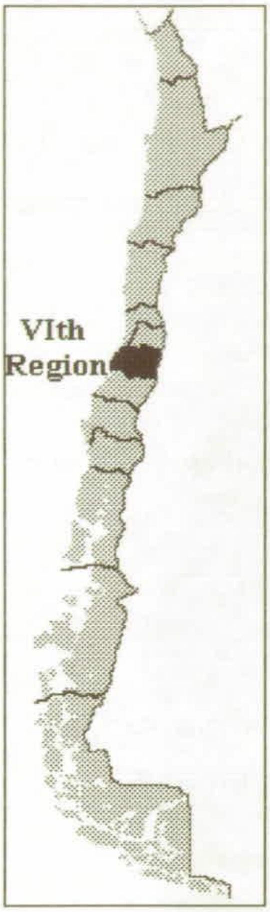
This means that within a micro-region the heterogeneity of farms has been reduced to a pattern of FS, according to the main cropping and livestock activities observed on the farm (i.e. productive orientations).

When this research started in 1993 the micro-regions had not been defined exactly or were not in use as administrative units. Thus the present study is based on three Counties which shared similar conditions.

5.3 DEFINING THE AREA UNDER STUDY

5.3.1 CHILE'S VITH REGION

Chile is divided into 13 administrative Regions, numbered from I to XII and a Metropolitan Region mostly covering the capital city, Santiago, and its surroundings. Each Region is subdivided into a variable number of Provinces and these into Counties ('Comunas'). The latter represent the lowest level of public decision making. The VIth Region, sub-divided into 33 Counties, is located in Central Chile (between 34°00' and 35°15' latitude South) and ranges from the Pacific Ocean (72°00') to Argentina (70°10').



The Region's total area is 16,893 km², of which 2,267 km² (13.4%) are used by agriculture. The land is mainly used for forestry (almost 8,000 km² or 48.9%). Table 5.1 shows the total regional area according to its potential use.

Table 5.1 VIth Region's land according to type (CIREN, 1989)

Land type	Area (ha)
Arable	383,700
Pastures	142,000
Woodland and forests	603,500
No agricultural or forestry use	444,600
Not classified	61,200
Total	1,635,000

In 1992 the Region's population was 696,369 inhabitants (5.22% of the Chilean population), of which 251,289 (36.09%) lived in rural areas. This percentage more than doubles the national figure (16.54%). Table 5.2 shows the total population of the VI Region and its distribution.

Table 5.2 Distribution of population in Chile's VIth Region in urban and rural areas (INE, 1992)

	Regional	Urban	Rural	% rural
Employed	219,777	142,595	77,182	35.1%
Unemployed	20,884	13,853	7,031	33.7%
Not economically active	248,358	155,965	92,393	37.2%
Under 15 years	207,350	132,667	74,683	36.0%
Total population	696,369	445,080	251,289	36.1%

From the point of view of the Region's relief, its physiognomy is typical for Central Chile. The morphologic units are the Coastal Plain, the Coastal Mountains ('Cordillera de la Costa'), the Central Plain or Valley and the Andes Mountains ('Cordillera de los Andes'). The combination of the Coastal Mountains (600 or 800 m above sea level) and a wide coastal plain originate a hilly relief, which prevents the penetration of the coastal breeze to the Central Plain. The absence of transversal hills in the Central Plain facilitates the movement of weather fronts once they have been able to bridge the Coastal Mountains and thus increases the rainfall. The Andes Mountains can reach a height of up 4,000 to 5,000 m above sea level. Both mountain chains are highest in Northern Chile, losing height continuously while going South (CIREN-CORFO, 1990).

The Region's climate is mainly Mediterranean or variations of it, as in most of Central Chile. Rainfall is confined to the cold season and this is followed by a dry and hot season. The temperature has a sub-tropical pattern (INIA, 1989). Without irrigation winter cereals, winter legumes, oil seed rape, vineyards, olives, almond trees, fig trees, cherries, etc. can all be grown. Irrigated areas can produce corn, rice, beans, potatoes, and orchard fruits like apples, peaches, plums, kiwis, citrics, and avocados.

Temperature and moisture patterns develop according to the distance from the ocean, the amount of blocking effect of the coastal mountains and the height of the coastal mountains. The rainfall increases from North to South, as well as with height, but it is lower to the East of the Coastal Mountains, because they block the rainfall on the oriental declivity and the Central Valley.

Using INDAP's definition of peasant agriculture, in 1994 the Region had a total of 44,157 peasant farms (Table 5.3). Most of them can grow any crop as they are located in the Central Plain and therefore have access to irrigation. The problem is that the size of these farms is very small. In the Coastal dryland the farms are larger and devoted mainly to pastures and woods, with areas for dryland crops. Of all the peasants farm, just over 11% (4,959) take part in the technology transfer programmes (INDAP, 1994).

Table 5.3 Distribution of peasant farms in the VIth Region, according to main use and irrigation equivalent size (INDAP-CIREN-FOSIS, 1994)

Main use	0-1 ha	1-5 ha	5-12 ha	Total
Any crop	17,824	7,096	7,274	32,194
Arable with limitations	784	470	177	1,431
Pastures and woods	7,739	1,466	694	9,899
Other	360	133	140	633
Total	26,707	9,165	8,285	44,157

5.3.2 THE MICRO-REGION

This study covered most of the Region's coastal Mountain area, specially the Counties of Litueche, Marchihue and Pumanque (Figure 5.1). These three Counties, with a total area of 175,375 ha (1.1% of the Region), cover a major part of the coastal mountains, specially its eastern or interior declivity and have a marine Mediterranean climate. The winter is mild with a frost-free period of more than four and a half months, with average maximum temperatures between 10°C and 20°C during the cold months and over 21°C during the hot months, and a dry season of more than five months (INIA, 1989).

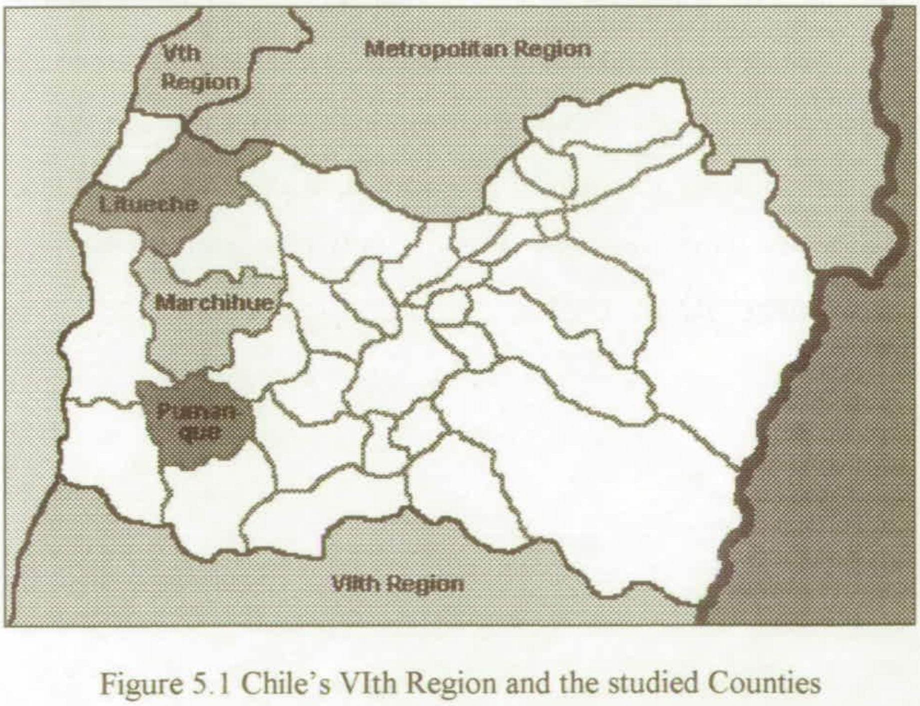


Figure 5.1 Chile's VIth Region and the studied Counties

5.3.3 THE MICRO-REGION'S AGRO-CLIMATIC DISTRICTS

An agro-climatic district, is an area with homogenous climatic conditions given a group of temperature and moisture parameters, which represent the average climatic conditions of summer and winter with relevance for plant growth and production (CIREN-CORFO, 1990). One agro-climatic classification is provided by the Chilean Agricultural Research Institute ('Instituto de Investigaciones Agropecuarias' or INIA). This system considers winter and summer types, as well as temperature and moisture regimes. Accordingly three agro-climates can be found in the micro-region, namely Constitución, Hidango, and Pumanque (Figure 5.2). Nevertheless only two of these agro-climates (Hidango and Pumanque) are relevant, as the other one occupies only a minor coastal area of Litueche[2].

Table 5.4 shows the main features of these districts. Hidango and Pumanque agro-climates have a similar temperature pattern, but not from the point of view of rainfall, as the blocking effect of the Coastal mountains is less in Hidango and

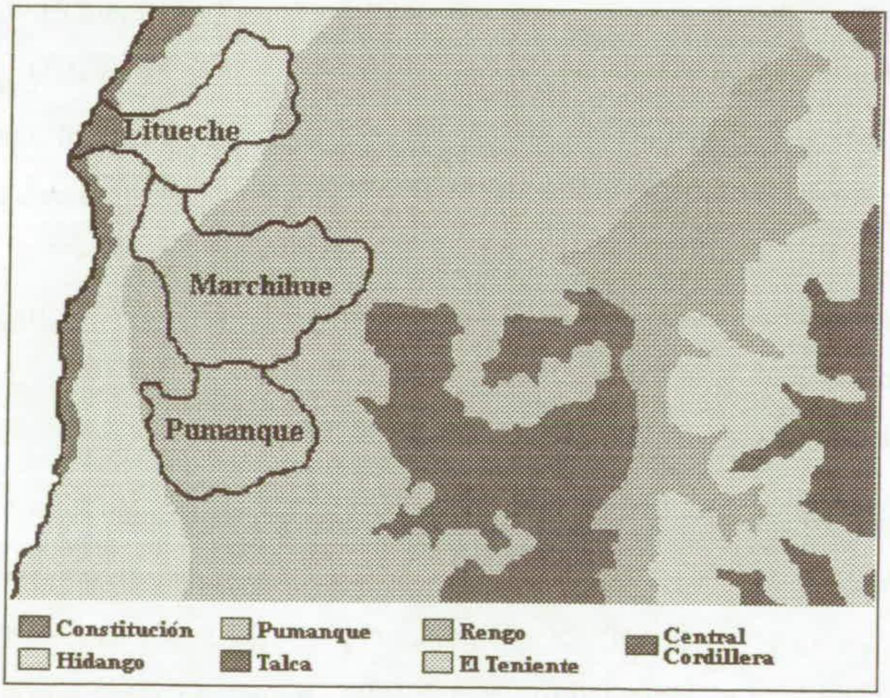


Figure 5.2 VIth Region's agro-climates and their geographic relation with the three Counties under study

[2] Only one of the eight farms used to evaluate sustainability (Chapter 6 onwards) was located on the Hidango agro-climate.

Table 5.4 Location and climatic features of the micro-regional agro-climates (INIA, 1989)

Agro-climatic district	Constitución	Hidango	Pumanque
Mean annual T°	14.0°C	13.6°C	14.9°C
Hottest month	Jan.	Feb.	Jan.
Hottest month's mean max. T°	24.0°C	24.7°C	27.7°C
Coldest month	July	June	July
Coldest month's mean min T°	6.0°C	5.4°C	5.8°C
Frost free months	Sep. to May	Oct .to May	Sep. to June
Dry months	Nov. to Mar.	Nov. to Mar.	Nov. to Apr.
Rainfall	900 mm	900 mm	440 mm
Evapo-transpiration	1280 mm	1330 mm	1730 mm

T°: Temperature

higher rainfall is observed. The agro-climate of Constitución has a temperature pattern with milder extreme temperatures due to the stronger influence of the Pacific Ocean.

5.3.4 THE MICRO-REGION'S PEASANT AGRICULTURE

The micro-region has an estimate of 2,496 small holdings (i.e. smaller than 12 ha irrigation equivalent), of which 577 receive technical support from INDAP. This area is almost exclusively based on rainfed agriculture, with a reduced number of farms with small areas under irrigation. INDAP has also classified these farms according to their productive orientation, i.e. the main crops and livestock present on the farm (Table 5.5). The larger number of productive orientations observed in Litueche is due to the higher rainfall observed in this County (Figure 5.2 and Table 5.4).

The dominant arable crop is wheat (Figure 5.3) in a five year rotation with fallow (Figure 5.4) and rough grazing[3] (three years). When the moisture conditions are adequate a grain legume (mainly beans and chickpeas) are sown on fallow before wheat. Irrigated land is dedicated to vegetables for home consumption (potatoes, maize, orchards, etc.), and some cash crops (e.g. strawberries). From such a

[3] After wheat harvest, the field is not ploughed for three years. During this period the field is grazed and some degree of growth in natural vegetation is observed.

classification it can be seen that mixed agriculture has a high prevalence, dominating the combination of wheat and sheep and/or cattle (Figure 5.5).

Table 5.5 Number of small holder farms and their participation in technology transfer programmes (TTP) by County and productive orientation.

County	Productive orientation	Farms	%[1]	TTP
Litueche	Wheat-sheep	279	32.0	47
	Wheat	157	18.0	26
	Wheat-maize-orchard	79	9.0	13
	Wheat-strawberry-cattle	26	3.0	4
	Wheat-beans-sheep	105	12.0	18
	Wheat-chickpeas-sheep	157	18.0	26
	Wheat-broad beans-sheep	44	5.0	7
	Other	26	3.0	4
Marchihue	Wheat-pasture-cattle	748	76.0	164
	Wheat-pasture -cattle-beans-maize	236	24.0	52
Pumanque	Wheat-chickpeas-sheep	575	90.0	194
	Wheat-vineyard-sheep	64	10.0	22
	TOTAL	2496		577

1: percentage of farms within County

Source: INDAP, VIth Region

Figure 5.3 A peasant wheat field and hills showing signs of soil degradation[4]

[4] The pictures shown in Figure 5.3 to Figure 5.8 were taken during September 1995

Figure 5.4 A recently prepared fallow

Figure 5.5 Local crossbred cattle foraging straw with rough grazing areas behind them

5.4 THE THREATS TO SUSTAINABILITY

As for the rest of the country, poverty is an important problem. According to the VIth Region's Planning Service in 1991 45.6% of the rural population lived below the poverty line, and 16.2% of them were destitute. Therefore there is still need to increase the income of the population who live from agriculture. One of the objectives of the present government is to achieve economic growth with an equitable distribution of the benefits of this growth. Thus an important issue of this thesis was how certain policies affect different groups of peasant farmers.

Although the economic objective of growth was shown from a public point of view, there is little doubt that the primary concern of any household is also to increase its income.

A second problem faced by Chilean agriculture at a national level arises from the changing economic and social environment. One of the cornerstones of Chilean economic development has been its increasing participation in world markets, favouring exports and signing trade agreements. Nevertheless, this integration coupled with changes in agricultural polices at the international level, falling international prices of basic products, increasing production costs, and other countries starting to compete with Chile for agricultural product markets, posed new threats to Chile's development strategies. The government, acknowledging that agriculture and the rural world are an essential sector and way of life of the country, is concentrating its effort to achieve a profound productive transformation and modernisation of the agriculture (Ministerio de Agricultura, 1995).

In environmental terms, the main threat to sustainability comes from accelerated soil loss and the related problem of land degradation. Soil loss occurs in this area when the intense winter rain falls over bare fields or degraded pastures. The run-off then washes an important part of the upper soil away. Based on the data provided by IREN (1979) it was estimated that over 63% of the Coastal Mountains and surrounding plains of Central Chile (Vth to VIIth Regions) had been subject to severe or high soil erosion (Kerrigan, 1994)[5]. This would represent one of the highest proportions of highly eroded land in Chile. A previous study determined that only 31% of the Region's Coastal and Interior dryland (616,000 ha) showed no sign of erosion, 1% had been subject to wind erosion and 68% to sheet and gully erosion (IREN, 1965). Of the latter, 32% (196,000 ha) had suffered from either severe or high erosion.

Although the data presented was obtained from aggregate and large scale values (1:500,000) and thus must be taken with care, the visual observation of the area shows clear signs of long running soil degradation and erosion. Wheat-fallow-rough grazing rotation, continuous grazing, removal of bushes and trees (Figure 5.6), specially *Acacia caven* to produce charcoal, have all contributed towards this. As a result degraded pastures and rill and gully erosion are frequently observed (Figure 5.7 and Figure 5.8).

Figure 5.6 Fallow with almost complete removal of bushes (*Acacia cavens*)

[5] Chile's Natural Resource Research Centre ('Centro de Investigación de Recursos Naturales' or CIREN) is doing up to date research on soil erosion, covering also the Coastal Mountains of the VIth Region. Their results were not available at the time of writing this thesis.

Figure 5.7 Wheat on hilly land and hills showing severe gully erosion

Figure 5.8 Wheat grown on hills with signs of soil degradation

5.5 THE DEFINITION OF INDICATORS

Based on the evaluation framework (Chapter 4) and the threats to sustainability described in Section 5.4 indicators of economic performance, environmental impact and social acceptability at the farm and micro-regional level were defined. The main restriction to the definition of such indicators was that they had to be quantitative, as otherwise they could not be included in a mathematical programming model.

5.5.1 INDICATORS OF ECONOMIC PERFORMANCE

According to classic economic theory the leading objective of a firm is maximisation of profit, which is in line with most of the studies on farmers' objectives. Thus the first objective was defined as maximisation of profit or a surrogate measure of it. But, every farm plan is in effect a set of states or outcomes, with associated probabilities of occurrence or non-occurrence and consequences for each pair of action and state (Selley, 1984). To include this fact in the model a second important private economic objective was introduced: risk. It was included because any measure towards its reduction benefits the farmer (Anderson and Dillon, 1992). Thus the model to evaluate sustainability included two criteria of economic viability, both of which are objectives of a private nature: maximisation of profit and minimisation of risk.

5.5.2 INDICATOR OF ENVIRONMENTAL IMPACT

From the environmental point of view, the major threat to peasant agriculture in this micro-region is soil erosion. Other well known negative environmental impacts of agriculture are not so important in this area. A low use of fertilisers and almost no use of pesticides determine that chemical pollution is not an urgent problem. Low use is also made of underground water and therefore salinisation and waterlogging are also marginal concerns. The problem of habitat change and loss of bio-diversity has not been studied at all, so that some basic research is required before any further steps can be taken.

Soil erosion is the most damaging impact of agriculture on the environment (Soule *et al.*, 1990; Cook, 1992; Tivy, 1990). Erosion reduces land productivity and the resulting sedimentation is one of the major forms of downstream water pollution (Tivy, 1990); its reduction therefore represents the criterion of environmental soundness and is of both private and public interest.

5.5.3 Indicator of Social Acceptability

This was undoubtedly the most difficult indicator to define and then to operationalise, specially if the question that what agricultural policy is socially acceptable is to be answered. Due to the natural limitations of any research work, it was not possible to establish a framework to evaluate the acceptability of any development alternative. Also these features can only be determined once the feasibility of them has been tested using the framework being proposed here. To overcome these limitations the following assumptions were made.

First it was assumed that any existing farming system was (at least up to certain extent) acceptable to farmers in the area. This did not of course mean that the FSs were environmentally sound or that the farmers did not want to improve them. It only implied that they were willing to continue producing as they were, provided there was no better alternative.

Second it was assumed that a new alternative would not be rejected (which is not a sufficient condition for acceptance) if it fitted into the current farm plan and if it improved the FS's objectives.

Third at the policy making level an acceptable development policy had to meet the objective of equitable growth, i.e. it must improve farmer's income (as defined in Section 5.5.1) and specially that of farmers with the lowest income levels. To achieve this the criterion of income distribution between FSs was used as the indicator of acceptability and introduced into the micro-regional models.

5.6 Summary

In this chapter the conceptual model for the evaluation of the impact of local development policies on the sustainability of peasant farms was related to a micro-region of Chile's VIth Region. First the importance of peasant agriculture in this area was highlighted and then the problems threatening its sustainability were described. Low incomes and their variation are predominant problems in areas where the extent of poverty is striking. Soil loss and degradation have been present for a long time, progressively reducing fertility and productivity. Added to this is the fact that given development actions will not have the same impact on all the farmers involved. Thus policy evaluation has to consider a measure of its differential impact. Based on these aspects the conceptual model states that for this micro-region, any method to measure the impact of given policies on the sustainability of FSs has to consider at least the following issues:

i. A bi-level structure, as it is the policy maker who selects development alternatives according to his objectives, but it is the farmer who has to decide if the proposed alternatives are feasible for his particular conditions.
ii. Within a micro-region a variety of farming systems exist, and this heterogeneity has to be considered in the construction of the operational models.
iii. Efficient plans must be defined according to a set of criteria, which represent a mixture of private and public objectives.
iv. Four indicators are proposed to help evaluate the FSs sustainability: profit, risk, soil loss, and income distribution.

The preceding principles will now be used to develop a mathematical programming model (Chapter 7). But before this can be done the issue of farm diversity has to be analysed (Chapter 6).

6. A Typology of Peasant Farming Systems in the Coastal Dryland of Chile's VIth Region

6.1 Introduction

In this chapter, the second phase of the proposed framework for the evaluation of sustainability is developed. One of its fundamental parts is the recognition that farms and FSs are not uniform; farmers manage different resources under different circumstances. Perhaps it has been this failure to recognise and deal satisfactorily with the heterogeneity of FS within a geographic area which has been one of the major criticisms to FS Research and Extension.

As the study area is a micro-region with similar agro-climatic features, some of this heterogeneity was removed, but not all. As shown in Table 5.5 the farms within this micro-region can be classified into at least ten groups, according to the farm's productive orientation. Nevertheless a different grouping can be observed if the farm typology is created considering variables different from the type of crops or livestock, i.e. productive orientation.

This chapter deals with the issue of developing a typology suited to the purposes of this research project. First a general theoretical procedure for farm typification is developed, which is then used to generate a typology of peasant FSs in the study area to select representative farms for each of the relevant FSs.

6.2 STAGES INVOLVED IN FARM TYPIFICATION

Farms have been classified by types from the beginning of this century, although mainly from a geographic point of view. Some of the tasks of the Commission on Agricultural Typology, established in 1964 by the International Geographic Union, were to establish common principles, criteria, methods and techniques for agricultural typification, and to elaborate the typological and regional classification of world agriculture (Kostrowicki, 1977). The latter is contrary to the current belief that typification is short lived and purpose oriented, that is it is only useful within a given context, and therefore no universal typology can be found (Escobar and Berdegué, 1990). The importance of typification based on quantitative methods was recognised early, as qualitative typification based on expert opinion could show different results with time. It was recommended that typification should be based on a reduced number of variables, and that these should preferably be of a synthetic or composite nature (Kostrowicki, 1977). Lack of computer development and early stages in multivariate analysis determined that no specific clustering method was proposed. As a result most FS typologies were based on simple hierarchical univariate classifications (see for example Spedding, 1988 Chapter 7; Beets, 1990 Chapter 6; Jain and Dhaka, 1993). Nevertheless, during the last decade the improvement in computing facilities and the development of powerful analytical tools has allowed the use of quantitative methods for the identification of FSs.

The proposed procedure to construct such FSs is a five stage process drawn from the experience of RIMISP[1] (Escobar and Berdegué, 1990):

I. Determination of a specific context for typification and classification[2]

II. Selection of variables at the FS level

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[1] The 'Red Internacional de Metodología de Investigación en Sistemas de Producción' (International Network on Farming Systems Research Methods) is one of the biggest networks in Latin America on FS research.

[2] Typification deals with the creation of homogenous groups (types) and classification with the allocation of an observation within any of the existing types.

III. Application of surveys and other tools for data collection

IV. Multivariate statistical analysis of the data and interpretation of the results

V. Validation of the typology

The definition of the context within which the farms are typified (Stage I) allows the definition of the hypotheses on the FS's structure, on the FS's functioning and its evolution, as well as on its objectives and its relation with its sub-systems and supra-systems. It also establishes the purpose for classifying this population. To construct these hypotheses three types of inputs can be used. First, the researchers' previous experience and knowledge of the FSs; second, the objectives of doing a typification; and finally, the available information on the area's agriculture, economy, etc. (Escobar and Berdegué, 1990).

The choice of variables to use in multivariate analysis (Stage II) is one of the most critical steps in the research process as it requires assessing the importance of the variables to the problem (Aldenderfer and Blashfield, 1984). The point is that any observation, a farm for example, can be described by a very large set of variables, but only some of them are relevant in the context of the typification process. Therefore the variables which are able to capture the information required to verify the postulated hypotheses have to be selected from all the available variables. Although there is no general rule for their selection, groups of them exist which usually have a major role in farm typification, e.g. farm size, capital, labour, production pattern, soil quality, and managerial ability (Escobar and Berdegué, 1990). Further the identification of types ought to be based on internal and not external attributes. The use of both types of attributes would presuppose rather than prove the impact of external variables on the formation of FS (Kostrowicki, 1977).

Next the data have to be collected (Stage III), choosing the tool or method best suited to the type of data required, number of farms and their location, and other aspects specific to the research in hand. This data set is then analysed from a multivariate point of view, using mainly factor and cluster analysis as statistical methods (Stage IV). A theoretical background to these methods is given in Section 6.3.

Once the FSs have been defined it is necessary to validate them (Stage V). It is important to be sure that these groups are 'real' and not merely imposed on the data by the method (Aldenderfer and Blashfield, 1984). The problem is how to carry out significance or 'optimality' tests, to validate the classification (Sokal, 1977), as no formal procedure has been developed to do this. A good alternative is thus to contrast the FS types with the hypotheses about its structure, as well as with the researcher's perception with regards to the variety of FS observed empirically (Escobar and Berdegué, 1990).

6.3 MULTIVARIATE STATISTICAL ANALYSIS AND FARM TYPIFICATION

Three steps are involved in the multivariate statistical analysis process used to construct the FS typology. The first deals with variable selection from the set of collected data, the second is factor analysis and the third cluster analysis.

6.3.1 VARIABLE SELECTION

During the clustering process groups are constructed according to how similar or dissimilar the observations (i.e. farms) are, based on some measure of distance between observations or groups of observations. This distance measure is of course an aggregated value, due to the multivariate nature of the observations. Thus, if a given variable shows zero or a low variance (i.e. all observations show the same or a very similar value for that variable) its contribution to the measure of distance is very small and can therefore be discarded (Escobar and Berdegué, 1990). Also variables which show correlation between them ought to be discarded, as the uncritical use of highly correlated variables to compute a measure of similarity is essentially an implicit weighting of these variables (Aldenderfer and Blashfield, 1984).

Further, the data set may also hold variables which are not important to the typification itself. In a typification of peasant farms in Southern Chile (Berdegué, Sotomayor and Zilleruelo, 1990), it was seen that the typology initially obtained, although consistent with observable FSs, was not relevant for that particular study, because clustering gave the same weight to all variables included in the analysis, but not all of them were equally important for the study. Thus the authors recommended discarding variables which from a practical point of view are not so relevant for typification. They suggest taking two steps prior to typification: first, the use of an appreciation filter to reflect the importance of the information contained by the variable; and secondly, the choice of the variables included in the analysis should be made consistent with the research's objectives.

Finally, missing data for some variables in some observations are also a source of problems. As multivariate analysis cannot handle missing data it is necessary either to replace the missing value with the average value or to discard the observation or the variable. The use of average values may bias the results, especially when the number of observations is small or the number of missing values large. The question of eliminating observations or variables depends on the number of observations available and the importance of the variable in the context of the study. Also the characteristics of the missing data (number of missing values per variable or observation) are relevant.

6.3.2 Factor analysis

Next the problem's dimensionality can be reduced through factor analysis. The main uses of this method are (Kim, 1970):

i. The exploration and detection of patterning of variables with a view to the discovery of new concepts and a possible reduction of data, which is one of the most distinctive characteristics of factor analysis.

ii. The testing of hypotheses about the structuring of variables in terms of the expected number of significant factors and factor loading.

iii. As a measuring device in the construction of indices to be used as new variables in later analysis.

Factor analysis is concerned with the internal relationships of a set of variables (Lawley and Maxwell, 1971). Its aim is to construct a set of factors (hypothetical unobserved variables) from a set of observable variables. The factors are *common* when they contribute to the variance of at least two observed variables or *unique* when their contribution is only towards one variable. In other words, observed values (Y) are explained through a linear combination of the factors (B) and a residual (E):

$$Y = XB + E$$

Three steps are involved in factor analysis (Kim, 1970). First the correlation matrix is prepared, involving the calculation of appropriate measures of association between relevant variables. Although it is also possible to establish correlations between observations for a set of variables (Q-factor analysis), correlations are usually computed between variables within a set of observations (R-factor analysis).

The second step involves the extraction of the initial factors, which can be based on defined factors (Principal Component Analysis or PCA) or inferred factors (Common Factor Analysis). The main difference between the two methods is how they compute the communalities. The communality is the fraction of each variables' variance explained by the total variance of the extracted factors, and represents the extent of overlap between the extracted factors and the variable (Comrey and Lee, 1992). The total variance is given by the communality and by the residual or unique variance (i.e. determined by the correlation existing between variables) (Kim, 1970).

PCA transforms a given set of variables into a new set of principal components that are orthogonal (uncorrelated) to each other. The linear combination of variables which accounts for most of the variance in the data as a whole (i.e. the best) is chosen as the first factor. The second factor is chosen in a similar way but under the condition of being orthogonal to the first (thus accounting for part of the residual variance after the first factor was extracted). This process continues until there is no residual variance; thus the last factor accounts for all the residual variance. The number of factors will equal the number of variables, unless one variable is perfectly determined by the others (Kim, 1970; Lawley and Maxwell, 1971). In other words, this is a variance oriented method. PCA is often used when the variables under study are highly correlated (Aldenderfer and Blashfield, 1984).

Common Factor Analysis assumes that each variable is influenced by a set of shared or common factors and partly by idiosyncratic or *unique factors* (uncorrelated to every other factor). Thus correlation between variables is due to the existence of common factors. The implicit belief is that the number of common factors will account for all the observed relations and be less than the number of variables. Common Factor Analysis is thus a covariance or correlation oriented method (Lawley and Maxwell, 1971).

The first extracted factor is the largest (i.e. largest sum of squares). Most methods for factor extraction are designed to extract approximately as much variance as possible from the correlation matrix, creating highly complex factor constructs that relate to many of the variables rather than to just a few (Comrey and Lee, 1992). Since such a factor correlates substantially with many variables that are essentially uncorrelated to each other, they become difficult to interpret and to use for scientific description. Rotation of the factor matrix makes it possible to obtain factors which are easier to interpret and use.

A problem to be dealt with is determining how many factors should be extracted. The maximum number of factors equals the number of factors with positive Eigenvalues[3] when the communalities are specified. When the minimum residual

[3] The Eigenvalue or latent root indicates how much of the variation in the original group of variables is accounted for by a particular factor (Vogt, 1993)

method without communalities is used, then it is the number of factors extracted before the iterative process converges on vectors of opposite sign (Comrey and Lee, 1992). With real data, the actual number that merit retention is often considerably smaller than that upper bound, but there is no precise solution to the problem of how many factors should be retained. Several indicators can be used to solve this problem. If, for example the sums of squares of the loadings of an extracted factor are no longer dropping but are remaining at a low and rather uniform level, factor extraction may be terminated. Another test searches for a point where there is a break in the Eigenvalues. As factors are extracted from large to small, their Eigenvalues are also decreasing. When they are plotted, a straight line can be drawn through the latter smaller values. The earlier, larger values will fall above the straight line. Some authors propose that the last factor to be retained is the last factor which is above such a straight line (Comrey and Lee, 1992).

Another clue is given by the maximum remaining residual correlation. If it is less than 0.10, for example, it would be unnecessary to continue extracting, as any new factor would have very small loadings (Comrey and Lee, 1992).

A common rule is to extract all the factors with Eigenvalues of 1.0 or more (Kaiser's rule). This rule can only be used when 1's have been used as communalities, although even doing so it may not give the correct number of factors. The main thing to consider is that it is better to err on the side of extracting too many factors rather than too few. The point is to extract enough factors to be relatively certain that no more factors of any importance remain. Nevertheless if too many factors are extracted, appropriate steps must be taken to eliminate these extra factors as the rotation of too many factors may produce distortions to the solution (Comrey and Lee, 1992).

Finally, as the exact configuration of the factor structure is not unique, one factor solution can be transformed into another without violating the basic assumptions or its mathematical properties. In other words, the extracted factors may be rotated to a terminal solution. The factor's indeterminacy makes it possible to rotate them and to choose those which best satisfy the theoretical and practical needs, i.e. to achieve simpler and more meaningful factor patterns. The rotational method can be orthogonal (factors are uncorrelated) or oblique (factors may be correlated). The former are mathematically simpler to handle, while the latter are empirically more realistic (Kim, 1970).

6.3.3 Cluster analysis

The purpose of typification is to order objects according to similarities (or dissimilarities) between them, be this through judgement or with the use of a data matrix. Objects are thus classified according to *m*-variables of an *n*-dimensional attribute space. Mathematically, the similarity between any pair of observations can be computed using a distance coefficient, an association coefficient (for binary coded or nominal data), or a correlation coefficient. Cluster analysis (CA) is a multivariate statistical method, which can perform such classification. It brings out the underlying structure, but it also imposes structure according to the algorithm's specification (Sokal, 1977).

Hierarchical clustering models form an initial partition of *N* clusters (each object is one cluster) and in a stepwise manner proceed to reduce the number of clusters, one at a time until all *N* objects belong to one cluster. All models can be characterised by a set of *N* partitions and their corresponding similarity criterion values 'α'. Hierarchical methods differ on how 'α' is defined (Mojena, 1977).

Once the cluster sequence has been established, it is necessary to determine where the process will stop, and thus how many clusters will be defined. The two approaches to determine the number of clusters are heuristic procedures and formal tests (Aldenderfer and Blashfield, 1984). In heuristic procedures, which are the most commonly used ones, the hierarchical tree (dendrogram) is 'cut' through a subjective inspection of it.

A more formal but still heuristic procedure, is to graph the number of clusters against the change in the fusion coefficient (i.e. the difference between the distance coefficient at one clustering stage and the previous one). A flat or even curve suggests that no new information is portrayed by the following mergers. Further, when two dissimilar clusters are merged, the slope of the distance coefficient curve gets steeper. When plotting the coefficient's change, jumps can be seen at the stage of merging dissimilar clusters. The problem remains how to determine when a 'significant jump' occurs.

To solve this problem, 'stopping rules' have been defined to determine which partition best approximates to the underlying populations, i.e. which should contain the final solution (Mojena, 1977; Milligan and Cooper, 1985). These rules can be based on the distribution of the criterion 'α' or a suitable transformation of it. A significant change in 'α' from one stage to the next implies a partition which should not be undertaken. One stopping rule is based on the mean and standard deviation of the *N-1* items in the distribution of α (Mojena, 1977). Specifically it states that an optimal partition of a hierarchical clustering solution is selected when:

$$\alpha_{j+1} > \overline{\alpha} + ks_{\alpha}$$

where α_{j+1} is the value of the criterion on the stage $j+1$ of the clustering process, k is the standard deviate, and $\overline{\alpha}$ and s_{α} are the mean and the unbiased standard deviation respectively of the 'α' distribution. This rule essentially parallels a one-tail confidence interval based on the fusion values. If no value satisfies the inequality, the solution is (i) one cluster, (ii) the stage j for which $j+1$ yields the largest standard deviate, or (iii) some other heuristic rule is required (Mojena, 1977).

The problem of this approach, although simple, is the value of the standard deviate. When tested with artificial data sets ('natural clusters'), the best fit between the natural clusters and the clusters established by the stopping rule were found when using values in the range of 2.75 and 3.00 (Mojena, 1977) or 1.25 (Milligan and Cooper, 1985). Such a variable range for k has a significant incidence on the partition selection.

6.3.4 SOME APPLICATIONS OF MULTIVARIATE ANALYSIS FOR THE CONSTRUCTION OF FARMING SYSTEMS TYPOLOGIES

Although the use of multivariate analysis for the construction of farm typologies is not a new concept, it has not had widespread use. Of the over 30 studies reviewed in Section 3.2.4 only a few used multivariate methods to define a typical or average farm (e.g. Wossink *et al.*, 1992). One study chooses reference farm types, classified by size and marketing channels (Berbel, 1989); others use information on production systems from a survey on farm operators (Zhu *et al.*, 1993) or simply work with an 'average' farm (Cárcamo *et al.*, 1994; Holden, 1993; Hwang and Masud, 1979; Zekri and Herruzo, 1994). Further approaches use computer models to generate production systems (Schans, 1991) or plant growth simulation models to obtain yields (Deybe and Flichman, 1991). Less frequently, a given farm (Niño de Zepeda *et al.*, 1994) or simply possible crops for a 'typical ha' are used (Zekri and Romero, 1991).

Only a few articles during the last two decades presenting applications or theoretical aspects of typification of farming systems were found in the mainstream literature. On the European scene one article highlighted the need to use formal methods (PCA and CA) to establish a socio-economic classification of German farm households instead of the more or less intuitively based methods currently employed (Gebauer, 1987). Another paper analysed and classified farming systems in Central North China using CA (Hardiman, 1990). On the Latin-American scene, a set of typification exercises showing a variety of methodological variations is presented in Escobar and Berdegué (1990). One article describes a method used to typify and classify peasant FS in Central Chile, based on PCA, CA and discriminant analysis (Berdegué *et al.*, 1990). A second paper constructed two factors which were then used to generate a typology of dairy farms in Ecuador (Landín, 1990). Other researchers used PCA and CA to typify farms in certain areas of Colombia (Duarte, 1990) and Guatemala (Martínez, Ortíz and Reyes, 1990), or simply CA to typify farms in the Western Caribbean (Douglas, 1990).

6.4 TYPIFICATION OF PEASANT FARMS: AN APPLICATION TO THE CHILEAN SITUATION

Following the framework proposed in Section 6.2 first the purpose of having a farm typology and what type of information is required to construct such a typology was defined. In this case the purpose is to evaluate the response of peasant farms to the introduction of local development policies, and thus the information on which the typification is based has to be able to show different responses between farms when a given policy is introduced.

It was hypothesised that the response to the policies (as defined in Chapter 9) would depend essentially on the resources available. Thus the typification had to take account of the resource availability, i.e. labour, land and capital. Further as it was not feasible to get the necessary information from all farmers a random sample of 67 was chosen. Data was collected for each farm from INDAP's local data files. If some information was missing, it was collected directly from the farmer by extensionists working for the companies in charge of the technology transfer programme. Specifically the following information was collected:

i. Farm's location (County)

ii. Productive orientation (as assessed by INDAP)

iii. Household structure: number of members and age

iv. Labour availability: number of months worked on-farm and off-farm by family member

v. Available land according to source: owned, taken in and given out[4]

vi. Available land according to use capability: arable, permanent pastures, with no agricultural use or irrigated

vii. Actual land use: arable, vineyards and orchards, forage crops, natural pastures, artificial pastures, woodlands, bush lands, not agricultural land or other use)

[4] 'Given-out' and 'taken-in' is used in the remainder of this thesis to indicate if in a sharecropping system the farmer owns the land or if he supplies the labour to work on that land.

viii. Livestock by species and category: Cattle (cows, oxen, and total cattle), horses; sheep (ewes and total sheep), goats (does and total), pigs (sows and total) and poultry

The information collected considered mainly physical variables because data related to social variables were not available in INDAP´s files, social variables are frequently difficult to measure and model, and because the link between the adoption of a given technology and social variables is not always known. The later is specially relevant as the purpose is to find types which can show different responses to each policy.

6.4.1 DATA DESCRIPTION

Of all the farms surveyed, 13 were located in Litueche, 24 in Marchihue and 30 in Pumanque. From the information collected the 32 variables shown in Table 6.1 were used for further analysis. Some of them were obtained through the addition of the original information (e.g. total available land and male labour).

The farmers' age ranged from 21 to 80 years, being on average middle aged. All but one farmer worked all year on the farm and all of them were males. During the year, the average availability of female labour on the farm was eight months. On a yearly basis, on 30 farms there was no female labour, in 28 there is one woman, and in six there are two. When there is a woman on the farm she spent generally the whole year on it, as only three farms showed women spending part of their time off the farm. A similar pattern was observed in access to additional family male labour. Over 55% of the farmers (37) had no access to it, 12 to one person/year and eight to two persons/year. The number of males doing part time off-farm labour was higher than for women.

Table 6.1 Mean, standard deviation (SD) and coefficient of variation (CV) for all variables

Variable	Mean	SD	CV (%)	n
Manager's age	50.09	14.60	29.1	67
Manager working on-farm (months)	11.82	1.47	12.4	67
Female labour on-farm (months)	8.04	8.53	106.0	67
Male labour on-farm (months)[5]	7.10	10.52	148.1	67
Owned land (ha)	50.40	62.36	123.7	67
Taken-in land (ha)	11.60	25.88	223.2	67
Given-out land (ha)	2.46	10.80	439.8	67
Total available land (ha)	59.55	59.99	100.7	67
Arable land (ha)	34.44	28.44	82.6	61
Permanent pastures (ha)	18.71	36.94	197.4	60
Non-agricultural land (ha)	1.45	7.81	538.6	60
Irrigated land (ha)	0.96	1.85	192.7	62
Crops (ha)	7.89	6.20	78.6	67
Natural pastures (ha)	41.54	43.71	105.2	67
Artificial pastures (ha)	2.17	15.88	732.2	67
Forage crops (ha)	0.82	4.89	595.6	67
Vines and orchards (ha)	0.66	3.17	479.3	67
Woods and forests (ha)	2.72	7.66	281.2	67
Bushes (ha)	0.82	3.75	524.7	67
Other uses (ha)	0.62	1.26	458.9	67
Unused (ha)	2.36	12.37	203.2	67
Cows (n)	5.10	5.80	113.6	67
Total cattle (n)	9.30	11.39	122.5	67
Ewes (n)	25.64	23.38	91.2	67
Total sheep (n)	28.67	26.52	92.5	67
Does (n)	6.93	27.78	401.1	67
Total goats (n)	11.12	49.57	445.8	67
Sows (n)	0.46	1.00	217.2	67
Total pigs (n)	0.63	1.57	249.7	67
Total poultry (n)	14.60	20.03	137.2	67
Oxen (n)	0.21	0.62	295.0	67
Horses (n)	2.60	2.65	101.9	67

Note: The qualitative variable County is not shown here.

The average size of the farm (own land plus taken-in land less given-out land) was under 60 ha. Most of it was owned by the farmer himself, ranging from nothing to 400 ha (Table 6.2). But, it must be recalled that they all had a similar area of available land (under 12 ha) when expressed in terms of irrigation

[5] Excluding manager's labour

equivalence (i.e. standardising for land quality). An important type of land use was sharecropping. In this system two farmers make a deal to produce a crop (mainly wheat) or raise cattle, sharing inputs and outputs. For wheat production the landowner *gives land out* and contributes with half of the inputs (seeds and fertilisers). The farmer who *takes land in* contributes with the other half of the inputs and with all the labour. The harvested crop is shared in equal parts. When this deal involves cattle different situations are observed with regards to the contribution of animals, pasture (i.e. land) and labour. Land was more often taken-in than given-out. In fact 28 farmers took-in from 2.10 ha to 130 ha, while only seven gave-out between 4.50 ha and 72 ha. Three farmers simultaneously gave land out and took land in. These results were expected, as all these farmers receive advice and/or loan from INDAP, and are thus required to work their land.

Table 6.2 Distribution of farms according to land source variables, potential land use variables and two current land use variables (number of farms per category)

Category (ha)	Own	Taken in	Given out	Arable	Perm. pastures	Non agric.	Crops	Natural pastures
0	9	39	60	--	28	50	2	6
>0 to 10	12	12	4	19	113	10	45	11
>10 to 20	6	6	1	8	6	--	18	8
>20 to 30	7	3	--	6	4	--	1	9
>30 to 40	3	1	--	5	--	--	1	3
>40 to 50	2	2	1	7	1	--	--	7
>50 to 100	20	2	1	16	8	1	--	20
>100	7	2	--	--	--	--	--	3

Of the available land the farmers judged that 57.8% was arable and 31.4% permanent pastures. Due to the fallow/crop/pasture rotation commonly used in this micro-region, the area under crop was far smaller than the total arable land and the land under pastures higher than the amount of permanent pastures. Both crops and pastures used around 83% of the available land.

Vines and orchards were grown by 29.8% of the farmers, usually in areas of under five hectares (Table 6.3). Similar situations were observed in forage crops (19.4% of the farms), artificial pastures (16.4%), bushes (28.4%), other uses (22.4%) and non-agricultural use (34.3%). Woods were observed more frequently (43.3%) and not only in small, but also in larger areas (up to 54 ha). Access to irrigation was very limited. 24 farms (39%) have no irrigation at all, and 26 (42%) had it on less than one hectare of land.

Table 6.3 Distribution of farms according to availability of irrigation and seven land use variables (number of farms per category)

Category (ha)	Irrigated	Vines/ Orchard	Forage crop	Artificial pasture	Woods	Bushes	Other uses	Unused
0	24	47	54	56	38	48	52	44
>0 to 1	26	14	11	7	11	5	7	12
>1 to 2	3	3	--	--	1	5	3	3
>2 to 3	4	1	1	--	7	4	0	5
>3 to 4	1	--	--	1	--	2	3	1
>4 to 5	1	--	--	--	1	--	1	1
>5 to 10	3	1	--	1	5	--	--	1
>10		1	1	1	4	3	1	--

Cattle and/or sheep were common on all farms. Forty-six farms had both species, while seven had only sheep, six only cattle and only eight farms had neither. The sheep herd ranged from 2 to 113 heads and the cattle herd from 1 to 68 (Table 6.4). Goats were not frequently observed in this area (17.9% of farms), although in two farms they represented a considerable number (203 and 352 animals).

Table 6.4 Distribution of livestock existence on the surveyed herds

Range	Sheep	Cattle	Goats	Oxen	Horses	Pigs	Poultry
0	14	15	55	60	10	52	40
1-10	6	31	3	7	56	15	--
11-20	6	16	3	--	1	--	5
21-30	11	2	2	--	--	--	9
31-40	12	1	2	--	--	--	5
41-50	8	1	--	--	--	--	5
51-100	8	1	--	--	--	--	3
>100	2	--	2	--	--	--	--

Horses are the main source of draught power. Only seven farms had one pair of oxen and no farmer had a tractor to work the land. Eight farms had neither horses nor oxen, and depended on off-farm draught to work the land. Pigs and poultry were not common, and usually observed in small numbers. No farm had more than four sows and of the 27 farms with poultry (mainly chickens), only seven had between 50 and 70 chickens. Such numbers were not enough to generate a sufficient output to maintain a regular sale of products.

6.4.2 DATA SELECTION FOR CLUSTERING

Four different criteria were used to determine which of the initial set of 33 variables[6] would be used in clustering: *absence of missing data, relevance to the study, variation*, and *correlation* (see Section 6.3.1).

First the three variables related with land quality (arable, pastures, and non-agricultural land) and the variable available irrigation were discarded due to missing data. The impact of the elimination of these four variables on the generation of clusters was thought to be small, as irrigated land is scarce and land quality is related to land use. In fact arable land and permanent pastures were each correlated to 13 of the remaining variables.

Next four variables were deemed irrelevant for the purpose of this study and were discarded. As there was no farm in which the existence of poultry or pigs could be considered of significance for the production system, these variables were discarded. The County in which the farm is located had no relevance, because the unit of analysis was defined as the micro-region, and there was no reason to justify clusters based on location. If differences between Counties did exist, they should become evident after typification. Further, qualitative variables (like County) cannot be included into factor and cluster analysis. Its consideration would require its replacement by three variables (Litueche, Marchihue, and Pumanque) with values zero or one defining the location of the farm[7].

The third criterion, variability, was evaluated through the coefficient of variation or CV (Table 6.1). It was *a priori* established that variables with a CV of less than 50% would not be considered. Two variables did not match this criteria, i.e.

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[6] Thirty two variables shown in Table 6.1 plus the County variable.

[7] Actually only two variables are required, because the third variable is by default defined by the values of the other two, i.e. one if the other two are zero and zero if any of them is one.

manager's age and time spent by the manager on farm, the first of which is also not relevant for this typification.

Two new variables, number of ewes and does and number of sheep and goats were constructed, by adding the corresponding pair of variables. This was done for two reasons. First, from a management point of view both species had similar features (required inputs, quantity and timeliness of outputs, etc.) and second, on the sampled farms goats were not important and in ten out of twelve cases they were kept with sheep (Table 6.4).

Finally, Pearson correlation coefficients between the 25 remaining variables were computed (Table 6.5). The variables land given out and area under vines/orchards are not shown, as they were uncorrelated to any other variable.

The purpose of this analysis was to generate from the set of available variables two sub-sets, one containing variables to be used in multivariate analysis and the other with dropped variables, through various steps of inclusion and exclusion of variables. First, it was determined that two variables, land given out and area of vineyards and orchards, were uncorrelated to any other and were thus deemed to be included. Second, six pairs of highly correlated variables ($R^2 \geq 0.90$) were found and one variable of each pair was then discarded. The criteria followed to determine which variable to keep of each pair was the variable's relevance, the quality of the data obtained from the farm, and the availability of the data. Of the pair total available land and natural pastures the latter was discarded, because it is more susceptible to change every year than the total area of available land. Other correlated variables were the four pairs of variables relating number of livestock to number of females (i.e. cattle, sheep, goats and sheep & goats). As data on female livestock has a steadier level and determines to a great extent the total number of livestock, the four variables total number of cattle, sheep, goats and sheep & goats were discarded from further analysis (i.e. number of cows, ewes, does and ewes and does were kept). Finally the variables number of ewes and number of does were also discarded as they were as expected highly correlated to number of sheep and does.

Table 6.5 Correlation between farm variables after preliminary selection (only those with p≤5% are shown)

	Woman on-farm	Other males on-farm	Owned land	Taken land	Total available land	Arable land	Forage crop	Artificial pastures	Natural pastures	Woods/forest	Bushes	Other land	Unused	Cows	Cattle	Ewes & does	Sheep & goats	Oxen	Horses
Woman on-farm	1																		
Other males on-farm		1																	
Owned land			1																
Taken-in land			-0.28	1															
Total available land		0.26	**0.89**		1														
Arable land		0.31			0.33	1													
Forage crop			0.36		0.36		1												
Artificial pastures			0.25					1											
Natural pastures			0.25		**0.92**		0.34		1										
Woods/forest			0.26	0.27	0.37		0.28	0.29		1									
Bushes	0.27		0.70		0.71				0.66		1								
Other land				0.62								1							
Unused	0.31			0.25	0.33				0.27	0.54			1						
Cows		0.26	0.54		0.47	0.43			0.46					1					
Cattle		0.28	0.62		0.54	0.42			0.52		0.30			**0.96**	1				
Ewes & does			0.59		0.70				0.70		0.51	0.54				1			
Sheep & goats			0.52	0.29	0.68				0.67		0.54	0.64				**0.97**	1		
Oxen	0.37	0.34			0.27				0.28		0.42					0.42	0.45	1	
Horses		0.28	0.66		0.62	0.44			0.59		**0.81**			0.32					1

Next, variables with a small number of correlations were included in the final data set. These variables were woman working on-farm (three correlations), artificial pastures (three correlations), and other land (three remaining correlations because three had already been discarded).

Finally the ten remaining unclassified variables were analysed one by one. The variable other male members working on-farm was included because up to this stage only two variables to which it was correlated were in the data set. Owned land was excluded because of its high correlation with total available land (0.89) and because it was correlated to three variables already in the data set. Land taken in and area under forage crop were correlated to only two already selected variables, and were thus included. All remaining variables (arable land, woodland/forests, bushes, non agricultural land, oxen, and horses) were discarded because they had at least three correlated variables in the final set.

As a result of this process 14 variables were rejected and 11 were kept. The high number of correlations between the variables means that a lot of information is redundant. This confirms that typification surveys should contain relatively few questions but many observations (Escobar and Berdegué, 1990).

6.4.3 FACTOR ANALYSIS

The purpose of factor analysis was to further reduce the number of variables, which were then used in cluster analysis. PCA was used to construct 11 factors based on the selected variables for the 67 observations (Table 6.6). Depending on the criteria used a variable number of factors could be retained. When Kaiser's criterion (Eigenvalue > 1) was used four factors were retained. On the other hand the residual correlation rule required to extract eight factors, while the straight line rule retained six factors (Figure 6.1).

Table 6.6 Factor's Eigenvalue, difference between Eigenvalues, proportion of the total variation and cumulative variation explained by each factor

Factor	Eigenvalue	Difference	Proportion	Cumulative
1	2.375	---	21.6%	21.6%
2	1.850	0.525	16.8%	38.4%
3	1.400	0.450	12.7%	51.1%
4	1.180	0.220	10.7%	61.9%
5	0.991	0.188	9.0%	70.9%
6	0.936	0.056	8.5%	79.4%
7	0.661	0.275	6.0%	85.4%
8	0.628	0.033	5.7%	91.1%
9	0.517	0.110	4.7%	95.8%
10	0.370	0.148	3.4%	99.2%
11	0.093	0.277	0.8%	100.0%

Considering that a strict selection of correlated variables had been done, it was decided that a rather large number of factors should be retained. The rather homogenous reduction in Eigenvalues (slope of Figure 6.1) also suggested a conservative selection of factors. As a result, the first seven were extracted. The seven extracted factors explained 85.4% of the total observed variation and at least 70.0% of every original variable's variation[8].

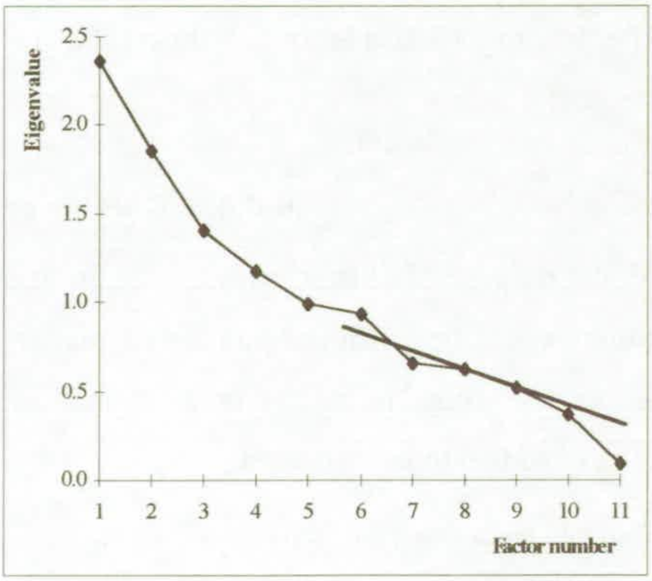

Figure 6.1 Eigenvalues v. number of factors

[8] No further analysis was performed on these factors, as this was outside the scope of this thesis.

6.4.4 Cluster analysis

6.4.4.1 Cluster construction

The seven retained factors were used to construct the clusters which later were used to define the FSs. Ward's minimum variance criterion was used as clustering method (SAS, 1985). This method, which minimises the variance within clusters, tends to find (or create) clusters of relative equal sizes and shapes as hyperspheres. It works by joining those groups or cases that result in the minimum increase in the within-groups sum of squares or the error sum of squares (Aldenderfer and Blashfield, 1984):

$$ESS = x_i^2 - \frac{1}{n(\Sigma x_i)^2}$$

The dendrogram in Figure 6.3 shows the sequence by which the clusters were merged.

6.4.4.2 Cluster selection

As the purpose of cluster analysis was to generate FSs, an ideal *a priori* distribution would be a reduced number of similarly sized groups. Farms not belonging to any group (in other words 'groups' of one) would only represent themselves and had to be discarded.

Four observations (farms 64 to 67, i.e. the last four farms in Figure 6.3) joined a cluster very late and thus were considered as belonging to different classes. A similar situation occurred with farms 62 and 63, which quickly merged in one cluster, but then did not join other observations until late in the analysis. Of the remaining 61 observations, 60 farms (number 1 to 60) were easily classified in four groups following the cutting line A shown in Figure 6.3. The next farm, i.e. number 61, merged farms 58 to 60 in a slightly later stage of the process. Thus, visually five types were recognised, while five farms remained unclassified. When a different cutting line was used (line B) farm 61 was merged to farms 58 to 60 and five clusters and four single observations remained.

Following a more formal approach, both the distance coefficient and its increase were plotted against the number of clusters (Figure 6.2). It was seen that until 17 or 18 clusters remained, the distance between joining clusters was small and fairly constant, without important jumps. Then the increase in the value of coefficient became bigger, but no meaningful jump was observed until 11 clusters remained. The next clustering produced a jump, as did the next three stages. The curve flattened again when seven to five clusters remained. This plot suggested that the appropriate number of clusters for this sample and this method was 11.

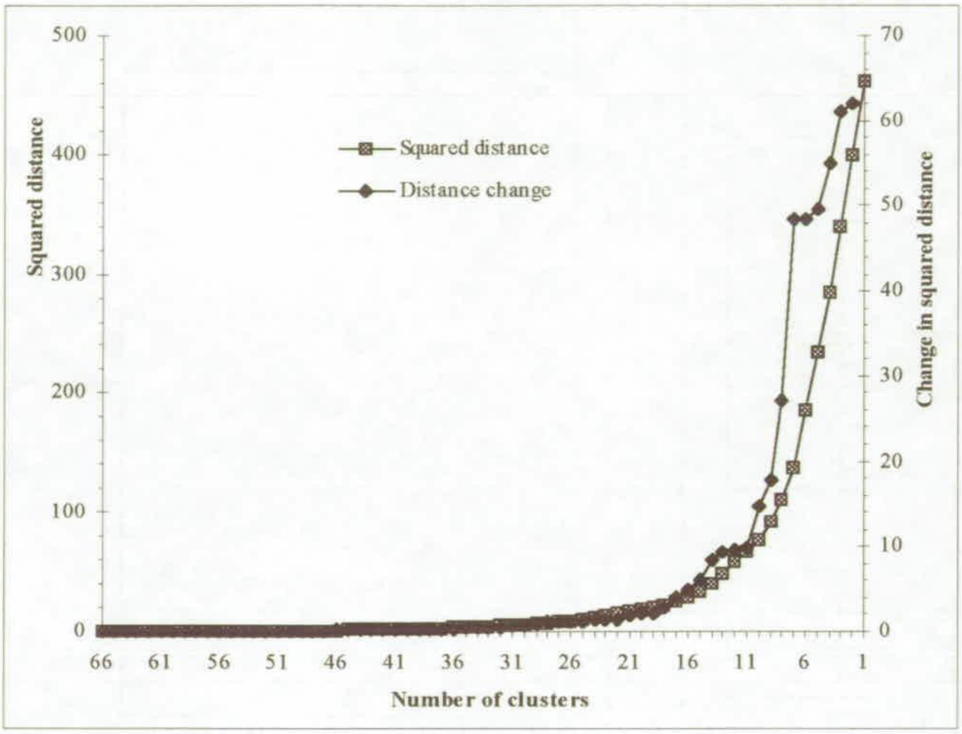

Figure 6.2 Plot of squared distance and change of squared distance against number of clusters

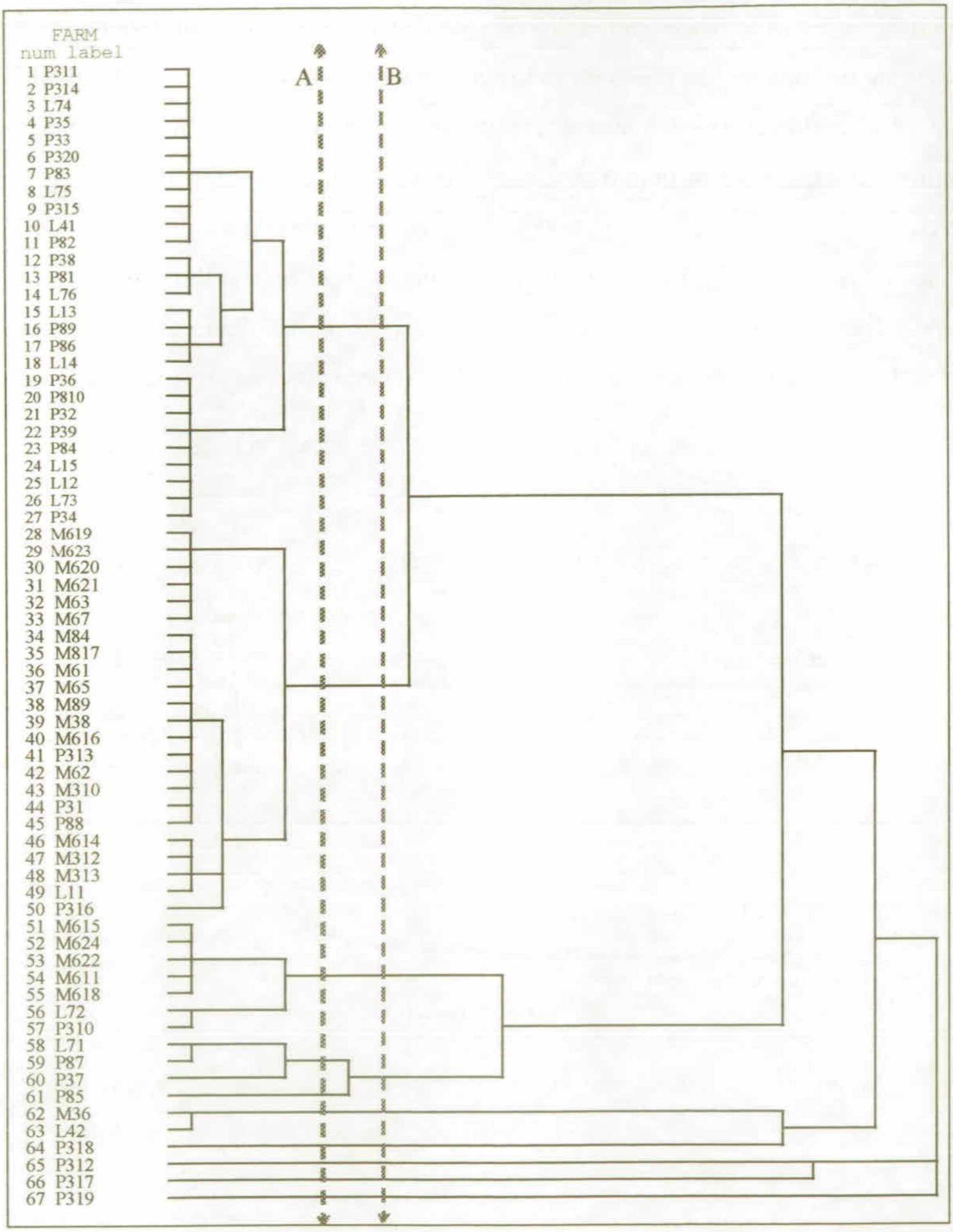

Figure 6.3 Dendrogram showing the full history of cluster construction and two cutting lines

Such a cluster pattern represented according to Figure 6.3 six clusters and five unclassified observations (one merger before line A) and was slightly different from the visual one (Table 6.7). The main difference was that Cluster II was split in two and that farm 61 remained definitively unclassified. In fact, the mergers of Cluster II-a with II-b and Cluster IV with Farm 61 produced the first two jumps in the distance coefficient.

Table 6.7 Comparison of clusters composition chosen under visual and distance jump criterion (by farm number)

Cluster	Visual criterion	Distance criterion
C-I	28 to 50	28 to 50
C-II	1 to 27	
C-II-a		1 to 18
C-II-b		19 to 27
C-III	51 to 57	51 to 57
C-IV	58 to 60 (and 61?)	58 to 60
C-V	62 to 63	62 to 63
Unclassified	64 to 67 (and 61?)	61, 64 to 67

To define the classes to be used in further analysis, the cutting line B was used, which was a relaxed jump criterion. The classes were cut when there were still nine clusters (including single observations). This means that C-I, C-II, C-III, C-IV (along with farm 61), and C-V from Table 6.7 were retained, while four isolated observations had to be eliminated.

6.4.4.3 Cluster characterisation

Table 6.8 shows the averages and standard deviations of the variables used for clustering and for those not used in the clustering process for each of the five clusters. As cluster analysis is a multivariate tool and mean comparison is an univariate one, the results on Table 6.8 have to be taken as a reference. Absence of significant differences did not mean that that particular variable was irrelevant in the clustering process, as CA considers the joint variation of all variables and not the variation of single variables. Also some rather large differences between clusters were not significant, due to the highly unbalanced nature of the clusters.

Table 6.8 Averages and standard deviations of the clustering variables for each cluster

	C-I	C-II	C-III	C-IV	C-V
Number of farms	23	27	4	7	2
Farmer's age	$48.7^{ab} \pm 13.3$	$47.4^{ab} \pm 16.7$	$66.8^{a} \pm 7.0$	$58.0^{ab} \pm 6.4$	$39.0^{b} \pm 19.8$
Farmer working on-farm	$12.0^{a} \pm 0.0$	$12.0^{a} \pm 0.0$	$12.0^{a} \pm 0.0$	$12.0^{a} \pm 0.0$	$6.0^{b} \pm 8.5$
Woman working on- farm	$0.7^{c} \pm 2.7$	$13.6^{b} \pm 3.9$	$24.0^{a} \pm 9.8$	$3.4^{c} \pm 5.9$	$0.0^{c} \pm 0.0$
Males on farm	$3.1^{b} \pm 4.9$	$3.6^{b} \pm 6.4$	$27.8^{a} \pm 16.5$	$24.0^{a} \pm 6.9$	$2.5^{b} \pm 3.5$
Owned land	$34.7^{b} \pm 32.6$	$37.0^{b} \pm 36.0$	$153.2^{a} \pm 169.8$	$50.1^{b} \pm 37.6$	$98.0^{ab} \pm 24.0$
Land taken	10.2 ± 19.7	6.3 ± 8.3	0.0 ± 0.0	33.1 ± 49.5	6.0 ± 8.5
Land given	$1.1^{b} \pm 3.0$	$0.7^{b} \pm 2.6$	$0.0^{b} \pm 0.0$	$0.0^{b} \pm 0.00$	$61.0^{a} \pm 15.6$
Available land	43.8 ± 31.5	42.6 ± 32.7	153.2 ± 169.8	83.2 ± 22.3	43.0 ± 31.1
Arable land	37.9 ± 24.1	24.1 ± 25.9	30.0 ± 41.0	55.7 ± 29.9	--
Permanent pastures	5.8 ± 15.4	16.1 ± 22.1	44.5 ± 62.2	18.9 ± 45.2	--
Non-agricultural	0.2 ± 0.7	0.8 ± 1.8	2.5 ± 3.5	8.6 ± 22.7	--
Irrigated land	0.5 ± 0.8	1.2 ± 2.5	0.5 ± 0.9	1.7 ± 2.2	2.1 ± 1.3
Crops	6.6 ± 4.0	7.4 ± 6.8	9.0 ± 7.4	15.5 ± 5.09	5.9 ± 2.7
Natural pastures	$35.1^{b} \pm 28.0$	$30.2^{b} \pm 27.9$	$111.1^{a} \pm 111.4$	$57.8^{b} \pm 26.3$	$26.5^{b} \pm 26.9$
Artificial pastures	$0.1^{b} \pm 0.2$	$0.1^{b} \pm 0.3$	$1.5^{a} \pm 3.0$	$0.0^{b} \pm 0.0$	$0.3^{b} \pm 0.4$
Area forage crop	0.1 ± 0.5	0.3 ± 0.6	0.8± 0.9	0.0 ± 0.0	0.0 ± 0.0
Vines/orchard	0.4 ± 1.5	0.2 ± 0.4	0.1 ± 0.1	0.2 ± 0.6	0.1 ± 0.1
Woods & forest	0.9 ± 2.7	1.4 ± 1.8	3.8 ± 4.3	7.8 ± 20.4	7.7 ± 10.3
Bush land	$0.2^{b} \pm 0.6$	$1.7^{b} \pm 3.8$	$25.5^{a} \pm 49.7$	$0.5^{b} \pm 1.4$	$1.5^{b} \pm 2.1$
Land on other use	0.3 ± 0.8	0.5 ± 1.1	0.0 ± 0.0	0.6 ± 1.5	1.0 ± 1.3
Unused	0.2 ± 1.0	0.9 ± 1.1	1.6 ± 1.4	0.9 ± 2.3	0.1 ± 0.18
Cows	$4.9^{b} \pm 4.2$	$2.9^{b} \pm 3.3$	$17.3^{a} \pm 14.1$	$6.3^{b} \pm 3.9$	$7.0^{b} \pm 1.4$
Total cattle	$7.0^{b} \pm 6.0$	$6.3^{b} \pm 7.0$	$38.0^{a} \pm 27.3$	$9.6^{b} \pm 5.4$	$16.0^{b} \pm 4.2$
Ewes	29.2 ± 22.7	20.6 ± 22.2	28.3 ± 39.7	21.7 ± 11.2	33.0 ± 17.0
Total sheep	31.9 ± 25.1	24.8 ± 26.5	33.5 ± 43.8	23.3 ± 12.2	27.5 ± 38.9
Does	$0.0^{b} \pm 0.0$	$4.2^{b} \pm 8.7$	$25.0^{a} \pm 50.0$	$0.0^{b} \pm 0.0$	$5.0^{b} \pm 7.1$
Total goats	$0.0^{b} \pm 0.0$	$4.9^{b} \pm 10.3$	$50.8^{a} \pm 101.5$	$0.0^{b} \pm 0.0$	$8.5^{b} \pm 12.0$
Ewes & does	29.2 ± 22.7	24.8 ± 23.6	53.3 ± 89.4	21.7 ± 11.2	38.0 ± 24.0
Sheep and goats	$31.9^{b} \pm 25.1$	$29.7^{b} \pm 28.2$	$84.3^{a} \pm 144.8$	$23.3^{b} \pm 12.2$	$36.0^{b} \pm 50.9$
Sows	0.1 ± 0.4	0.9 ± 1.3	0.8 ± 1.5	0.3 ± 0.76	0.0 ± 0.0
Total pigs	0.1 ± 0.4	1.3 ± 2.2	0.8 ± 1.5	0.3 ± 0.76	0.0 ± 0.0
Poultry	$27.83^{a} \pm 19.7$	$1.6^{b} \pm 5.9$	$0.0^{b} \pm 0.0$	$34.3^{a} \pm 25.1$	$27.0^{a} \pm 4.2$
Horses	$2.3^{b} \pm 1.2$	$2.2^{b} \pm 1.7$	$7.0^{a} \pm 8.7$	3.14 ± 2.3	$3.5^{b} \pm 0.7$
Oxen	$0.0^{b} \pm 0.0$	$0.3^{b} \pm 0.8$	$0.0^{a} \pm 0.0$	$0.2^{b} \pm 0.6$	$1.5^{b} \pm 1.0$

Note: Different superscripts in a same row represent significant differences ($p \leq 5\%$)

Nevertheless, when comparing the clusters it is seen that labour variables are very important in differentiating all clusters. The largest single difference between C-I and C-II is female labour, while male labour makes a distinctive difference between these two and clusters C-III and C-IV. Female labour is also relevant but not unique in distinguishing C-IV from C-V. Table 6.9 and Figure 6.4 highlight these and other differences between the selected clusters.

Table 6.9 Comparison between selected clusters

	C-I	C-II	C-III	C-IV	C-V
Farmer on farm	One year	One year	One year	One year	Half a year
Additional labour	Marginal	One woman	Two women, two men	Two men	Marginal
Farm size	Small	Small	Large	Medium	Small
Herd	Small	Small	Large	Small	Large
Arable/available	86.5%	56.6%	19.6%	67.0%	--
Crop/arable	17.4%	30.9%	30.0%	27.8%	--
Sharecropping	Takes-in	Takes-in	---	Takes-in	Gives-out

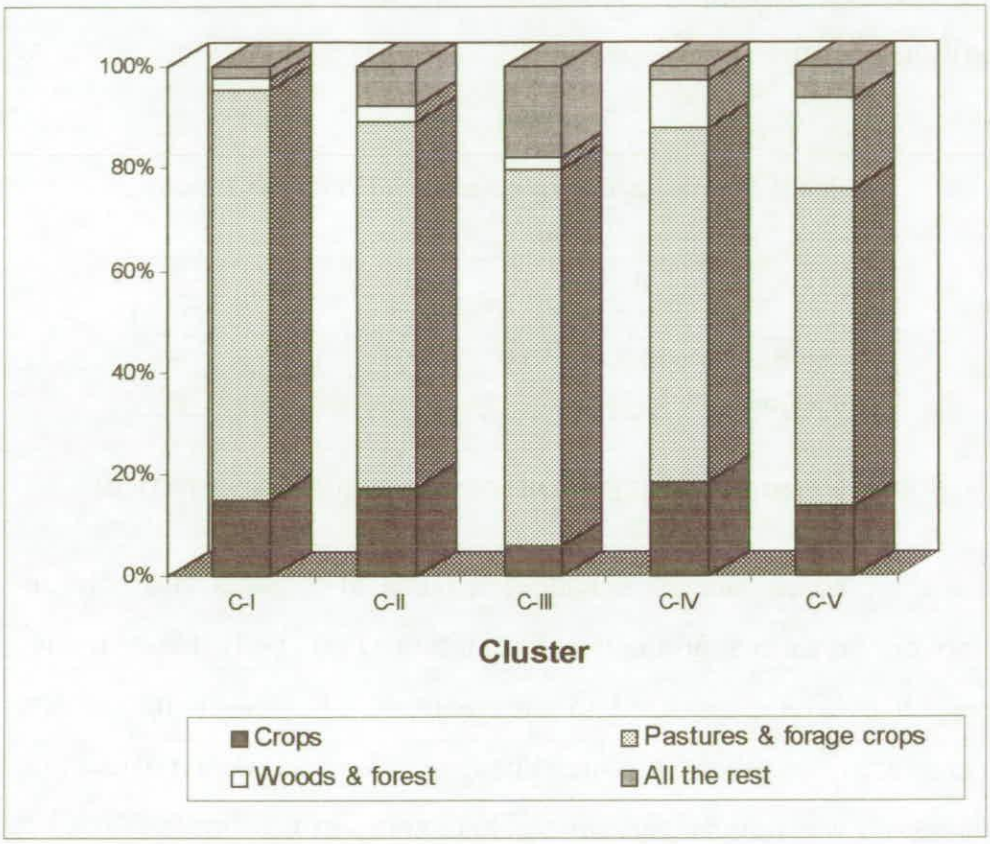

Figure 6.4 Land use as percentage of available land by cluster

C-II and specially C-III have less arable land, so that they make a more intensive use of it and the ratio of crop over arable is almost double that of C-I. For C-IV the availability of labour allows to have a high ratio. Under a normal rotation for that area, the expected ratio would be 20% (one year crop, three years pasture and one year fallow). Further the farms of type I have over 80% of their area under pastures, while around 18% of farm land of types III and V are under other use (mainly bushes) or woods.

The distribution of farms across Counties also showed a distinctive pattern (Table 6.10). Although χ^2 should not be used to analyse these results[9], it can be concluded that the distribution was not random. Farms located in Litueche and Pumanque concentrated in C-II while 75 % of Pumanque's farms belonged to C-I and none to C-II. The observed distribution in C-I and C-II was very different to the expected values of around 35 to 40 % of each Counties' farms in C-I and C-II, respectively. Finally, it should be mentioned that the four unclassified farms were all located in Pumanque. They had either large areas of vineyards, forage crops, artificial pasture or were under other use, as well as large sheep and/or goat herds.

Table 6.10 Percentage of farms of each County allocated to every cluster

	C-I	C-II	C-III	C-IV	C-V
Litueche	7.7	69.2	7.7	7.7	7.7
Marchihue	13.3	60.0	10.0	3.3	--
Pumanque	75.0	--	--	20.8	4.2

6.4.5 FARMING SYSTEM AND PRODUCTIVE ORIENTATION

Up to this stage no consideration had been taken of the area currently under a given crop or the farm's productive orientation (PO). Only the variable *area under crop* had been considered in the analysis. The reason not to consider specific crop areas was that these may change between years and affect the clustering process. It was thus judged preferable to consider the farm's PO as a typification criterion. The problem is that the inclusion of the qualitative variable PO in factor and cluster analysis would imply a large increase in the number of variables, i.e. one per type of PO. To avoid this it was decided that after clustering a cross-tabulation between clusters and INDAP's POs would be made thus putting a greater emphasis on present activities. In this way each of these Cluster-PO pairs was then identified as a Farming System.

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[9] Use of χ^2 is not recommended when more than 20% of the cells have expected values of five or less. In this case it was 81.5 % of the County-Cluster pairs.

Of a maximum possible of 30 FSs (six POs and five clusters), 16 were not empty. Of these only eight FSs had four or more observations, one had two observations while the other eight had only one farm (Table 6.11). Thus, even as the observations for each cluster are spread on various POs, it can be seen that they concentrated in one or two POs. These results also suggested that the typology was able to identify some of the data's underlying structure[10].

Table 6.11 Cross-tabulation of farms according to cluster and productive orientation

Productive orientation	C-I	C-II	C-III	C-IV	C-V
1. Wheat-sheep	1	**4**[B]			
3. Wheat-legume-sheep	**7**[D]	**11**[H]	1	1	1
4. Wheat-maize-orchard		1			1
6. Wheat-pasture-cattle	**11**[C]			**5**[E]	
7. Wheat-pasture-cattle-legume-maize		**4**[A]	1	1	
8. Wheat-vineyard-sheep	**4**[F]	**7**[G]	2		

Note: the superscript shows the letter used to identify each FS throughout this thesis

6.4.6 VALIDATION OF THE FARMING SYSTEM TYPOLOGY

An important issue of clustering, in this specific case FS definition, is the evaluation of the validity of the types defined. As CA allows the grouping of any collection of individuals or observations according to any set of variables, it is necessary to determine if the generated typology represents an observable classification or only a classification imposed on the data by CA. In other words the same set of observations in different contexts may lead to distinct typologies, each of them suited for the purpose of their own study. Thus the usefulness of a typology is generally restricted to the context in which it was constructed.

Some results suggest that the analysis was able to construct FSs reflecting different resource endowments, which would allow, as hypothesised, the FSs to respond differently to the development policies. In Chapter 5 it was shown that slightly different agro-climates determined that different POs were observed in the three Counties (Table 5.5). Now as the distribution of farms in a given cluster

[10] Again χ^2 should not be used due to the large number of PO-cluster pairs with expected values of less than five.

along Counties as well as along POs was not random (i.e. farms belonging to each cluster tended to be located in certain Counties and to present certain POs), it can be argued that the typification process was able to determine some underlying structure, as County and PO had not been considered in the set of clustering variables. Such non-random distribution strongly suggests that the typology here developed reflects differences in resource endowment (mainly natural environment) and that it can therefore be used for the evaluation of the impact of development policies on the FS's sustainability.

6.5 SELECTION OF REPRESENTATIVE FARMS

Finally, as time and budget constraints did not allow the construction of the operational FS models based on in-depth surveys of all farms, a selection of FSs and farms within FSs had to be done. First it was decided that the eight FSs (i.e. cluster-PO pairs in Table 6.11) with four or more farms were to be used to construct the models. FSs with only one or two farms were eliminated because they represented only a small fraction of the micro-region's farms. Second it was decided that a representative farm was the one more similar to the FSs average farm. The alternative of surveying all farms belonging to these eight FSs was also discarded due to budget and time limitations. Although the results obtained using representative farms (Chapters 9 and 10) instead of average farms may be different, it is not possible to determine how these differences will affect the evaluation of each policy. Nevertheless, the use of representative farms instead of average farms has no effect on the construction and validation of the farm level models (Chapter 8) and of the micro-regional model (Chapter 9).

The similarity between the average farm and a farm was computed through the total distance between both, defined as the sum of the squared standardised difference between every variable for the farm and its group average.

$$d_j = \sum_{i=1}^{n} \left(\frac{X_{ij} - \overline{X}_i}{sd_i} \right)^2$$

where d_j is the total distance between farm j and its corresponding average farm; X_{ij} is the value of variable i for farm j; $\overline{X}_i$ is the value of variable i for average farm; and sd_i is the standard deviation of variable i for the corresponding FS.

Next the distance between the observed and the average value was computed for each of the eleven clustering variables and each farm. Within each FS the farm with the lowest aggregate distance was then defined as the representative farm and selected for further surveying. Table 6.12 shows the partial and total deviations for each selected farm from its corresponding average farm. Before the actual farm surveys were undertaken, it was realised that the best farm for FS IV-6 (farm E* in Table 6.12) happened to have accessibility problems, which would have increased surveying costs. Therefore for this FS the second best farm is also shown, as this was the one used for modelling and policy evaluation (Chapter 8 and following).

Table 6.12 Partial standardised deviations and total squared deviations from the FS's average for all selected farms

Farm or FS[1]	D	C	F	B	H	A	G	E*	E
Cluster	I	I	I	II	II	II	II	IV	IV
PO[2]	3	6	8	1	3	7	8	6	6
Woman on farm	0.38				0.30		-1.35		
Other on farm	0.57	0.80	0.50	0.78	0.30	0.50	-1.13	0.45	0.45
Total available land	0.26	0.46	-0.13	-0.50	0.49	0.50	0.05	0.26	-1.06
Taken-in land	0.85	0.36			0.26	0.51	-0.05	0.45	0.45
Given-out land		0.55				0.50	0.38		
Vineyard/orchard	-0.08	0.67	-0.85	0.20	0.88	0.62	-0.21	-0.17	-0.17
Forage crop	0.38		-0.74		0.30	0.69	-0.16		
Artificial pasture	0.38		0.50		0.44	0.50	-0.50		
Other land		0.43	-0.87	0.50			0.57		
Cows	0.38		0.50		0.45	0.38	0.49		
Ewes and does	-0.44	0.61	-0.11	-1.14	0.62	0.75	-0.13	-0.71	0.71
Total	1.89	2.29	2.80	2.46	2.13	2.83	4.14	1.00	2.04

1: Letters identify the farms sorted from North to South and will identify from now on also the FS
2: See Table 6.11

6.6 Summary

This chapter dealt with the construction of a typology of peasant FSs in the micro-region. The typology is specific for this study and was based on variables which define the systems resource endowment, mainly labour and land. Before the typology was constructed, a method for this is presented. It demands first the definition of the purpose of the typology and then it constructs the FSs types using multivariate analysis of a set of selected variables. This method was then applied to a sample of peasant farms in the area. Using cluster analysis and seven factors constructed through Principal Component Analysis, five clusters were identified. The main differentiating variables between clusters were related to available labour. The clusters were further split according to the farm's productive orientation. Although it is difficult to validate the typology, the distribution of clusters across Counties and across PO's suggest that the typology recognised the underlying structure. Finally for each one of the eight larger FSs, a representative farm was chosen. This farm was then the subject of in-depth questioning and the data used to construct the operative models (Chapter 8). These models were based on an algebraic prototype model and are presented in the following chapter.

7. THE SPECIFICATIONS OF THE FARMING SYSTEM AND MICRO-REGIONAL PROTOTYPE MODELS

7.1 INTRODUCTION

In Chapter 5 both a description of the relevant micro-region in Central Chile and the conceptual model for the evaluation of sustainability of peasant farms were presented. Before constructing and using this model its algebraic form needs to be specified, taking into account the particular features of the peasant FSs in the study area. As these FSs have already been characterised and typified in Chapter 6, now the corresponding programming models are specified. A single base model, called the prototype model, forms the basis for developing an operational model for each of the FSs that have been typified. A similar prototype model is stated for the whole micro-region.

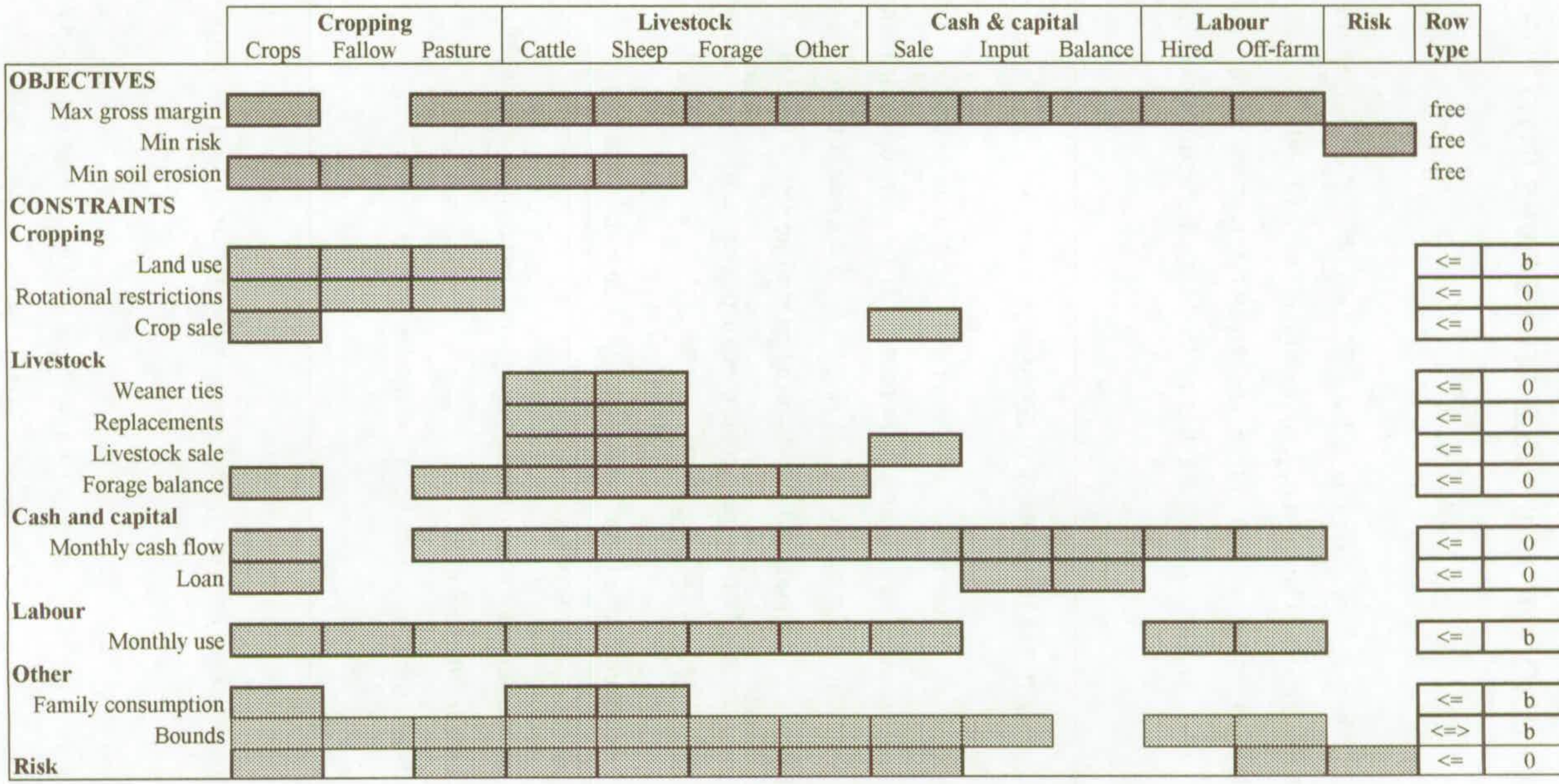
Although the construction of linear optimisation models can appear to be simple, the importance of constructing a good model must be emphasised. Any model can be optimised, but only the design of a model which represents reality can generate valid results (Zeleny, 1982). It is common to find applied farm models which did not take due care in farm selection and model construction. From the point of view of sustainability optimal system design requires the treatment and inclusion of agronomic (i.e. technical), economic, social and environmental data collected from both primary and secondary sources. This chapter deals with the farming system model, its structure, objective functions and constraints. Special note is taken of the analysis of risk, soil loss, and income differences. The data requirements of the models developed for the study are highlighted. At the end of the chapter some of the MCDM methods and the methods used to find the efficient solutions for the models developed are reviewed briefly.

7.2 THE SPECIFICATIONS OF THE FARMING SYSTEM MODEL

The structure of the prototype model can be shown as a matrix or a tableau, whose vertical columns represent productive and other activities on a farm type or region, and whose horizontal rows the constraints defining the relevant bounded environment (Figure 7.1). Having specified the three objective functions, five groups of restraints are defined. Cropping restraints define land use and rotational requirements, and the livestock restraints do the same for herd structure, its output and forage requirements. Cash and capital and labour restraints balance their availability and their use. Finally the risk vectors represent the deviation from the expected risk targets, as specified in a standard target-MOTAD format. Upper and lower bounds for specific activities are included.

The activities of the models are also grouped in a similar fashion. Cropping activities include all land based farm enterprises (crops, pastures, woods, etc.). The different cattle and sheep categories are modelled using livestock activities. Loans and working capital are part of the cash and capital activities. To allow the transfer of unused cash from one period (month) to the next cash transfers are also included. To allow hiring labour from outside the farm when labour deficit occurs labour hire activities are included. Similarly, off-farm labour activities allow the household to sell excess labour for off-farm activities. Finally the risk ties compute the yearly deviations between the total expected GM from the target value, and transfer those deviations to the objective function.

Figure 7.1 The matrix skeleton of the FS prototype model



Note: The shaded cells when replaced by coefficients derived from data collected for this study make the model operational

7.3 INCLUSION OF MULTIPLE OBJECTIVES INTO THE MODEL(S)

As explained in Chapter 5 each FS has at least the two objectives of maximising profit and minimising risk. The third objective, minimisation of soil loss, which is mainly a public objective and therefore has greater relevance at the micro-regional level, is included in the FS models to facilitate the optimisation of the models.

7.3.1 MAXIMISATION OF GROSS MARGIN

The first objective can be constructed using any of the various measures which estimate profit, such as gross margin[1], farm profit, net farm income, or management and investment income (MAFF, 1977). The selection of the measure depends mainly on the available data, and on the gain of accuracy with the use of more precise information. For the particular case of peasant farming systems GM was used as a proxy of profit because:

i. The absence of records reduces the availability of data and its accuracy
ii. Fixed costs are usually very low
iii. Fixed costs do not vary according to the optimal farm plan[2] and therefore do not affect the optimal solution

Eq. [7.1] represents the first objective of the model.

$$Max\ Z_1 = \sum_{j=1}^{n} GM_j x_j \qquad [7.1]$$

Where x_j is the level of activity j; and GM_j is the per unit GM of activity j.

[1] As the unit of analysis is the farm, gross margin will be referred to total farm gross margin and not the GM of particular enterprises.
[2] An exception is the opportunity cost of the capital invested in fixed assets, especially livestock

GM is computed for all real activities. Unless the farmer is working off-farm the opportunity cost of labour is assumed to be zero, due to the difficulty of estimating its value. Nevertheless, future research should explore the alternative of using a measure of labour income, e.g. GM divided by the amount of family labour used to produce that income, or to value family labour. As time is a basic resource of households it would be rational for households to seek to maximise the return to their labour. This is necessary because the opportunity cost of family labour is almost certainly not likely to be zero (Low, 1992).

7.3.2 MINIMISATION OF RISK

During the last few decades analysis of risk at farm level has been the focus of considerable research activity and particularly in agricultural economics received a great deal of attention. Thus, the purpose of this section is to describe some methods used in risk analysis, criteria to evaluate the efficiency of the proposed methods, and algorithms to include risk into LP and MCDM models. Finally, the method taken for the analysis of risk in this thesis is described.

It is obvious that every action produces not only a single outcome but a set of outcomes, to which an objective or subjective probability of occurrence can be attached. As each of these outcomes affects the decision maker's utility differently he has a different preference for each of them. Risk analysis looks for methods to rationally find the optimal action from the point of view of the distribution of all possible outcomes. The objective is to sort outcomes according to preferences, and then to select the action with the best outcome from the decision maker's preferences point of view. Thus, the elements of the decision problem are actions, states with associated probabilities of occurrence, consequences associated to each pair of action/state, and a decision criterion for ordering actions (Selley, 1984).

Two main models exist for the analysis of risk (Robison, Barry, Kliebenstein and Patrick, 1984). One is the expected utility model. This model assumes that the decision maker will select a plan which maximises his expected utility, defined as the sum of the utility of each possible outcome weighted by its probability of occurrence.

$$EU = \sum U(x_i)P_i$$

where EU is the expected utility; $U(x_i)$ is the utility generated by action x under state of nature i; and P_i is the probability of occurrence of state of nature i.

The second model is the lexicographic utility model. A sequential ordering of multiple goals is established and only once the highest goal has been achieved at a threshold level, the second order goal can be considered, the first goal acting as a constraint in this problem. Safety first rules are commonly used in lexicographic models, assuming that the DM is primarily concerned with achieving a minimum level of utility, before its maximisation.

Under both the expected utility and the lexicographic utility models, different decision rules are found. A decision rule defines how alternative courses of action are evaluated and how this information is used to solve the decision problem (Selley, 1984). Game theory deals with decision rules under uncertainty, when no information on probabilities exists. Rules like minimisation of maximum loss or minimum regret can be used to solve this kind of problem. This is not a common situation, because most of the time at least subjective probabilities exist. Decision rules for solving risk problems include expected utility maximisation, safety first rules, mean-variance analysis, mean-semi variance analysis, and mean-absolute deviation analysis (Hazell, 1971; Robison, *et al.*, 1984; Selley, 1984).

The best solution to the problem of risk is to measure the farmer's utility function and to determine the point of tangency of the set of iso-utility functions with the efficient E-V boundary, as in Figure 7.2 (Hazell, 1971). As the elicitation of the utility function is not free of problems, an alternative to the previous approaches is to obtain a set of efficient farm plans optimising both expected income and risk estimates simultaneously, allowing the DM to make the choice from within this

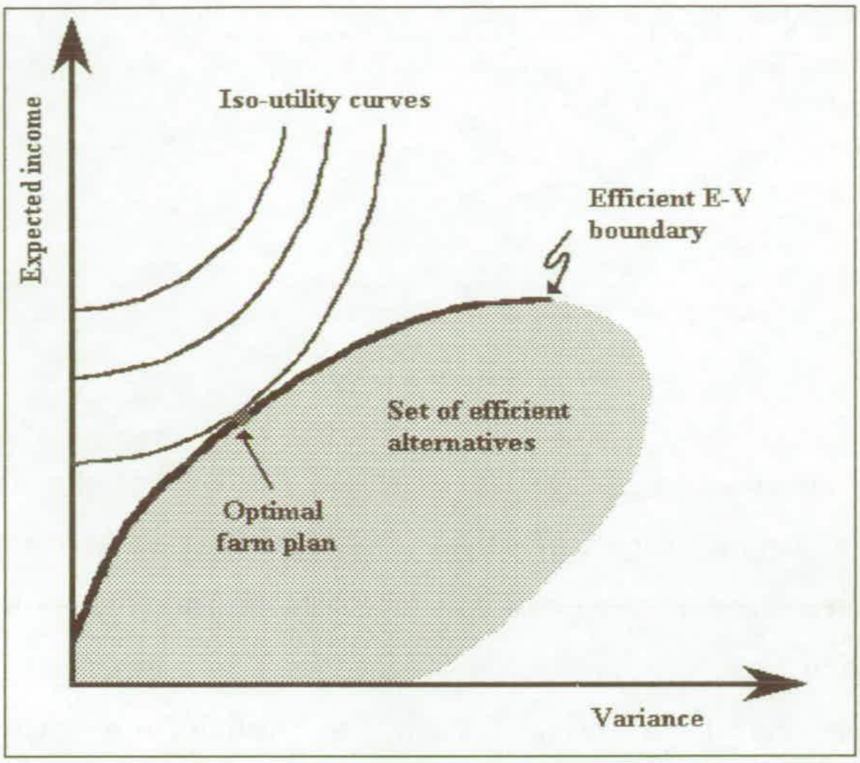


Figure 7.2 The efficient expected income -variance (E-V) farm plan (Hazell, 1971)

set. From an operational point of view linear programming, quadratic programming, stochastic programming, and non-linear programming models have been used to analyse decision making problems involving risk (Hardaker, Pandey and Patten, 1991). When linear programming is used, as it is the case for the proposed models, the mean-absolute deviation rule can easily be included. Specifically, the minimisation of the total absolute deviations or MOTAD model computes for a series of states of nature (e.g. years) the difference between the expected GM for each activity and the average GM for that activity over all states of nature (Hazell, 1971).

$$Min\ A = \sum_{r=1}^{s}(n_r + p_r)$$

subject to

$$\sum_{j=1}^{n}(c_{jr} - g_j)x_j + n_r - p_r = 0$$

$$\sum_{j=1}^{n} f_j x_j = \lambda$$

$$\sum_{j=1}^{n} a_{hj} x_j \leq b_h$$

where c_{jr} is the observed gross margin of activity j under state of nature r; g_j is the sample mean gross margins of activity j; f_j is the expected GM of activity j; n_r is the negative total deviation from zero under state of nature r; p_r is the positive total deviation from zero under state of nature r; λ is a parameter; a_{hj} is the technical input/output relationship of activity j to constraint or resource h; and b_h is the level or value of constraint h.

By solving this model using different λ values the efficient set of solutions is obtained (efficient E-V boundary). The optimal farm plan will then be given by the point of tangency between the efficient E-V boundary and the iso-utility line with the highest utility (Figure 7.2).

A problem of MOTAD is that the comparison of the results obtained from different models can lead to erroneous and misleading conclusions. The reason for this is that MOTAD uses the average GM as a reference point, but this average changes from model to model. To overcome this problem Tauer (1983) and Watts (1984) developed the target-MOTAD approach, which computes the deviations relative to a target and not to the mean. Now, as a common reference point or target is used, a ranking may be obtained (Watts, Held and Helmers, 1984). This approach can be useful because the DM often wishes to maximise expected return but is concerned about returns falling below a given target (Tauer, 1983). Mathematically, the target-MOTAD model is stated as:

$$Max\ E(z) = \sum_{j=1}^{s} f_j x_j$$

subject to

$$\sum_{j=1}^{n} c_{jr} x_j + n_r \geq T$$

$$\sum_{r=1}^{s} P_h n_r = \lambda$$

$$\sum_{j=1}^{n} a_{hj} x_j \leq b_h$$

where $E(z)$ are the expected returns; T is the target level of total farm return; n_r is the deviation below T for state of nature r; and P_h is the probability that state of nature h will occur.

In both MOTAD and target-MOTAD the efficient set is found using the constraint method, i.e. one criterion is optimised while the other is treated as a parametric restraint. But, as risk is in essence a two-criteria problem, relating expected income with a measure of its variability, MCDM models seem to be specially suitable to handle it. Examples are the Mean-Partial Absolute Deviations model, which is a multi-objective risk programme for Tauer´s target-MOTAD model (Berbel, 1988; Berbel, 1993), and compromise risk programming (Romero, Rehman and Domingo, 1988).

The FS models developed here will measure risk using the target-MOTAD method in a two-criteria setting, because:

i. It is easily incorporated into LP models (Tauer, 1983).
ii. It does not need to state explicitly the risk preference/awareness of individual farmers.
iii. Its formulation can emulate a safety first rule, by which the difference between a minimum income and a set of possible outcomes is minimised.
iv. It allows the comparison of the results obtained from different models.

Specifically, in the FS models target-MOTAD was modelled by including a second objective function, which minimises the negative deviations from the target value, and a set of restraints which compute the differences between the expected GM and the target value (Eq. [7.2])

$$
\begin{aligned}
& Max\ Z_1 = \sum_{j=1}^{n} GM_j x_j \\
& Min\ Z_2 = \sum_{r=1}^{s} n_r \\
& subject\ to \\
& \sum_{j=1}^{n} GM_{jr} x_j + n_r \geq t
\end{aligned}
\qquad [7.2]
$$

where n_r is the negative deviation of expected GM from target for year $r=1,\ldots,s$; GM_{jr} is the expected gross margin[3] for x_j during year r=1,...,s; and t is the target level.

7.3.3 MINIMISATION OF SOIL LOSS

This objective function specifies that a farm's total soil loss should be minimised:

$$Min\ Z_3 = e_j x_j \qquad [7.3]$$

where e_j is the soil erosion incurred by pursuing activity j.

One of the most widespread methods to estimate soil erosion as associated with various farming practices is the Universal Soil Loss Equation or USLE (Wischmeier and Smith, 1978):

$$E = R * K * L * S * C * P \qquad [7.4]$$

where E is the predicted soil loss; R is the rainfall and runoff; K is the soil erodibility factor; S is the slope length; L is the slope gradient and steepness; C is the soil cover and management factor; and P is the erosion control practice factor.

USLE estimates the soil loss due to run-off by simultaneously considering soil type and other parameters as given above (Wischmeier and Smith, 1978; Brady,

[3] Observed GMs are those which are obtained using farm survey data; the expected GMs are those values calculated using time series data applicable to the study area.

1984, pg. 534). A revised version of the USLE called RUSLE (revised USLE) has been developed which maintains the basic structure of USLE, but uses different algorithms to calculate the individual factors (Renard, Laflen, Foster and McCool, 1994).

The rainfall and run off factor (R) estimates the rain's erosive potential. It is well known that soil erosion is related to the rain's kinetic energy. This energy is determined not only by total rain energy (E), but also by the rainfall's intensity, defined as the amount of rain fallen during the 30 minutes of maximum intensity (Wischmeier and Smith, 1978). Part of the R-factor calculation involves a seasonal distribution to permit weighting of the soil erodibility value and the cover management factor of rainfall (Renard *et al.*, 1994).

The soil erodibility factor (K) is a measure of the inherent erodibility of a soil, i.e. its natural susceptibility to erosion (Wischmeier and Smith, 1978). It states that a soil with a given value will suffer more than one with a lower value, if both are exposed to the same rainfall. The two most significant soil characteristics influencing erosion are infiltration capacity and structural stability. The former is influenced by organic matter content, soil texture and depth, types of clays present, etc., and the latter by the granule stability (Brady, 1984, pg. 541). RUSLE also allows K to vary seasonally and to account for rock fragments on or in the soil (Renard *et al.*, 1994).

The next factors are usually considered together, as both steepness of slope and its length (S and L) affect the velocity of run-off (not the amount) and so the potential erosion (Wischmeier and Smith, 1978). RUSLE uses separate slope length relationships, considering the susceptibility of the soil to rill erosion relative to inter-rill erosion (Renard *et al.*, 1994). The attention given to the L-factor is not always warranted because soil loss is less sensitive to slope length measurement than any other USLE factor. For typical slope conditions, a ten percent error in slope length measurements results in a five percent error in computed soil loss, but a ten percent error in slope steepness gives about a twenty percent error in computed soil loss (Renard *et al.*, 1994).

Cover and management factor (C) represents the ratio of soil loss from an area with specified cover and management to that from an identical area in clean-tilled continuous fallow; C adjusts soil loss according to the particular combination of cover, crop sequence and management practice, as well as to the particular stage of growth and development of the vegetal cover at the time of the rain. Factor C is usually given in terms of its average annual value for a particular combination of crop system, management, and rainfall pattern (Wischmeier and Smith, 1978).

Due to the dynamic behaviour of its components, C is the most difficult factor to determine; it will also vary according to local circumstances (Wischmeier and Smith, 1978). For its computation, soil loss ratios are weighted according to the distribution of erosivity during a year (Renard *et al.*, 1994); therefore, the erosivity distribution and an estimate of the percentage of uncovered soil during the yearly rainfalls are required. RUSLE computes soil loss ratios as a function of prior land use, crop canopy, surface of ground cover and surface roughness (Renard *et al.*, 1994).

Finally, the support practice factor (P) reflects the benefits from practices that slow the run-off water and thus reduce the amount of soil it can carry (Wischmeier and Smith, 1978). P is computed for each soil protection practice as the ratio of soil loss with a support practice to that with straight row farming up and down the slope. This is the least reliable of the USLE or RUSLE factors (Renard *et al.*, 1994).

One important aspect of the model is that it had to able to take into account the main factors affecting soil loss, i.e. the six coefficients which determine soil loss according to USLE (Eq. [7.4]) to be considered. Rain erosivity (R), soil erodibility (K), and erosion control practice (P) were accounted for by considering different farms. Soil cover and management factor (C) were specific to each crop and its production practice, and were thus considered when each activity was defined. To consider possible variations in factors L and S, which have a significant impact on soil loss when steeper fields were cropped, the model had to allow for the inclusion of fields with different slopes (see page 134).

7.3.4 MINIMISATION OF INCOME DIFFERENCES BETWEEN FSs

Two of the most commonly used tools for the analysis of the distribution of income among groups of people are the Lorenz curve and its derivative the Gini coefficient (Dovring, 1991). According to some authors these tools are the most appropriate methods to measure and illustrate inequality (Henkel, 1989). Other methods to measure inequality are distributive functions (like the logarithmic function) and size group frequencies (Dovring, 1991).

The Lorenz curve (Figure 7.3) is a graphical representation showing the degree of inequality of a frequency distribution in which the cumulative percentages of a population are plotted against the cumulative percentage of the variable under study (e.g. aggregate income). A straight line rising at an angle of 45° from the origin indicates perfect equality. The greater the distance between this equality line and the Lorenz curve the larger the inequality within the population for that particular variable (Cowell, 1977). From this graph the Gini coefficient (G), a measure of equality, can be obtained by determining the ratio between the area under the Lorenz curve and the area under the equality line. The Gini coefficient can be computed from the sum of absolute differences between all observations (Henkel, 1989):

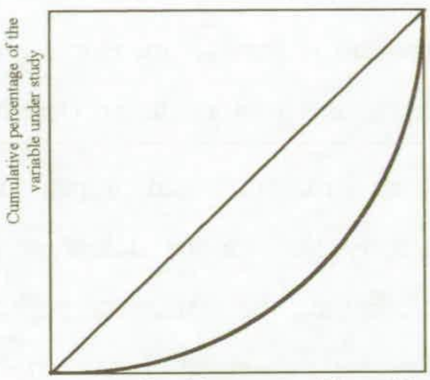


Figure 7.3 Lorenz curve

$$G = \frac{\Delta}{2\bar{x}} = 100 - \frac{1}{100}\left[X_i P_i + \sum_{i=2}^{N} X_i \left(P_i + P_{i-1}\right)\right]$$

$$\Delta = \frac{1}{N^2}\sum_{j=1}^{N}\sum_{i=1}^{N}\left|a_i - a_j\right|$$

where N is the number of observations; a_i is the value of the variable under study for observation i; $\bar{x}$ is the population mean; X_i is the percentage share of the variable under study in observation *i*; and P_i is the cumulative percentage of the share of the variable in question in observation *i*.

Perfect equality has a coefficient of '0', and the higher this value, the higher the inequality. One of the problems associated with this coefficient, and which has provoked considerable discussion within welfare economics, is the fact that different Lorenz curves can result in the same Gini coefficients (Dovring, 1991). In other words a ratio between two areas does not define the shape of them (even if one of them has a known shape as in the case of the equality line). A second problem is that all measures are dependant on the number of observations: the greater the number the greater the inequality is expected to be (Henkel, 1989).

From a mathematical programming point of view it is not possible to generate directly the Gini coefficient, so that alternative approaches must be found. One is to compute the difference between the equality line and the Lorenz curve when they are expressed in absolute instead of relative values. The area under the equality line is given by

$$A_e = \overline{GM} * N\left(\frac{N+1}{2}\right) = \sum_{i=1}^{N} GM_i \left(\frac{N+1}{2}\right)$$

and the area under the Lorenz curve by

$$A_L = \sum_{i=1}^{N} (N - i + 1) * GM_i$$

where $\overline{GM}$ is the average micro-regional GM; N is the total number of farms; and GM_i is the GM of farm *i*.

A MP model including such an approach would be

$$\begin{aligned} &Min\ D \\ &Subject\ to \quad A_e - A_L - D = 0 \end{aligned}$$

The problem of such an approach is that the farms have to be sorted in ascending order of GMs, i.e. $GM_i \leq GM_j \ \forall \ i<j$, as this order defines the weight each farm receives when A_L is computed. This condition is not guaranteed when efficient solutions are generated.

An alternative approach can be taken to overcome this problem. Essentially Gini's approach compares the average income of the groups/individuals with the lowest income with the average of the total population. The higher the difference the higher is the degree of inequality. Thus an approach similar to target-MOTAD can be taken, which minimises the differences between all individuals/groups below average and the population average. The difference between each FS's expected GM and the population average is computed as

$$\overline{GM} - GM_i - nid_i + pid_i = 0 \qquad [7.5]$$

where nid_i is the negative difference between average and observed GM of farm i; and pid_i is the positive difference between average and observed GM of farm i.

Further, as the sum of the negative deviations necessarily has to equal the negative of the sum of the positive deviations, the objective function can simply be stated as

$$Min \sum_{i=1}^{n} w_i nid_i \qquad [7.6]$$

where w_i is the weight of deviation i in the objective function.

Such an approach is fairly simple and does not depend on sorting the FSs according to GMs. Nevertheless, the problem that equal values can be obtained with different distributions is present and is enhanced. Figure 7.4 shows two hypothetical populations with the same average income and the same sum of absolute negative deviations, but whose Gini coefficients differ significantly; i.e. G for population A is 34.5% while for population B it is 24.0%.

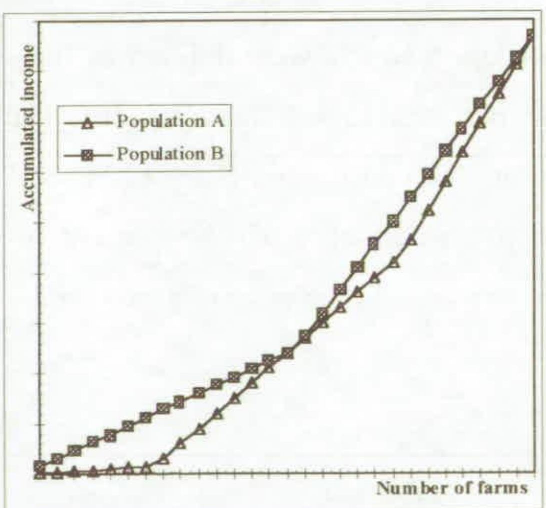


Figure 7.4 Two hypothetical income distributions with equal average and equal sum of negative absolute deviations

Thus, this approach does not guarantee the absence of alternatives which are not dominated by the optimal solution. Nevertheless this approach was taken as a proxy of income distribution among farms, as it was the only way to minimise income differences using MCDM models.

7.4 THE RESTRAINTS OF THE PROTOTYPE FARMING SYSTEM MODEL

As seen in Figure 7.1 the model's activities and restraints were grouped under five headings: cropping, livestock, cash and capital, labour, and risk. These will now be described in detail.

7.4.1 THE CROPPING ACTIVITIES, RESTRICTIONS AND TIES

The first sub-matrix of the model defined land use, rotational practices and crop sale, by relating available land with a set of observed cropping activities.

Land use considered three land types according to the predominant slope: slopes of less than 5% were defined as flat, slopes between 5% and 15% as hilly, and slopes over 15% as mountainous. Then, for each possible land type one restriction was constructed (Eqs. [7.7] to [7.9]). Such an approach also required that activities which could be present in different land types had to be split into activity-land type pairs (e.g. flat land wheat or hilly-land fallow).

$$\sum x_j = fal \qquad [7.7]$$

$$\sum x_j = hal \qquad [7.8]$$

$$\sum x_j = mal \qquad [7.9]$$

where *fal* is the available flat land; *hal* is the available hilly land; and *mal* is the available mountainous land.

Strict equalities were used in the previous equations, because the use of inequalities could determine that land is left idle when soil loss is minimised, as idle land implies zero soil loss. Nevertheless idle land is in fact a pasture or rough grazing and therefore presents soil loss.

The model also allowed for the three different types of land property systems observed in that area. In addition to cropping own land, sharecropping is a common practice. According to particular circumstances farmers may 'take land in' or 'give land out'. To 'take land in' means that the farmer provides labour and half of the inputs (seeds and fertilisers) while the sharecropper provides the land and the other half of the inputs. When the farmer 'gives land out' he provides the land and half of the inputs while the sharecropper provides labour and the rest of the inputs. In both cases the harvested crops are shared in equal parts. For both land taken-in and given-out the three land type categories (flat, hilly, and mountainous) were considered. As the possible crops to be grown and the rotations on taken-in or given-out land were different from the ones grown on own land the set of activities was also split according to land property. As a result each crop was represented by up to nine combinations of land type (flat, hills, mountains), and property (own, given-out, or taken-in).

Constraints on the available land of both types were set for flat land (Eqs. [7.10] and [7.11]), hills (Eqs. [7.12] and [7.13]), and mountains (Eqs. [7.14] and [7.15]).

$$\sum x_j \leq ftl \qquad [7.10]$$

$$\sum x_j \leq fgl \qquad [7.11]$$

$$\sum x_j \leq htl \qquad [7.12]$$

$$\sum x_j \leq hgl \qquad [7.13]$$

$$\sum x_j \leq mtl \qquad [7.14]$$

$$\sum x_j \leq mgl \qquad [7.15]$$

where *ftl* is the maximum flat taken-in land; *fgl* is the maximum flat given-out land; *htl* is the maximum hilly taken-in land; *hgl* is the maximum hilly given-out land; *mtl* is the maximum mountainous taken-in land; and *mgl* is the maximum mountainous given-out land;

As mentioned before the main crop in this area is wheat grown in a rotation of fallow/wheat/rough grazing. Each year in late winter or early spring the farmer ploughs a field and leaves it fallow, to control weeds and some soil borne diseases. Next autumn he sows wheat. After harvest, the field is left for two years as rough grazing, without any pasture management. Eqs [7.16] and [7.17] represent such a rotation for own flat land.

$$fwh1 - ffa1 \leq 0 \qquad [7.16]$$
$$2fwh1 - frg1 \leq 0 \qquad [7.17]$$

where $fwh1$[4] is the wheat grown on own flat land; $ffa1$ is the fallow prepared on own flat land; and $frg1$ is the flat rough grazing on own land

This pair of ties was also constructed for the remaining eight land type-land property combinations.

If soil humidity is enough some farmers sow chickpeas on fallow before wheat. It is assumed that this is possible every third year. This fact is reflected in the models through a wheat/chickpea tie for each land type combination (Eq [7.18] for own flat land).

$$-fwh1 + 3fch1 \leq 0 \qquad [7.18]$$

where fch are the chickpeas grown on flat land

For farmers sowing any other crops the correspondent set of rotations were defined later. The final set of cropping activities were related to crop sale and consumption. Farmers keep part of the harvested crops for home consumption, and therefore ties were included to balance total crop output (i.e. for each land type) with sale and consumption. Such ties were constructed for wheat (Eq. [7.19]) and chickpeas (Eq [7.20]). As the output has to be fully used (i.e. consumed or sold) all output ties were strict equalities

[4] The first letter identifies the group of activities to which the variable belongs (f: flat, h: hilly, m: mountain, l: livestock, h: hired labour, c: cash, n: negative risk deviation) and the following two the variable itself. Crops and livestock variables are followed by a number (1: own, 2: given-out, 3: taken-in). Other numbers may represent a year (85 to 94) or a month (01 to 12). On the individual FSMs, the letter identifying the farm precedes the variable name.

$$o_{fwh1} fwh1 + o_{hwh1} hwh1 + \ldots + o_{fwh2} fwh2 + \ldots + o_{mwh3} mwh3 - swh - cwh = 0 \quad [7.19]$$
$$o_{fch1} fch1 + o_{hch1} hch1 + \ldots + o_{fch2} fch2 + \ldots + o_{mch3} mch3 - sch - cch = 0 \quad [7.20]$$

where o_{fwh1} is the wheat output for flat own land (and so on); *swh* is the amount of sold wheat; *cwh* is the amount of wheat kept for own consumption; o_{fch1} is the chickpea output for flat own land (and so on); *sch* is the amount of sold chickpeas; and *cch* is amount of chickpeas kept for own consumption. As most households consume part of their wheat and chickpea production, minimum consumption levels for them were set (Eqs. [7.21] and [7.22]).

$$cwh \geq \min_{wh} \quad [7.21]$$
$$cch \geq \min_{ch} \quad [7.22]$$

where min_{wh} is the minimum wheat consumption level; and min_{ch} is the minimum chickpea consumption level. Each of these minimum consumption bounds represented in fact risk aversion behaviour (Holden, 1993; López-Pereira *et al.*, 1994). These minimum consumption levels have also been set in terms of protein and energy intake (van Duivenbooden and Veeneklas, 1993), but this assumes no preference between nutrients of different sources.

7.4.2 The livestock activities, restrictions and ties

Animals, particularly cattle and sheep[5] play an important role in all the micro-region's farms. They make use of wheat straw and of the rough grazing which forms part of the normal wheat rotation. Unfortunately, modelling extensive live-stock systems is not an easy task, especially when small holders are involved. Some of the reasons behind this are:

i. Lack of monitoring systems and records
ii. There is generally no fixed time schedule for input use and output generation
iii. Animals can be sold when there is cash shortfall, and these shortfalls can occur at any time of the year

[5] As none of the subsequently surveyed farms had goats, no further reference will be made to activities or ties relating to this species.

iv. As in these FSs livestock performs a dual role of saving account (the farmer keeps animals instead of cash in a bank account) and extensive business, the farmer is not prepared to make a heavy use of inputs

v. The performance of the system may vary greatly between years

vi. The small number of animals involved determines that reproductive rates and productive rates are not continuous and can vary greatly from one year to the next[6], so that average values over a long period would be required

vii. Difficulties in establishing clear and unequivocal animal categories for all farms

viii. Difficulties in establishing pasture productivity and food intake

ix. Low and irregular use of labour

To overcome most of these problems the modelling approach has to be simple, taking into account only the most important issues. It meant that within the framework of this study only cash flow and carrying capacity (i.e. balance between available food and food consumption) were established. To define cash flow, amount and timeliness of inputs and outputs were required.

In extensive systems it is very probable that in most cases no inputs were used, and if used they would only be medicines. Outputs are basically defined by reproductive rates and culling rates. Thus, to achieve the level of detail necessary to model the relationship between this sub-system and cash flow and forage availability, three topics had to be considered: herd structure, forage balance and product sale.

7.4.2.1 Herd structure

For cattle and goats three animal categories were defined: dams, replacements and offspring. Sires were not considered in the model because of the small number of bulls or rams usually present in the farms. To define the yearly relationships between animal categories for each species replacement ties (Eqs [7.23]

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[6] In fact a farm with just two cows or sheep can have only a birth rate of 0%, 50% or 100%, assuming there are no twins.

and [7.24]) and weaner ties (Eqs [7.25] and [7.26]) were defined. When needed both ties were also defined for taken-in and given-out livestock.

$$rr_{ca} lcc1 - lch1 \leq 0 \quad [7.23]$$

$$rr_{sh} lse1 - lsr1 \leq 0 \quad [7.24]$$

$$- wr_{ca} lcc1 + lcy1 \leq 0 \quad [7.25]$$

$$- wr_{sh} lse1 + lsl1 \leq 0 \quad [7.26]$$

where *lcc1* is the number of own cows; *lch1* is the number of own heifers; *lcy1* is the number of own yearlings; *lse1* is the number of own sheep; *lsr1* is the number of own ewe-lambs; *lsl1* is the number of own lambs; rr_{ca} and rr_{sh} are the replacement rates for cattle and sheep respectively; and wr_{ca} and wr_{sh} are the weaning rates for cattle and sheep respectively.

The replacement tie defined the number of heifers and ewe-lambs required to keep a herd at a given size. There must be sufficient ewe-lambs and heifers to replace dead and culled dams as well as to cover for mortality of the replacement group. Weaner ties define the number of offspring produced by the herd which can be sold or kept as replacements. To avoid problems related with birth rates and pre-weaning mortality, weaning rates instead of birth rates were used.

7.4.2.2 Forage balance

The second set of constraints aimed to balance forage availability with forage consumption, i.e. the crop sub-system (adjusting for purchases and sales if any) with the livestock sub-system. Two issues have to be considered when constructing forage balances: first forage availability and consumption over time, and second the food component or components to be modelled. Two extreme options are balancing the yearly consumption of dry matter or the monthly consumption of dry matter and of a group of nutrients (energy, protein, etc.). Naturally the second option required large amounts of data and would increase significantly the model's size, while the first one would be extremely simple and based on untenable assumptions. Thus, a compromise was required between available information and gain of reliability through their inclusion. The lack of reliable data on monthly composition and output of rough grazing determined that only the dry matter intake of the dry and the wet season were considered. For each season a forage balance tie was used, allowing the transfer of forage between consecutive seasons (Eqs [7.27] and [7.28]).

$$\Sigma f_{j1} x_j + lft_1 - te * lft_2 \leq 0 \qquad [7.27]$$

$$\Sigma f_{j2} x_j - te * lft_1 + lft_2 \leq 0 \qquad [7.28]$$

where f_{j1} is the forage production or consumption by activity x_j during season 1; f_{j2} is the forage production or consumption by activity x_j during season 2; lft_1 and lft_2 are the forage transfers between seasons 1 and 2; and te is the forage transfer efficiency. Transfer efficiency reflects the fact that keeping forage involves a loss in both quantity and quality.

7.4.2.3 Product sale

The final restraints establish the yearly relationship between weaned and sold offspring. These restraints are different for cattle and sheep. It was expected to observe household consumption of lambs but not of steers. As sheep are bred and weaned at a given season, lamb sales are concentrated during the months of September and October, when the selling price is at its highest. Different sale restraints were used for cattle (Eq. [7.29]) and sheep (Eq. [7.30]). As cows have no fixed breeding seasons yearlings are ready for sale throughout the year, depending on cattle price and their weight. On the contrary, lambs are born over a period of two or three months and sold during September and October, when the demand for them is highest. Thus Eq. [7.29] included monthly yearling sales while Eq. [7.30] considered a fixed selling date. Also only lambs were consumed on-farm.

$$lcy1 - lch1 + lcy2 - lch2 + lcy3 - lch3 - \sum_{i=1}^{12} sy_i = 0 \qquad [7.29]$$

$$lsl1 - lsr1 + lsl2 - lsr2 + lsl3 - lsr3 - sla - cla = 0 \qquad [7.30]$$

where $lcy1$, $lcy2$, $lcy3$ are respectively the number of own, given-out and taken-in yearlings; $lch1$, $lch2$, $lch3$ are respectively the number of own, given-out and taken-in heifers; sy_i is the number of yearlings sold in month i=1,...,12; *lsl1, lsl2, lsl3* are the number of own, given-out and taken-in lambs; *lsr1, lsr2, lsr3* are the number of own, given-out and taken-in ewe-lambs; *sla* is the number of sold lambs; and *cla* is the number of lambs consumed by the household.

7.4.3 CAPITAL AND CASH FLOW RESTRICTIONS AND TIES

A third sub-matrix of the FSM dealt with capital availability and expenses. Peasant systems are characterised by their lack of working capital and the difficulty they have to obtain it from formal markets (i.e. commercial banks). It is precisely one of the aims of INDAP to break down the vicious circle of poverty and lack of capital by giving peasant farmers' access to fresh capital through agricultural loans. Thus any model which intends to mimic peasant farmers' behaviour must include cash flow constraints as the economic viability of a plan requires the farmers to meet the cash demands of household and farm. Despite the importance of such restraints, they are only occasionally used in agricultural planning models (Cárcamo *et al.*, 1994; Holden, 1993; Romero, Amador and Barco, 1987; Zekri and Romero, 1991).

To model these constraints the following assumptions were made:

i. At the beginning of each year (April[7]) the farmer has a given amount of money (initial working capital).
ii. During April the farmer can take a loan from INDAP, but only to purchase seeds and fertilisers.
iii. According to his production plan the farmer has monthly incomes and expenses.
iv. Each month the farmer has a fixed amount of cash expenses to cover the household's needs.

[7] The yearly cycle begins in April and finishes in the following March, i.e. starting before the first crop is sown and finishing after the last one has been harvested. It also coincides with the dates INDAP's loan is taken and repaid.

v. After each year the farmer's cash surplus has to be equal or higher than the initial working capital, so that the (same) production cycle can be repeated indefinitely in time.

First, to satisfy the condition that INDAP's loan can only be used in cropping activities an input purchase restriction was included, balancing seed and fertiliser purchase with the own capital available and the loan taken (Eq. [7.31]). Then a maximum loan restraint was defined through Eq. [7.32].

$$rf_j x_j - cil - coc \leq 0 \qquad [7.31]$$

$$cil \leq mil \qquad [7.32]$$

where rf_j are the toal cash requirements for buying fertiliser and seed for crop x_j; *cil* is the loan taken from INDAP for the purchase of crop inputs; *coc* is the own capital used to purchase fertilisers and seeds; and *mil* is the maximum INDAP loan.

Next, based on the previous assumptions a set of twelve constraints were constructed, each preventing the farmer from having negative cash balances at the end of any month. Equation [7.33] represented the cash flow restraint in April, Eq. [7.34] the restraints for May to February and Eq. [7.35] the restraint in March.

$$\sum cf_{j,1} x_j + cb_1 + cce + coc - cwc = 0 \qquad [7.33]$$

$$\sum cf_{j,i} x_j - cb_{i-1} + cb_i + cce = 0; \quad i = 2,\ldots,11 \qquad [7.34]$$

$$\sum cf_{j,12} x_j - cb_{11} + cce - ir * cil + cwc + cci = 0 \qquad [7.35]$$

where $cf_{j,i}$ is the cash flow generated by activity x_j on month i=1,…,12; cb_i is the cash balance on month i=1,…,11[8]; *cce* are the household's monthly cash expenses; *cwc* is the working capital or initial capital available; *ir* is the interest rate on loan; and *cci* is the increase in working capital.

This set of cash flow restraints can be considered as the model's second risk aversion feature, as the set of feasible solutions is restricted to those which meet the monthly cash requirements.

[8] Only 11 months as cwc + cci = cb_{12}

7.4.4 LABOUR RESTRICTIONS AND TIES

Labour availability is, after cash availability, the second major constraint faced by the farmers. Seasonality of agricultural practices requires that monthly demand and supply had to be considered. To balance labour availability with its monthly on-farm and off-farm use, a set of 12 constraints was used (Eq. [7.36]). It was assumed that off-farm labour had a maximum monthly demand (Eq. [7.37]), and it would imply a yearly commitment, i.e. the same amount for each month.

$$\sum l_{ji} x_j + ofl - hl_1 \leq al_1; \quad i = 1,...,12 \quad [7.36]$$

$$ofl \leq mol \quad [7.37]$$

where l_{ji} is the amount of labour used by activity x_j during month i=1,…,12; hl_i is the amount of labour hired during month i=1,…,12; ofl is the monthly off-farm labour; al_i is the available labour during month i=1,…,12; and mol is the maximum demand for off-farm labour.

A draw-back to this approach is that despite using monthly restraints no activity can be anticipated or delayed according to labour availability. Modelling methods which allow the shifting of activities between months have been proposed (Arias, 1993), but their specification would increase the model's size with unknown effects on the results.

7.4.5 RISK VECTORS

The final set of restraints construct what is defined as a target-MOTAD model. They are in fact accounting vectors which measure the deviation of the expected income over a series of years from the target. To operate this model a series of GMs for each activity had to be constructed over a ten year period. It was expected that such a time frame would represent suitably the observed variations in the GMs. Then ten vectors (one per year) are constructed which measure the difference between these yearly expected GMs and the target (Eq. [7.38]).

$$\sum_{j=1}^{m} gm_{rj}x_j + n_r \geq t; \quad r = 1,\ldots,10 \qquad [7.38]$$

where gm_{rj} is the expected GM of x_j on year r=1,...,10; n_r is the negative deviation from target (i.e. underachievement); and t is the target level from where the yearly absolute deviations are measured.

Two comments have to be made. First the combination of expected GM and target income determined that the method is similar to a safety first rule, as the risk-optimal farm minimises the under-achievement of a certain income level. Such an approach is quite different from Hazell's (1973) original MOTAD model, in which the risk-optimal plan is the one in which GM has the minimum variation. Second only the negative deviations from the target were considered, as positive deviations represent incomes higher than the target and therefore not 'risky' from a safety-first point of view.

7.5 CONSTRUCTION OF THE PROTOTYPE MICRO-REGIONAL MODEL

The prototype MRM is made up from the previous prototype FSMs (Eqs. [7.1] to [7.38]) plus additional objective functions and constraints. The MRM's objective functions are constructed through the weighted addition of the FSM objective functions (Eqs. [7.1] to [7.3]).

$$\text{Max } Y_1 = \sum_{l=1}^{u} w_{1l} Z_{1l} \qquad [7.39]$$

$$Min\ Y_2 = \sum_{l=1}^{u} w_{2l} Z_{2l} \qquad [7.40]$$

$$Min\ Y_3 = \sum_{l=1}^{u} w_{3l} Z_{3l} \qquad [7.41]$$

where Z_{il} is the value of objective i in FS l; and w_{il} is the weight of FS l in objective function i. The weights for GM and risk objectives are given by the number of farms in each FS, and for soil loss by the area covered by each FS.

Such a model assumes that the three objectives are additive, this is that the micro-regional objective equals the sum of the FS objectives. The following arguments make such an assumption tenable:

i. Only the GM, risk, and soil loss achievement levels of peasant farmers are of interest for the policy maker who will use the models here developed. The contribution of other sectors towards the micro-regional GM, risk or soil loss are therefore unimportant.

ii. There is no multiplier effect of income as the absence of trade between farms determines that any change of income in one FS does not alter the income of another FS.

iii. As the aggregate output of all farms is not able to affect regional product prices, a change in the production pattern of any farm will not affect the risk coefficients of another farm. Further, as risk is computed for each FS as the deviation from a fixed reference point, the aggregate risk represents the level of GM under-achievement for all farms.

iv. There is no reason to believe that the level of soil loss of any farm could affect the soil loss of third parties.

To include the objective of income distribution the method described on page 131 is taken, introducing one objective function (Eq. [7.42]) and two additional restraints (Eqs. [7.43] and [7.44]).

$$\text{Min } Z_4 = \sum_{i=1}^{8} w_{4i}\, nid_i \qquad [7.42]$$

$$\overline{GM} - GM_i - nid_i + pid_i = 0; \quad i = 1,\ldots,8 \qquad [7.43]$$

$$\frac{1}{53}\sum_{i=1}^{8} n_i Z_{1i} - \overline{GM} = 0 \qquad [7.44]$$

where w_{4i} is the number of farms in FS i; nid_i is the negative difference in GM between FS i and the mean GM; pid_i is the positive difference in GM between FS i and the mean GM; and $\overline{GM}$ is the average GM.

Finally, the aggregation of eight FS prototype models constitute the base constraints of the prototype MRM (eight times the set of Eqs. [7.7] to [7.38]). As it was assumed that each FS acted as an independent unit no other restraint was required, unless the aggregate effect of the eight FSs was judged as enough to alter the implicit supply or demand functions. As it will be seen in Chapters 9 and 10 such an effect is only possible when new crops or production techniques were introduced. In these cases additional restraints were added. The specification of these restraints is presented in Chapter 10.

7.6 FINDING THE EFFICIENT SOLUTION FOR THE MICRO-REGIONAL MODEL

The optimisation of linear models is the procedure by which one or more objective functions are optimised, subject to a set of linear equations, called restrictions[9]. The most elementary case, in which only one objective or criterion is optimised (maximised or minimised) is called Linear Programming (LP), where the optimal solution is found from within the set of feasible solutions[10]. Such a point is normally found in LP through the use of the Simplex algorithm. When the problem is one of Multiple Criteria Decision Making (MCDM) as more than one criterion is involved, the problem is rather different now as instead of a single optimal solution a set of efficient solutions exists. These efficient or Pareto-optimal solutions are 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 (Romero and Rehman, 1989). Different techniques, usually based on the Simplex algorithm can be used to find this subset of efficient solutions. Further, to find a preferred solution the DM has to define preferences between the objectives. He can do this in different ways (Cohon, 1978):

[9] It is beyond the scope of this thesis to present a detailed explanation and comparison of the different optimisation methods. For details on GP, CP, IMGP, and MOP see Romero and Rehman (1989). For an introduction to DP see Cooper and Cooper (1981).

[10] A solution is a vector of values for each of the decision variables.

i. *A priori*: The DM gives relative values or absolute preferences for each objective before the problem is solved (e.g. Goal Programming and Compromise Programming)[11].

ii. Progressively: Through an interactive procedure, the DM selects and discards inferior solutions (e.g. Interactive Multiple Goal Programming).

iii. *A posteriori*: Once the efficient set has been defined, the DM selects the preferred solution (e.g. Multi Objective Programming).

7.6.1 SOME METHODS FOR MULTIPLE-CRITERIA ANALYSIS

In Goal Programming or GP the individual objectives are converted into goals which are then included as restrictions. The goal consists of the objective, a target or desired level of achievement, and deviational variables, which measure by how much the target was either under- or over-achieved. The objective is then to minimise the sum of unwanted deviations, i.e. the under-achievement of maximising goals and the over-achievement of minimising goals. There are two variants for GP. In the first version, called Weighted GP (WGP), the decision maker gives an assessment of the relevance of each goal, through the specification of their weights, so the deviational variables of more important goals have greater coefficients than those of less important ones. The second, called Lexicographic GP (LGP), requires that the decision maker defines absolute preferences for his goals, that is he must state an 'ordering'. Thus, less important goals can be optimised only once the goal or goals with higher priority have been optimised. The optimisation of the former must also involve no change in the achievement of the latter.

In Compromise Programming or CP, "alternatives that are closer to the ideal are preferred to those that are farther away. To be as close as possible to the perceived ideal is the rationale of human choice" (Zeleny, 1982). To find the optimal solution requires determining the "ideal" solution, which is by definition

[11] Strictly speaking, these methods are able to find a single optimum solution within the feasible set, but if the weights, preference, or metric chosen varies, new optimum solutions are found.

unattainable, and to measure the distance between the ideal and any efficient alternative. CP establishes this ideal solution through the 'in-turn' optimisation of the individual objectives and then minimises the distance between the ideal and the set of efficient solutions.

The purpose of Interactive Multiple Goal Programming or IMGP is to obtain the aspiration levels from the decision maker interactively. The basic principle of the technique is that starting from an anti-ideal solution, the decision maker has to decide if the solution is acceptable or not. If it is not then he has to decide which objective has to be improved and if the additional gain in one objective is enough to compensate the loss in the other ones. This is done until the decision maker is confronted by a solution he considers acceptable.

Finally, Multiple Objective Programming or MOP is a vector optimisation technique in which the multiple objectives are optimised simultaneously. The idea is to find the complete set of efficient solutions and to let the decision maker choose one alternative from within this set. As the set is very large most methods try to find a subset of it using filtering techniques. Specific resolution algorithms include the constraint method, the weighting method, and the Non Inferior Set Estimation (NISE) method.

As no rule exists for the selection of the method to use to find the efficient solutions (Rehman and Romero, 1993), the nature and features of this problem were considered to select the technique. Interactive methods were discarded because of the impossibility of having a fluent interaction with the decision makers. MOP techniques are attractive because of the little information required from the decision maker(at least until the efficient set of solutions is obtained) but their computational burden increases with the number of objectives and the DM decision maker have problems in choosing a single alternative when confronted by a large number of solutions. Finally CP was preferred to GP because it does not require defining the target values, something very important when desirable achievement levels are unknown (e.g. risk and income distribution). Further, as CP generates a small subset of efficient solutions it is possible to measure the trade-offs between objective functions, which is not possible in GP where a single solution is found. Nevertheless this decision of using CP instead of GP involved an increased demand of computer time and more importantly the loss of information on shadow prices as the interpretation of the dual solution becomes very complex.

7.6.2 THE MICRO-REGIONAL MODEL AS A COMPROMISE PROGRAMMING MODEL

To find the compromise solutions a measure of distance has to be defined. The notion of a family of L_p metrics or a family of distance measures providing a generalisation of the Euclidean distance was introduced to measure distance within an n-dimensional space (Romero and Rehman, 1989).

$$d = \left[\sum_{j=1}^{n} \left(x_{1j} - x_{2j} \right)^p \right]^{1/p}$$

Although an infinite number of metrics do exist (i.e. for $p=1,\ldots,\infty$), CP can only calculate two of them. When L_1 is minimised the total geometric distance between all objective functions and the *ideal* is minimised. The minimisation of L_∞ searches for the solutions which minimises the maximum deviation of any individual objective from the *ideal* solution (Romero *et al.*, 1987). Nevertheless the solutions obtained with these metrics characterise the bounds of the compromise set (Yu, 1973), that is any optimal solution in terms of a different metric will lie between these two points.

To find the L_1 solution the following LP problem has to be solved (Romero and Rehman, 1989):

$$Min\ L_1 = \sum_{j=1}^{n} w_j \frac{Z_j^* - Z_j(\underline{x})}{Z_j^* - Z_{*j}} \qquad [7.45]$$

subject to

$\underline{x} \in \underline{F}$

where w_j is the weight attached to objective j; Z_j^* is the ideal value of objective j; Z_{*j} is the anti-ideal or *nadir* value of objective j; $Z_j(\underline{x})$ is the value of objective j in the solution $\underline{x}$; $\underline{x}$ is the solution vector; and $\underline{F}$ is the set of feasible solutions.

On the other hand, to find the L_∞ solution the problem to solve is (Romero and Rehman, 1989):

$$\begin{aligned} & Min\ L_{\infty 1} = d \\ & subject\ to \\ & w_j \frac{Z_j^* - Z_j(\underline{x})}{Z_j^* - Z_{*j}} \leq d; \quad j = 1, \ldots, n \\ & \underline{x} \in \underline{F} \end{aligned} \qquad [7.46]$$

where d is the largest deviation.

7.7 SUMMARY

In this chapter the algebraic structure of the FS and the micro-regional models are discussed, as well as the rationale behind the different approaches taken. The main features of the models are:

i. At the farm level the optimisation criteria are maximisation of GM and minimisation of the total negative deviations from a target.

ii. At the micro-regional level four optimisation criteria are used: the two mentioned at the farm level, minimisation of expected soil loss, and minimisation of the negative deviations of farm GM from average micro-regional GM.

iii. The target-MOTAD approach is taken to estimate risk, as it allows the comparison of results between models and it is easily included into a linear model .

iv. The FS models includes minimum levels for monthly cash expenses and for household consumption of wheat, chickpeas and lambs, which can be considered as additional risk averse features.

v. To include all the variables affecting soil erosion, the available land was classified into three types according to its predominant slope.

vi. Although the model is based on a one-year decision making period, it considers monthly balances of labour and cash and seasonal forage balances.

vii. The model was specified bearing in mind the restrictions on available data from both the farm and secondary sources. It was expected that no further simplifications would be required due to data shortage.

viii. The results from optimising the aggregate model will only be different to the optimal solutions of the FSs models if differences in GMs are minimised or if additional restraints are included.

ix. CP will be used to find a set of efficient solutions, as it has acceptable computational demands and information requirements.

In the next chapter these prototype models will be transformed into operational models by replacing all the coefficients of the restraints and objective functions with the values observed at the farm level. Therefore topics related to data collection, and model construction, calibration and validation will also be discussed in that chapter.

8. CONSTRUCTION, CALIBRATION AND VALIDATION OF THE FARMING SYSTEM MODELS

8.1 INTRODUCTION

This chapter deals with the construction of the operational versions of the prototype models developed in Chapter 7. The secondary information collected previously identified and characterised the FS, but was insufficient to formulate the objective functions and constraints for the models. An important amount of additional information therefore had to be collected directly from the chosen representative farms. Both the primary and the secondary types of information were used to compute the coefficients for the models. In what follows the processes of data collection and model construction are described detailing, when necessary, both the assumptions and the computations required.

8.2 THE SURVEY

The construction of the FSMs required in-depth questioning and observation of the selected farms. Information on the following topics was collected:

i. Available resources- land, labour and capital, including livestock
ii. Cropping and livestock enterprises observed on the farm during the present and previous year

iii. Quantities of inputs used on the different enterprises and the timing of their purchases and/or uses

iv. Quantities of outputs produced by the different enterprises and the timing of their production and/or sale

To obtain these data at least three alternative survey methods could be used. The first is 'dynamic' surveys. These are a series of visits usually covering a year, during each of which the events and activities happening in the period between successive visits are recorded. They are useful when precise data on the time of input use and output generation is required. Their obvious drawback is the requirements of time, both of the enumerator and of the research project itself (it takes a year just to collect the data). A second method uses in depth surveys. They consist of a single visit to the farmer during which all information is collected, which is especially suitable when very precise information is required or the questions themselves are precise. The method was not considered suitable for this research project, as it was expected that the farms would present a great variety of enterprises and therefore a large questionnaire covering all possibilities had to be prepared. The third method, which was used to collect the required information for this project, is the sequential semi-structured survey. This method considers a series of surveys, collecting data from a general to a specific context and from minimum to maximum detail (Ramírez, Martínez and Mora, 1994). The method was originally divided into five stages. The first stage defined the available resources; the second the system's structure; the third the production schedule, quantifying the inputs used; the fourth, a quantification of the results of the production process; and the last the interaction between the system and its external environment. All this information could be collected in four to eight visits. Compared to a single visit method the costs are probably higher, due to increased travelling costs (various visits) and a higher possibility of lost visits (farmer not present).

For this research project three stages were involved. During the first stage general data on the farming system were collected, with special emphasis on available resources and existing enterprises. The second stage entailed the description of the production process behind each of the enterprises. The final stage determined the amount of resources used in each stage of the production process as well as its outputs. The questionnaires used to collect the information on each stage (Appendix 1) were applied on three visits, with a gap of three to four weeks between them, and each with a duration of 20 to 40 minutes. The time between visits was used to analyse the data already collected, to detect missing or contradictory information, and to adapt the next questionnaire to the particular features of each farm.

One of the major advantages of this surveying method was that it matched data collection with model construction (Table 8.1). The information from the first questionnaire was used to construct the FS prototype model and a base spread-sheet matrix with all activities and restraints. This matrix, similar to Figure 7.1, represented in detail the problem's structure. The data collected during the second stage allowed specification of the activities and constraints of each FS and converting the base matrix into FS matrices. Each FS matrix helped to determine its non-zero values and the data needed to construct those coefficients. This knowledge was used to improve the questionnaires and to adapt them to the specific needs of each FS. The data collected during the last stage was used to compute input-output relationships and GMs for each FS (Appendix 2) and used to construct the operational models.

Table 8.1 Objective and results of each stage of the sequential semi-structured survey

Stage	Objective	Results
I	Identify the farm's resources and activities	Prototype model showing the activities and constraints observed in all FSs
II	Characterise the production processes	Extended prototype models with specific activities and constraints for each FS
III	Collect data on inputs and outputs	Input-output relationships and construction of operative FS model

An important feature of the models was that only observed activities were included, assuming that the existing pattern of cropping and livestock activities was the 'best' combination the farmer could have under his circumstances. Thus unobserved activities were generally not specified in the operational models.

8.3 DESCRIPTION OF THE SURVEYED FARMS

Figure 8.1 shows the approximate location of the surveyed farms. With the exception of farms C and D they were evenly distributed along a 80 km long strip of the coastal mountains. The farms' most relevant characteristics are shown in Table 8.2.

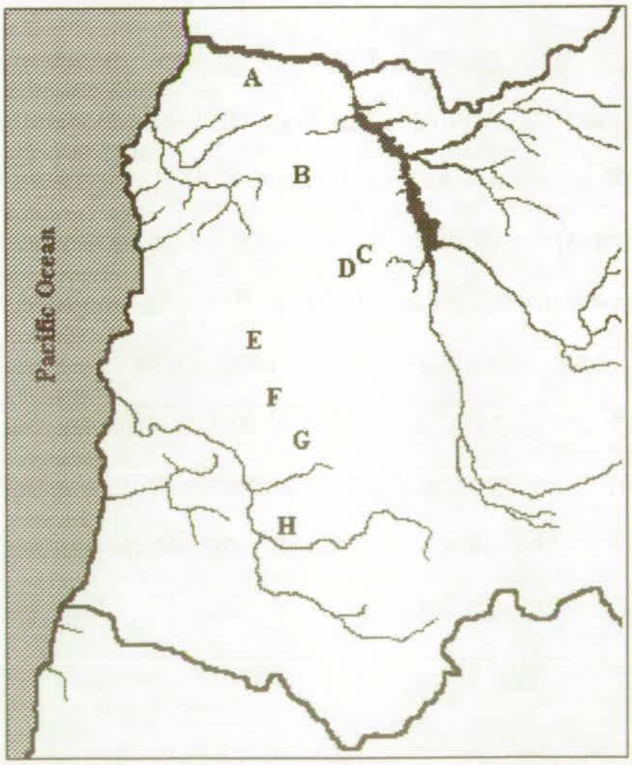


Figure 8.1 Approximate location of the representative farms

The farming systems' main features were:

i. FS-A: farmer with labour surplus, who had to take land in to use this labour
ii. FS-B: traditional wheat-cattle-sheep system based on own labour
iii. FS-C: wheat-sheep system with capital restrictions
iv. FS-D: the farm had a large labour deficit as the farmer could not work due to chronic illness

Table 8.2 Principal features of the representative farms

FS	Age	Labour	Land	Crops	Livestock	PO	Other income
A	40	Works with brother	4.6 ha (own) 9.4 ha (taken-in)	Wheat, chickpeas, vineyard, pasture	Sheep, cattle (given-out)	Wheat-cattle-maize-pasture-legumes	
B	52	Works alone	75 ha (own)	Wheat, chickpeas, peas, lentils, oats and pasture	Sheep, cattle, horses	Wheat-sheep	
C	57	Works alone	50 ha (own)	Wheat	Sheep, horses	Wheat-pasture-cattle	
D	62	Retired	24 ha (given-out)	Wheat (given-out), pasture	Sheep, horses	Wheat-legume-sheep	Monthly pension
E	61	Works with a son	76 ha (own)	Wheat, maize, pasture, charcoal	Cattle, horses, sheep (given-out)	Wheat-pasture-cattle	Interest on bank deposit
F	60	Hires labour	42 ha (own) 6 ha (given-out) 12 ha (taken-in)	Wheat, oat and clover, vineyard, eucalyptus, pasture, charcoal	Ewes, cattle (own and taken-in), horses	Wheat-vineyard-sheep	
G	26	Works with brother	30 ha (own)	Wheat, phalaris, lemon, tomato, oats, pasture, eucalyptus, charcoal	Sheep, horses	Wheat-vineyard-sheep	
H	45	Works alone	9.5 ha (taken-in)	Wheat, charcoal	Sheep (given-out), cattle (given-out)	Wheat-legumes-sheep	Full-time off-farm labour

v. FS-E: large farm with substantial available labour

vi. FS-F: the fact that the farmer took land in and gave land out meant that high labour demanding land (arable) was replaced by low labour demanding land (pasture) reflecting that labour shortage occurred on this system

vii. FS-G: diversified system without wheat during the previous year; he grows greenhouse tomatoes but has problems planting his tomatoes early enough to sell his product at the higher spring prices[1]

viii. FS-H: landless farmer who works full-time on a nearby farm, using an important part of his spare time to sharecrop wheat and fallow

It was seen that the relation between the PO and the observed production pattern was not good. Nevertheless the chosen farms showed substantial differences between them, suggesting that the multivariate analysis (Chapter 6) had succeeded in constructing a typology suitable for the analysis of sustainability. It was concluded that the eight surveyed farms did represent different FSs and that therefore the FSMs could be constructed based on them.

It should be noted that each farm model was constructed using observed activities and observed coefficients, and not using all activities observed across farms nor average coefficients computed over the eight surveyed farms. The reasons for doing so were that each model should represent as good as possible a real farm and not an average hypothetical farm. Further, the use of average values can hide the variability observed across farms and average values could be biased estimates of the population average, as in many cases the variables were obtained from a small number of farms. Nevertheless such an approach increases considerably the time required for model construction and increases the need of collecting reliable information for each farm.

[1] Tomato prices fall sharply from January to March as the field tomatoes become available.

8.4 MODELLING THE CROPPING SUB-SYSTEM

The calculation of cropping coefficients was straightforward. Land use, labour use and cash flow data were available to generate the necessary coefficients.

In addition to the fallow-(chickpea)-wheat-rough grazing rotation the following rotations were considered: fallow-peas-rough grazing (three years), fallow-wheat-lentil-rough grazing (three years), fallow-wheat-oats-rough grazing (three years), fallow-oats and clover-pasture (three years), and fallow-oats-rough grazing (three years). The necessary ties were constructed to characterise these situations.

For eucalyptus first year trees, second year trees and growing trees (three to twenty years) were considered as separate activities in the models. During the first year soil is prepared, and trees are planted and watered. In the second year, labour is only used to water the trees and control weeds. After this and until the trees were harvested (after 20 years), only labour for wood maintenance is required. This production cycle required the inclusion of additional restraints to establish the relationship between the three types of trees (Eq. [8.1] and [8.2]).

$$-meu01 + meu02 \leq 0 \qquad [8.1]$$

$$-18meu02 + meu3f \leq 0 \qquad [8.2]$$

where *meu01* represents growing first year eucalyptus on mountains; *meu02* represents growing second year eucalyptus on mountains; and *meu3f* represents growing third to final year eucalyptus on mountains.

To assign a GM to each of the three activities a yearly gross margin was estimated as the net present value (with a ten percent discount rate) over 20 years divided by that number of years[2]. It was assumed that cash flow data were always nil, because in Chile forestation programmes can claim back up to 75% of the planting costs, including labour. Further a loan schedule for small farmers allows them to buy trees and other inputs, repaying it with the subsidy. As a result, using

[2] The net present value of one ha of *Eucalyptus globulus* planted on that area by a smallholder, using all the available benefits was $ 1,478,400 (Rodríguez and Garfia, 1995; personal communication).

both loan and subsidy, small-farmers are able to forest part of their land, without any financial cost, as the 25% of the expenses not covered by the subsidy, are own labour costs.

8.5 Modelling the Livestock Sub-System

For both cattle and sheep three categories were defined: dams (cows or ewes), replacements (heifers or ewe-lambs), and offspring (yearlings or lambs). For each of them productive and reproductive coefficients as well as dry matter intake coefficients were computed.

8.5.1 Productive and Reproductive Coefficients

Constant weaning rates, mortalities and replacement rates were used across farms as they were difficult to estimate for each farm. The weaning rate, which takes account of mortality of young animals, was obtained by averaging the information from the surveyed farms. For sheep the weaning rate was 81%, while for cattle it was 74%. Replacement rate, defined as the percentage required to keep a herd of stable size and stable age, was set at 20% for sheep and 15% for cattle. Culling rate was defined as replacement rate minus five percent, which accounts for mortality in both dams and replacements. No other mortality rates were considered.

8.5.2 Forage Production Coefficients

Pastures in this area present low output and a marked seasonal production pattern. Their growth is nil during the dry summer period, slow during autumn and winter, and highest during spring (Figure 8.2). As a consequence of the different soil types and management systems the pastures present a great variability of production and botanical composition. The dry matter production ranges from 200 to 3,700 kg/ha/year, averaging 1,600 kg/ha/year (Rodríguez, 1991). A previous study showed similar results, indicating that production by mid August, mid September, and mid October was 750 kg/ha, 1,025 kg/ha, and 2,037 kg/ha respectively (Gastó and Contreras, 1979). Such a seasonal growth pattern determined that two seasons were defined. During Season I (May to November) an estimated 1,200 kg/ha of forage was produced, while during Season II (December to April) natural decomposition produced loss of forage. Based on data from Rodríguez (1991) it was estimated that transferring forage from Season I to Season II implied a dry matter loss of 30%. Although it is known that the amount of residues left on the pasture and the number and canopy area of acacia trees affect the pastures' productivity (Ovalle and Squella, 1988), lack of data determined that this synergetic relation could not be considered.

Straw production was estimated using a wheat harvest index of 38% (CIMMYT, 1986). The harvest index gives the ratio between crop dry matter and total above ground level dry matter.

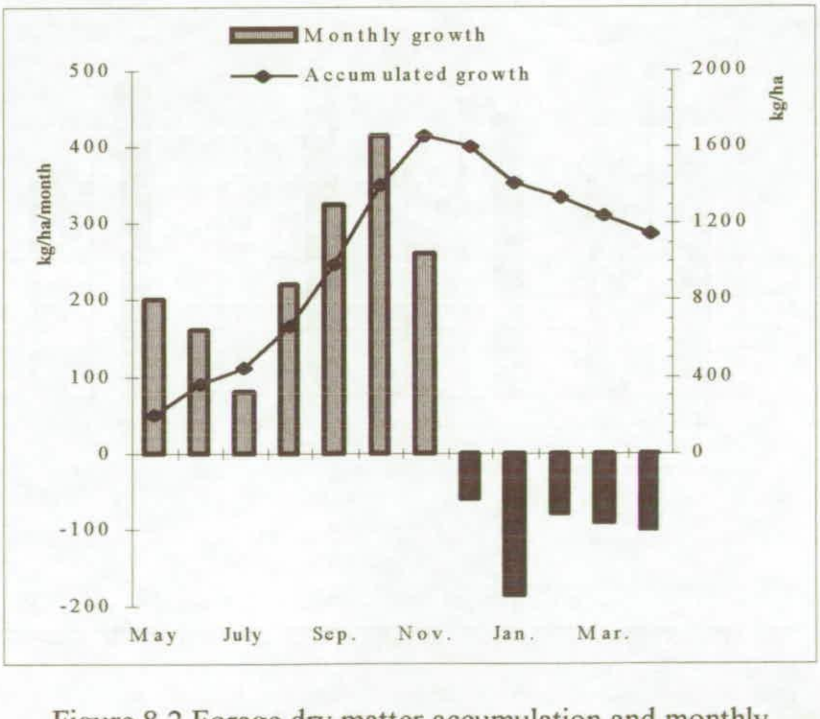


Figure 8.2 Forage dry matter accumulation and monthly growth of a natural pasture in the coastal dryland of the VIth Region, Chile (Rodríguez, 1991)

8.5.3 Dry matter intake coefficients

To determine dry matter intake (DMI) theoretical models were used as experimental or field data for local conditions and breeds were not available. The methods used to estimate DMI of sheep were developed by NRC (1985), Forbes (1995), AFRC (1993), and SCA (1990). Of the four estimates two allowed for corrections due to forage quality (AFRC and SCA), having both similar estimates (Figure 8.3 and Table 8.3). The other two methods showed higher DMI estimates. Under local conditions, little is known about DMI of sheep. Only one study reports that ewes on a clover-phalaris pasture consumed between lambing and weaning (116 days) 239 kg of dry matter, i.e. 2.06 kg per day (Crempien and Squella, 1987). During this period lambs consumed 41 kg of dry matter. Based on this data the total adjusted consumption for a sheep-lamb unit during 92 days would be 222 kg. This value suggests that AFRC probably underestimates the consumption of a ewe.

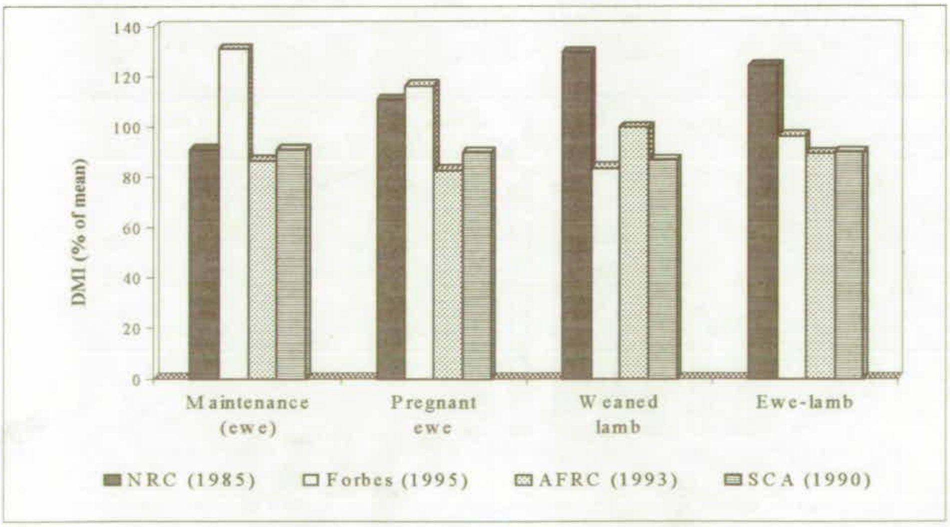


Figure 8.3 DMI estimated through four methods for all sheep categories and expressed as a percentage of the average DMI

Table 8.3 DMI estimates for each sheep category according to four methods (kg per head per year)

Category	NRC (1985)	Forbes (1995)	AFRC (1993)	SCA (1990)	Average
Ewe maintenance	383	553	365	383	421
Ewe lactating	527	553	393	426	475
Lamb	79	51	55	53	60
Replacement	386	298	277	278	310

DMI for cattle was estimated using the methods proposed by NRC (1984), Forbes (1995), AFRC (1993), and SCA (1990). The method proposed by SCA showed the lowest values except for growing cattle where AFRC is lower. No pattern could be found for the rest of the data (Figure 8.4 and Table 8.4).

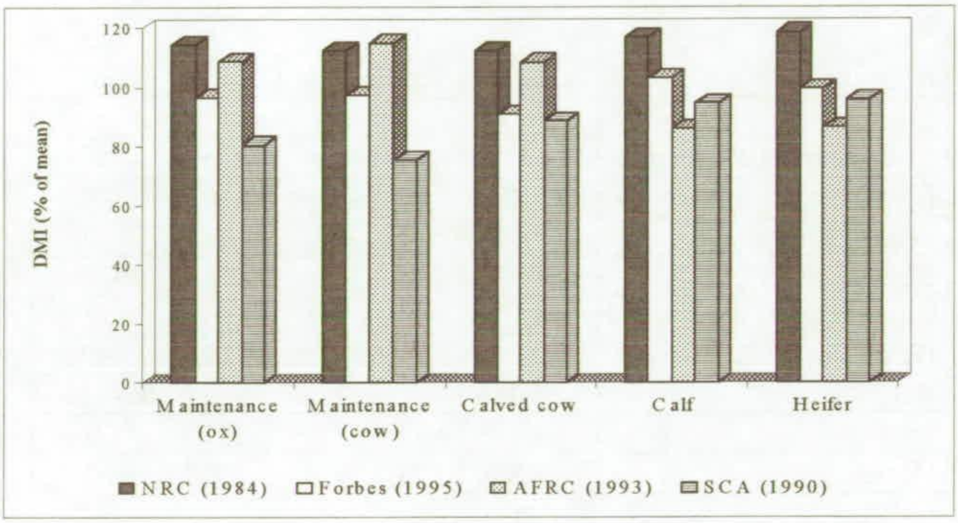


Figure 8.4 DMI estimated through four methods for all cattle categories and expressed as a percentage of the average DMI

Table 8.4 DMI estimates for each cattle category according to four methods (kg per head per year)

Category	NRC	Forbes	AFRC	SCA	Average
Dry cow	3212	2947	3285	2154	2858
Lactating cow	3443	2947	3487	2804	3063
Calf	817	1223	600	660	699
Heifer	4188	5339	3209	3560	3718
Ox	4490	3264	3504	2592	3223

The data used to construct the operational models was the average DMI of all estimates. Seasonal distribution of DMI was estimated according to the days spent by each category in both seasons (Table 8.5). For cattle, due to the non-existence of seasonal calving patterns, the estimated yearly DMI was distributed in fixed amounts between each season. As ewes have a known reproductive cycle, it was possible to estimate the seasonal DMI. Lambs only consumed forage during Season I. Finally, as the FSM only considers dams, for both sheep and cows the DMI of pregnant and dry animals was pooled, using the weaning rate as weight. This value then was used as an estimate of the DMI of an average dam. The maintenance intake of a mature horse (8.5 kg dry matter per day) was used as the reference value for DMI of horses (NRC, 1978).

Table 8.5 Seasonal DMI, annual DMI and average liveweight as estimated for all animal classes (kg)

	DMI			Live-
Animal class	Season I	Season II	Total	weight
Ewe	246	175	421	55
Ewe pregnant & lactating	277	198	475	55
Ewe-lamb	173	137	310	20-50
Lamb	61	---	61	20-30
Cow	1,676	1,182	2,858	500
Cow pregnant & lactating	1,796	1,267	3,063	500
Heifer	2,180	1,538	3,718	80-400
Calf	410	289	699	80-180
Ox	1,889	1,333	3,222	600
Horse	1,819	1,283	3,102	600

8.5.4 CASH FLOW COEFFICIENTS

As livestock are reared extensively, only minimal inputs are used and income is generated solely through the sale of offspring and culled dams. To establish the cash flows a standard management system was used. Lambs are sold during spring when they weigh around 30 kg and are three to four months old. Yearlings are sold during October, before forage becomes scarce. As culled cows and ewes have no fixed sale pattern at farm level it was assumed that their sale is spread evenly throughout the low pasture season (December to April).

8.6 CAPITAL AND CASH FLOW DATA

In addition to the cash flows for cropping and livestock activities, monthly cash expenses and working capital were determined. The monthly cash expenses, defined as money spent by the household on non-farming activities, were assumed to be constant and computed for each farm as the yearly farm income less the yearly paid farm expenses divided by twelve. But, as agricultural income in this area is concentrated between spring and summer, cash shortfalls are normally observed during late winter, making constant monthly expenses unfeasible for any household. Therefore the previous figure was reduced by 20%, allowing the household to reduce its expenses when there is a shortfall in cash. As working capital (capital available at the beginning of each year) could not be obtained from the farmers it was assumed to be the amount of money required at the beginning of the year to follow the observed farm plan without showing a negative cash balance in any month. Therefore it was computed as the minimum balance in the observed farm cash flow. Farm D, which had an important source of off-farm income, never showed a negative balance and therefore its working capital was assumed to be zero.

As INDAP limits the borrowing capacity of each farmer according to his assets, the actual loan was set as the top borrowing capacity.

8.7 MODELLING LABOUR

Monthly labour availability was given by the number of days per month multiplied by the number of persons working on that farm, and no restriction was made on the amount of labour a farm could hire. The number of days per month currently spent working off-farm was defined as the maximum off-farm labour. As FS-H sold all his labour and worked only during weekends on-farm, monthly labour transfer activities were defined, so that available labour could be used on-farm or off-farm (Eq [8.3]). In total he had 26 days holiday which he could use whenever he required (Eq. [8.4]). No allowance was made for hiring labour on this farm.

$$\sum l_{j,1}x_j + ofl - tl_1 \leq al_1; \quad i = 1,\ldots,12 \qquad [8.3]$$

$$\sum tl_1 \leq 26; \quad i = 1,\ldots,12 \qquad [8.4]$$

where $l_{j,i}$ is the amount of labour used by activity x_j during month i=1,…,12; ofl is the monthly off-farm labour; tl_i are the holiday used during month i=1,…,12; and al_i is the available labour during month i=1,…,12.

8.8 CONSTRUCTING THE RISK VECTORS

The risk coefficients considered only economic risk through the variation in product price. To compute the risk vectors a ten year series of wholesale prices for products in Santiago were used. It was assumed that, although the prices observed in Santiago (some 150 km from the micro-region) were probably better for both inputs and outputs, their yearly variation should reflect variations in local prices. When the series for a given input or output were unknown, the actual price was used as a constant value. Although this reduced the GM variability for that activity, it was better than not including that input or output, as this would have reduced or increased the expected GM. The most frequent missing data was related with minor inputs like disinfectants, agro-chemicals or harvest costs. Ignoring them would overestimate expected GM and thus make it easier to achieve the minimum income target. When an activity lacked information on income variation (e.g. hired labour, eucalyptus and charcoal), yearly GM variation was artificially generated by weighting the observed GM for these activities by the yearly variation of the farm GM. The average farm GM over the period of ten years was assigned a factor of 100% and the yearly values expressed in relation to this value. The yearly farm GM was calculated using the observed variation in retail prices and assuming that the activity levels for each year were the same as the ones observed (Appendix 2). The risk target was defined as maximum farm GM obtained during these ten years. Nevertheless as the risk target was easily achieved in most farms this target was increased in all farms by 20%.

8.9 OTHER CONSTRAINTS

Depending on the individual situation of each farm, additional restrictions were set, principally as upper and lower bounds for certain activities. These constraints included:

i. Maximum number of given-out livestock: To avoid farms giving-out an unlimited number of livestock, the maximum number of livestock to give-out was defined as the actual number of livestock given-out.
ii. Minimum number of horses/oxen: As these were used as a source of power their actual number had to be kept.
iii. Minimum purchase of alfalfa hay: Some farms did buy this better quality forage to feed their horses, thus its purchase was at least the present level.
iv. Maximum vineyard: As the establishment of productive vines takes some years, the area under vines could not be higher than the actual one.
v. Maximum product sale: For farmers who were able to sell charcoal and straw the actual amount sold was set as a maximum.
vi. Maximum irrigated area.

8.10 SOIL LOSS ESTIMATION

8.10.1 ESTIMATION OF THE SOIL LOSS FACTORS

As mentioned in Section 7.3.3 soil loss was estimated[3] for each farm and for each activity using the Universal Soil Loss Equation (Wischmeier and Smith, 1978)

[3] The help of Mr. Manuel Casanova and Mr. Ian Homer was invaluable in the determination of the potential soil erosion in the micro-region.

and its revised version RUSLE (Renard, Laflen, Foster and McCool, 1994). These equations estimate the amount of soil lost per area unit within a given time period (t/ha/year).

The rain erosivity factor (R) depends on the rain's total energy and the rainfall during the 30 min of highest intensity. Both variables are obtained from rain fall graphs of each individual storm and location. As this precise data were not available for an adequate number of meteorological stations, the modified Fournier Index was used (Casanova, personal communication):

$$F_m = \sum_{i=1}^{12} \frac{P_i^2}{P_{ann}}$$

$$R = a + b * F_m$$

where P_i is the average rainfall for month i (mm); P_{ann} is the yearly rainfall; and a, b are site specific constants.

The constants a and b are unknown for Chile, but as rainfall distribution in this area is similar to the one observed in California and Oregon, the factors for these States (-3.00 and 0.66) were used (Lal and Elliot, 1994). The iso-erosivity curves were estimated by interpolating the values computed for a set of meteorological stations (Figure 8.5). Combining this information with the location of the farms the R values for each farm were computed (Table 8.7).

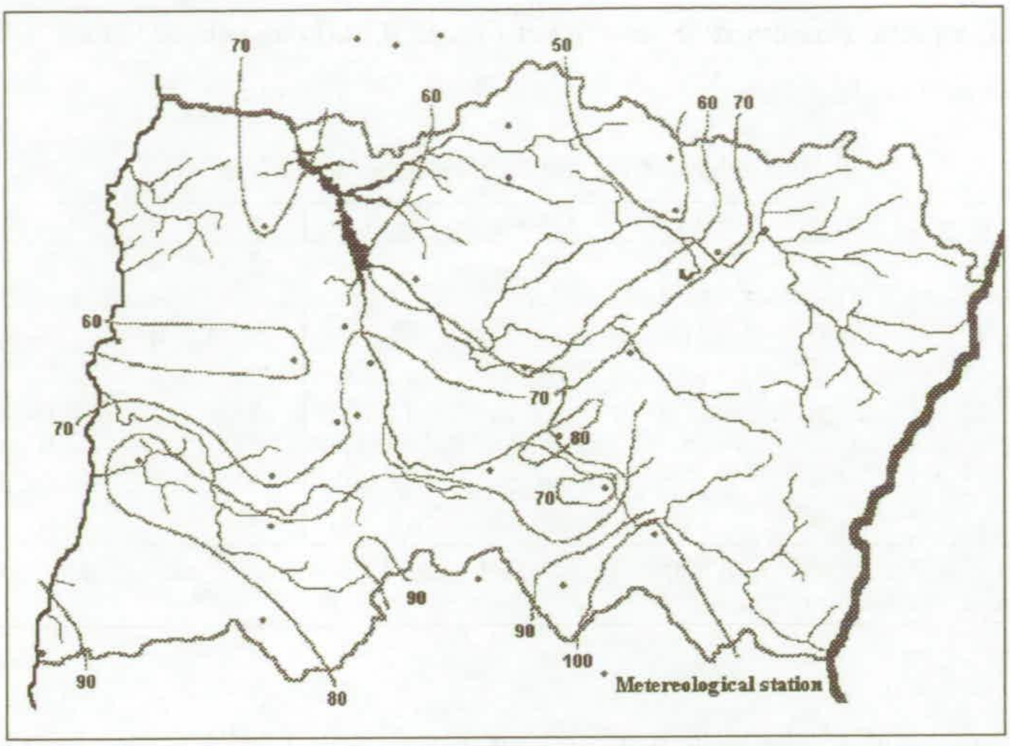


Figure 8.5 Estimated iso-erosivity curves for Chile's VIth Region
(M. Casanova and I. Homer, personal communication)

The erodability factor (K) was estimated through (Wischmeier and Smith, 1978):

$$100K = 2.241 * \left(2.1 * 10^{-4} * (12 - J) * M^{1.14} + 3.25 * (S - 2) + 2.5 * (p - 3)\right)$$

$$M = (\%VFS + \%L)(100 - \%Cl)$$

where J is the content of organic matter in the soil; M is the texture index; $\%VFS$ is the percentage of very fine sand (0.05-0.10 mm) in soil; $\%L$ is the percentage of lime (0.002-0.05 mm) in soil; $\%Cl$ is the percentage of clay (<0.002 mm) in soil; S is the soil structure index (1: very fine sub-angular; 2: fine sub-angular; 3: medium sub-angular; 4: any other type); and p is the permeability index (1: >10 cm/h; 2: 5-10 cm/h; 3: 3-5 cm/h; 4: 1-3 cm/h; 5: 0.5-1 cm/h; 6: <0.5 cm/h).

For each farm a sample of the superficial horizons was taken from one field and analysed at the Irrigation and Water and Soil Chemistry Laboratory, Faculty of Agricultural and Forestry Sciences, University of Chile. Clay, lime, sand, very fine sand and organic matter content were determined in the lab and permeability and soil structure assessed at farm level (Table 8.6). Using these values K was determined (Table 8.7).

Table 8.6 Values for soil characteristics at each farm

Farm	%Clay	%Lime	%Sand	%VFS	p	S	J
A	10.9	19.9	69.2	25.26	2	4	0.71
B	21.8	21.6	56.6	15.26	3	4	1.60
C	9.5	21.2	69.3	15.26	3	4	1.29
D	7.8	12.9	79.3	13.18	2	2	0.86
E	11.6	21.3	67.1	11.10	3	3	1.58
F	8.6	17.3	74.1	13.90	3	2	2.49
G	10.0	19.3	70.7	10.87	3	2	2.69
H	11.2	15.2	73.6	11.28	5	2	2.40

Notes: %VFS: very fine sand content; P: permeability code; S: soil structure code; and J: organic matter content (%).

Field slope and field length were determined at field level and the LS factor computed using RUSLE and the condition of soil degradation (Renard and Foster, 1995). Tabular values were used to estimate factor C, which represents the effect of plants, soil cover, soil biomass, and disturbing activities on erosion. Finally, as no farm presented soil conservation practices a value of one was assigned to the factor P for all farms (Table 8.7).

Table 8.7 Estimated soil erosion and values of the factors used to estimate it for the sampled field of the representative farms

Farm		L (m)	S(%)	R	K	LS	C*	P	A
A	Wheat	200	1.8	76.6	0.773	0.358	0.380	1.00	8.06
B	Fallow	150	8.8	75.1	0.576	3.450	1.000	1.00	108.61
C	Natural pasture	100	1.2	65.8	0.663	0.178	0.011	1.00	0.09
D	2nd year rough grazing	50	1.2	65.8	0.319	0.196	0.026	1.00	0.11
E	1st year rough grazing	250	8.2	65.3	0.501	1.973	0.056	1.00	3.61
F	Natural pasture	200	2.6	64.9	0.389	0.453	0.011	1.00	0.11
G	Natural pasture	300	1.8	64.1	0.360	0.304	0.011	1.00	0.08
H	Wheat	400	2.6	68.2	0.427	0.666	0.380	1.00	7.37

* : Mitchell and Bubenzer (1980)

8.10.2 ESTIMATED SOIL EROSION FOR EACH FIELD

The expected soil erosion for each sampled field was calculated using these factors (Table 8.7). The importance of each factor under these conditions was analysed by computing for these eight plots the correlation between estimated soil erosion and each factor. The R^2 coefficient values between A and R, K, LS, and C were 0.63, 0.23, 0.87, and 0.92, respectively. Under these circumstances, factor LS and particularly factor C had the greatest impact on expected soil erosion. Although K showed large variability, its impact on soil erosion was minimal. This highlights again the importance of considering crop and slope in the construction of the model's decision variables.

8.10.3 ESTIMATED SOIL EROSION FOR OTHER PLOTS OR CROPS

To extend these results to be applicable to any crop it was assumed that all plots were square; the average slope of flat, hilly and mountainous land was 2.5%, 7.5% and 12.5% respectively; and R and K were constant for the whole farm. The main weakness of these assumptions is the constant value of K; but to overcome it a great number of soil analyses would be required for each farm. This was unfeasible due to its prohibitive cost and because it implied an increased number of soil types which would have made the aggregate micro-regional model difficult to solve and the results almost impossible to interpret. The low R^2 value between A and K also justified such an assumption.

The soil cover factor was obtained from tabular data (Table 8.8), as it was not possible to measure it on the field nor to estimate it from the monthly distribution of erosivity and the monthly percentage of uncovered soil for each crop as suggested by Wischmeier and Smith (1978). When secondary values for given crops, were not found, assumptions were made to estimate that value.

Table 8.8 Soil cover factor value and characteristics for each relevant crop

Crop	C(%)	Crop characteristics
Natural pasture	1.1[a]	Undisturbed land without vegetal canopy and 95-100% vegetation at ground surface
1st year rough grazing	5.6[b]	1st year meadow after conventional wheat
2nd year rough grazing	2.6[b]	2nd year meadow after conventional wheat
Fallow	100.0[b]	Continuous fallow tilled up and down slope
Wheat, oat, oat/phalaris	38.0[b]	Wheat-fallow rotation, turn ploughed during autumn
Peas, lentils	51.0[c]	Beans after corn, spring plough, on field with residues, conventional till, and 20% mulch cover after harvest
Oat & clover	34.2	Wheat value reduced by 10%[d]
Phalaris (2nd to 5th year)	2.3[b]	Average of 1st and 2nd year rough grazing and natural pasture
Strawberries	12.0	Pooling of 60% idle land without canopy and 20% ground cover[b], with 40% land completely covered by plastic
Lemons	8.8[a]	Undisturbed land with 3 m high trees, 25% vegetal canopy cover, and 60% vegetation at ground surface
Maize	62.0[b]	Autumn turn ploughed conventional corn with residues removed or burned
Vineyard	8.6[b]	Undisturbed land with 1.50 m high bushes, 25% vegetal canopy cover, and 60% vegetation at ground surface
1st year eucalyptus	9.1[a]	Permanent pasture without appreciable canopy, and only 60% vegetation at ground surface
2nd year eucalyptus	4.1[a]	Undisturbed land with tall weeds, 0.5 m effective height, and 80% vegetation at ground surface
3rd to 20th year eucalyptus	1.1[a]	Undisturbed land with 2 to 4 m high brush, 25% vegetal canopy cover, and 95-100% vegetation at ground surface

a: Wischmeier and Smith (1978)

b: Mitchell and Bubenzer (1980)

c: Wischmeier and Smith (1978, pg. 23) and Figure 8.6

d: estimated value, reduction due to better surface cover provided by clover

The introduction of chickpeas shortens the normal one year long fallow, and thus reduces its expected soil loss. It was estimated that the average soil cover between September and January for this crop is 60%. But as the rainfall during this period is only 13% (Figure 8.6), the reduction of soil loss compared to continuous fallow was 7.8%.

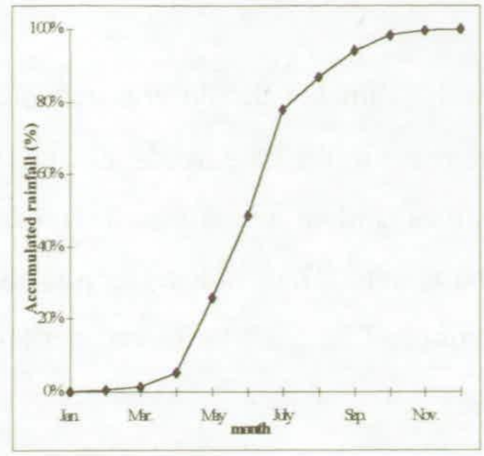


Figure 8.6 Accumulated rainfall (%)

Trees have two effects on soil erosion. First they increase the surface area covered with mulch or vegetation, and second the trees' canopy reduces the rain's energy[4]. Therefore a different C factor was used for each eucalyptus activity, taking into account surface cover and canopy.

Finally both grazing and charcoal production reduce the soil cover and thus favour soil erosion. Although both effects are complex and difficult to measure, not considering them may result in farm plans with very high stocking rates and with a large removal of acacias. According to Wischmeier and Smith (1978) the C factor for undisturbed land without vegetal canopy is 1.1% when there is 95 to 100% vegetation at ground surface and 4.3% when this cover is reduced to 80%. Assuming that C increases linearly when forage is consumed, then consuming one kilogram from the available of 1,200 kg/ha of forage increases C by 0.0027%. This value was then weighted by dry matter intake to estimate C for different types of animals. If animals were given-out, it was assumed that their impact on the micro-regions erosion would be the same. To estimate the impact of cutting acacias it was assumed that each acacia covers four square meters and that one bush is required per bag of charcoal. As reducing a two meter high vegetal canopy from 25 to 0% on undisturbed land with 20% vegetation at ground surface increases C from 22 to 24% (Wischmeier and Smith, 1978), then the production of one bag of charcoal increases C by 0.0032%.

[4] The vegetal canopy is only relevant when the soil level cover is less than 95%

Both estimates should consider different land types (slopes), but this means an increase in the data needs, already based on gross estimates rather than observed values, and an increase in the model's size with an unknown gain of accuracy in the results. Thus, soil erosion produced by grazing and charcoal production was estimated for each farm considering only hilly land.

8.11 MODEL VALIDATION

Validation is the process by which a model is determined to be a valid portrayal of the system modelled. Within a time perspective, models can be evaluated *ex post* or *ex ante*. *Ex post* validation evaluates the performance of the model's prescriptions, comparing the observed results with expected ones, while *ex ante* validation evaluates the model before results are known. Unfortunately *ex post* validations can rarely be used because they are expensive and time consuming (McCarl and Apland, 1986).

In order to judge if an LP model is valid, the optimal values of the primal decision variables, the dual variables and the objective function should be systematically validated. Specifically validation of LP models can be by construct or by results (McCarl and Apland, 1986). Validation by construct relies on procedures believed to be appropriate by the model builder. These are based on experience, precedence, and/or theory, using scientific estimation or real world data. It may also use special constraints to replicate an observed outcome. As such restraints may force the validity of a model, they should only be used when theory and/or knowledge of the problem strongly dictate it *a priori*. The problem of validation by construct is that the models validity is assumed, not tested. Validation by results usually follows validation by construct and consists of a comparison of model solutions with corresponding real world outcomes. First sets of parameter describing the environment and outcomes associated with them are collected. These are then used in validation experiments, which yield information on the model's ability to replicate various portions of the outcome sets. Any of the following tests may be used with the complete model or part of it (McCarl and Apland, 1986):

i. *Feasibility experiment*: it is checked if the observed values of the decision variables belong to the set of feasible solutions in both the primal and its dual model, by analysing if the replacement of the decision variables with their observed values violates any constraint.
ii. *Quantity experiment*: the shadow prices are observed after constraining outputs supplied or inputs demanded at the present levels and removing price parameters.
iii. *Price experiment*: for models with endogenous prices.
iv. *Prediction experiment*: the model is solved with parameters fixed at existing levels, and the solution (primal and dual) compared to the observed values.
v. *Change experiment*: a comparison is made between the change observed in the real world and the change in the solution when scenarios representing these changes in the real world are modelled.
vi. *Tracking experiment*: using a parameter set the model's changes over time are compared to the observed adjustments in the system.

8.11.1 CALIBRATION OF THE FARMING SYSTEMS MODELS

8.11.1.1 Land type calibration

The initial model did not show any preference in cultivating flat land over steeper land. Such a situation is not rational, as steeper land implies more labour and probably less output due to previous soil loss. To reflect the effect of slope, due to the lack of field of experimental information it was assumed that for each increase in slope range (this is different land type) the output was reduced by five percent and the labour input increased by five percent. All other inputs were constant for all land types. These adjustments were made for all crops and pastures.

8.11.1.2 Forage balance calibration

One of the major concerns was that as both forage intake and forage production had been estimated large forage deficit or surplus could be observed under present stocking rates. In fact FSs B, E and F had the deficits of five to ten tonnes of dry matter. Therefore pasture productivity was increased in these farms by ten to twenty percent. Although FS-C had a large forage surplus, no adjustment was made as the farmer was aware of this surplus.

8.11.1.3 Cash flow calibration

It was recognised that actual plans in farms with cattle were not feasible because of a negative cash balance during early spring (August, September). In real circumstances, although better cattle prices are obtained during September and October, the farmer can sell steers in other months to cover cash shortfalls. It was concluded that the model's design, without flexibility in cattle (yearling) sale, imposed severe restrictions on the farm's cash flow. As this contradicts the perception of livestock as a source of cash when it becomes scarce, allowance was made for monthly sales of yearlings. Nevertheless a fixed selling date (October) was maintained for both given-out and taken-in cattle, because an agreement of both farmers is required to sell cattle. Lambs are sold between August and October depending on the farm, as they are not ready for sale earlier in the year. Sale flexibility was also not feasible for crops because of lack of storage facilities. Such modification of the FSM determined a large reduction in the necessary working capital of farms with cattle.

The inclusion of variable month of sale necessitated the consideration of price variation, as the highest prices are achieved between July and September and the lowest between November and May[5] (Figure 8.7). As local price variations were unknown, change in Santiago's prices was used to adjust local prices[6]. Although

[5] Chile's main meat supply comes from the South, where forage is scarce during winter and abundant in spring and summer.
[6] Prices in June were given an index value of 100% and the remaining prices were expressed in relation to this reference value.

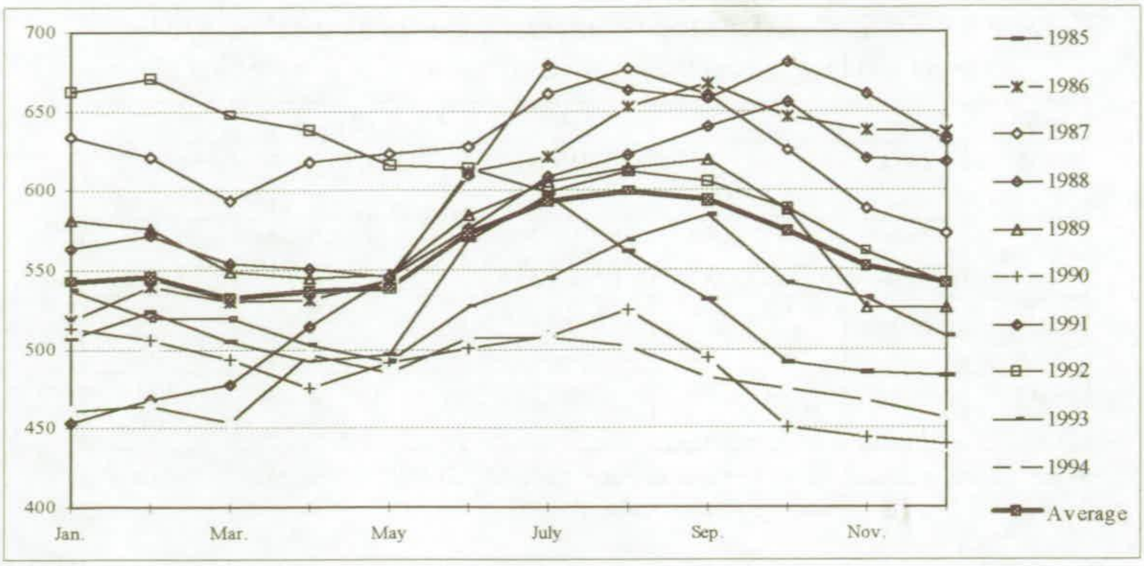


Figure 8.7 Monthly variation of live steer prices during the last ten years in cattle markets of Santiago (in $ in March 1995). (ODEPA, Ministry of Agriculture, Chile, 1995)

heifers were valued the same as a yearling steer, when differential sale of yearlings was included no value was given to heifers and only sold yearlings contribute towards the objective function.

8.11.1.4 Working capital calibration

According to the survey six farmers depended entirely on INDAP's loan for the purchase of seeds and fertilisers, but according to the model's initial results they were also using their own capital for this purpose. Thus, to reflect the situation of capital restriction working capital was iterativelly reduced until no own capital was used for the purchase of fertilisers and seeds (Table 8.9). This reduced FSM-B's working capital by 63.9% with only a 1.2% reduction in GM. The low impact on GM is because farmer-B could reschedule the steer sale to compensate for the reduction of available capital. In FSM-C the working capital was reduced by 15.1% and GM by only 0.59%. FSM-F's working capital was reduced by 18% and FSM-G's working capital by 5.3%, while their GMs were only slightly reduced (0.49% and 0.10% respectively). It was impossible to reduce the amount of own capital used to purchase fertilisers in FS-D, as working capital was already nil.

Table 8.9 Value of working capital, gross margin, own capital used to buy fertilisers and loan during the iterative adjustment of some FSMs ($)

FSM	Round	WK	GM	Own capital	Loan
B	first	754,617	2,795,614	303,110	0
	last	272,165	2,764,290	0	339,110
C	first	957,864	1,819,002	143,808	569,291
	last	808,055	1,808,214	0	713,098
F	first	1,095,899	3013186	196752	137908
	last	899,147	2998430	0	334660
G	first	741,476	2865575	38952	175932
	last	702,524	2862654	0	214884

Note: all prices are expressed in Chilean Pesos with March 1995 as the base. At that time around 630 Pesos equalled one Pound Sterling

A special case was FSM-E in which a reduction in working capital(51.6%) was balanced by an earlier sale of yearlings (Table 8.10). To determine an absolute minimum working capital, the model was reformulated removing the possibility of giving out cows and sheep and setting no limits on the number of livestock. The working capital was now only 12.7% of the initial one while the GM was still 69.5% of the original. The new farm plan made extensive use of cattle and sheep, as well as of purchased forage. These results confirmed the importance of livestock when cash resources are scarce, as livestock can be sold when cash is needed and their demand for inputs and thus cash is very low.

Table 8.10 Changes in GM and some decision variables when working capital of farm-E is reduced

Round	WK ($)	GM ($)	Own capital ($)	Loan ($)	Ewes (n)	Cows (n)	Alfalfa (kg)
1	1226195	4547634	631879	384013	10.79	20.00	3000
2	594316	4469788	743	1025025	10.22	20.00	3000
3	593573	4468040	41	1025025	10.19	20.00	3000
4	539532	4467943	3	1025025	10.19	20.00	3000
5	593529	4467936	0	1025025	10.19	20.00	3000
6	593529	4342377	13367	1025025	62.72	13.31	5556
Min	155766	3159951	13367	1025025	62.72	22.48	47668

Note: 6 and Min were obtained when limits on livestock where removed (see text)

8.11.2 VALIDATION OF THE FARMING SYSTEMS MODELS

The validation experiments conducted were primal feasibility test and prediction experiments. When rows were violated or large differences between RHS and the achieved level were observed in the primal feasibility test, the restrictions were analysed for possible adjustments. Non-observed variables like cash transfer were not tested. As shadow prices of some resources could not be determined the dual feasibility test was not performed. The prediction experiment consisted of maximising GM for each farming system model. Then for all measurable variables the primal solution was compared with the observed farm plan and the differences between both analysed.

8.11.2.1 Validation of the FSM-A

The feasibility test showed that the actual farm plan violated four rows. Violations of rotational constraints (wheat-chickpea for flat and hilly land) were due to differences in plot sizes, which do not allow for perfectly balanced rotations. The farmer had only a small herd, which determined that livestock constraints (ewe-lamb tie) were not respected. Labour use was higher than its availability during August which probably meant that some activities may in reality be performed in late July or early September. A solution to this problem would have been to allow for the displacement of activities between months (Arias, 1993), which implies an increase in the model's size. There was further slack own land, which was used to grow vegetables and staple crops for the household, and a forage deficit of 646 kg during Season II.

The optimisation of FSM-A generated a farm plan with $ 554,037 of GM, using a lower working capital (Table 8.11). The higher GM (6.6%) was due to a larger area under wheat and the rearing of cattle on the farm. As there was more straw some cows could be kept instead of giving them out and therefore yearlings could be sold in August to meet cash demand.

Table 8.11 Comparison between observed and predicted values for main decision variables of FSM-A

	Unit	Observed	Model	Change
GM	$	513001	554038	41037
Flat wheat (taken-in)	ha	1.57	1.57	
Flat fallow (taken-in)	ha	0.78	1.57	0.79
Flat chickpea (taken-in)	ha	0.78	0.52	-0.26
Hilly wheat (taken-in)	ha	1.57	1.57	
Hilly fallow (taken-in)	ha	0.78	1.57	0.79
Hilly chickpea (taken-in)	ha	0.78	0.52	-0.26
Mountain wheat (taken-in)	ha		1.57	1.57
Mountain fallow (taken-in)	ha	3.13	1.57	-1.57
Mountain chickpea (taken-in)	ha		0.52	0.52
Ewe	hd	2.00	2.00	
Ewe lamb	hd		0.40	0.40
Lamb	hd	2.00	1.62	-0.38
Cow	hd		0.12	0.12
Heifer	hd		0.02	0.02
Yearling	hd		0.09	0.09
Cow (given-out)	hd	2.00	1.88	-0.12
Heifer (given-out)	hd		0.28	0.28
Yearling (given-out)	hd	1.00	1.39	0.39
Forage transfer	kg	2,573	3,733	1,160
Sold wheat	kg	4,272	5,444	1,172
Sold chickpea	kg	798	779	- 19
Sold yearling (Aug.)	hd		0.07	0.07
Working capital	$	60,934	56,174	- 4,760

Note: In this and the next comparison tables only the observable decision variables (e.g. wheat, ewes or cows, but not cash transfer) which were different to the observed values are shown.

8.11.2.2 Validation of the FSM-B

The feasibility test showed that the farmer had less fallow than required to grow the actual amount of wheat and peas, therefore the rows defining the relation between fallow and crops were violated. The model also overestimated the number of steers and underestimated the number of lambs.

The optimal solution showed that flat land peas and oats were replaced by lentils, and that adjustments were made on area under wheat, chickpea, fallow and grazing to satisfy the rotational constraints (Table 8.12). On hilly land, peas were also replaced by lentils and the areas with other crops were adjusted. Replacement of peas by lentils only reflected the farmer's inability to sell fresh peas, which would produce a higher income as was his original intention. The non-existence of alternatives for mountain land determined the same results for the actual farm plan and the optimal solution. Only minor differences were observed in livestock activity levels. The number of cows increased to satisfy cash flow requirements and the number of ewes reduced to balance forage output with consumption.

Table 8.12 Comparison between observed and predicted values for main decision variables of FSM-B

	Unit	Observed	Model	Change
GM	$	2562962	2764290	201328
Flat wheat	ha	4.03	4.62	0.59
Flat fallow	ha	4.03	4.62	0.59
Flat chickpea	ha	1.24	1.54	0.30
Flat lentil	ha		1.54	1.54
Flat oats	ha	1.00		-1.00
Flat pea	ha	1.00		-1.00
Flat rough grazing	ha	9.00	9.23	0.23
Hilly wheat	ha	3.00	3.46	0.46
Hilly fallow	ha	3.00	3.46	0.46
Hilly chickpea	ha	1.00	1.15	0.15
Hilly lentil	ha		1.15	1.15
Hilly pea	ha	1.00		-1.00
Hilly rough grazing	ha	9.00	6.92	-2.08
Mountain rough grazing	ha	40.00	40.00	
Ewe	hd	61.00	50.64	-10.36
Lamb	hd	54.00	41.02	-12.98
Ewe lamb	hd	13.00	10.13	-2.87
Cow	hd	7.00	9.04	2.04
Heifer	hd	1.05	1.35	0.30
Yearling	hd	5.60	6.69	1.09
Yearling sale (June)	hd		1.81	1.81
Yearling sale (July)	hd		1.77	1.77
Yearling sale (Aug.)	hd		1.75	1.75
Yearling sale (Oct.)	hd	5.60		-5.60
Working capital	$	789577	272165	-517412
INDAP loan	$	458870	339110	-119760
Monthly hired labour (Jan)	d		21.25	21.25

The sensitivity of this solution to price changes was tested. A decrease of ten percent in lamb prices resulted in the replacement of most of the ewes by cows, leaving only enough to satisfy home consumption. Thus the observed mixture of both species can be seen as a strategy to reduce income risk, assuming their prices are not highly correlated (the correlation for the ten year price series was 38%). Discrepancies in month of steer sale may be due to non-existence of monthly price variations at local level, as assumed by the model, or due to particular cash requirements during the previous season. Further, because of lack of data coupled to excessive complexity in the models it was necessary to assume that a steer could be sold in any month without age or weight considerations.

8.11.2.3 Validation of the FSM-C

Also in this FS the feasibility experiment violated the rotational constraints for wheat-fallow and wheat/pasture, which reflects the problem of modelling rotational constraints when farm plots have a fixed size. The observed GM was 12% higher than the model's GM (Table 8.13), due to the violation of the rotational restrictions. The farm's stocking rate was sub-optimal, a fact recognised by the farmer, who would like to increase it with cattle because they are less liable to be stolen.

Table 8.13 Comparison between observed and predicted values for main decision variables of FSM-C

	Unit	Observed	Model	Change
GM	$	2040501	1808217	-232284
Flat fallow	ha	3.00	3.00	
Flat wheat	ha	4.00	3.00	-1.00
Flat rough grazing	ha	5.00	6.00	1.00
Hilly fallow	ha	4.03	7.00	2.97
Hilly wheat	ha	8.00	7.00	-1.00
Hilly rough grazing	ha	15.97	14.00	-1.97
Ewe	hd	20.00	38.02	18.02
Ewe-lamb	hd	4.00	7.60	3.60
Lamb	hd	18.00	30.89	12.80
Working capital	$	941784	808056	-133729
Loan	$	855720	713099	-142621

8.11.2.4 Validation of the FSM-D

As the actual farm plan did not respect rotations the prediction experiment showed that land given-out (both flat and hilly) as well as actual GM were higher than predicted by the model (Table 8.14). The farm could also have a higher stocking rate.

Table 8.14 Comparison between observed and predicted values for main decision variables of FSM-D

	Unit	Observed	Model	Change
GM	$	480399	443400	-36999
Fallow flat(given-out)	ha	2.35	3.00	0.65
Rough grazing flat	ha	5.74	6.00	0.26
Wheat flat (given-out)	ha	3.91	3.00	-0.91
Fallow hilly (given-out)	ha	2.34	3.00	0.66
Rough grazing hilly	ha	5.76	6.00	0.24
Wheat hilly (given-out)	ha	3.90	3.00	-0.90
Ewe	hd	20.00	26.11	6.11
Lamb	hd	18.00	21.15	3.15
Ewe lamb	hd	4.00	5.22	1.22
INDAP loan	$	230520	167697	-62823
Own cash for fertiliser	$	0	9399	9399

8.11.2.5 Validation of the FSM-E

The feasibility experiment only showed a small violation of labour use during September. The area of wheat was lower than in a balanced rotation; thus the wheat-pasture constraints show significant levels of under-achievement.

The model's results showed a larger area under wheat and less under pastures, requiring additional labour during September to prepare the fallow and a larger loan taken from INDAP (Table 8.15). More area under wheat meant that more dry matter was available and that the number of ewes given-out was smaller, as some of them could be reared on-farm. To satisfy cash flow requirements, steers were sold during August and September.

Table 8.15 Comparison between observed and predicted values for main decision variables of FSM-E

	Unit	Observed	Model	Change
GM	$	4030589	4475771	445182
Flat wheat	ha	7.50	9.50	2.00
Flat fallow	ha	7.50	9.50	2.00
Flat rough grazing	ha	23.00	19.00	-4.00
Hilly wheat	ha	7.50	9.29	1.79
Hilly fallow	ha	7.50	9.29	1.79
Hilly rough grazing	ha	24.00	19.42	-4.58
Ewe	hd		20.00	20.00
Ewe lamb	hd		4.00	4.00
Lamb	hd		16.20	16.20
Ewe (given-out)	hd	20.00		-20.00
Ewe lamb (given-out)	hd	4.00		-4.00
Lamb (given-out)	hd	18.00		-18.00
Cow	hd	20.00	18.66	-1.34
Heifer	hd	3.00	2.80	-0.20
Yearling	hd	16.00	13.81	-2.19
Cow (given-out)	hd		1.34	1.34
Heifer (given-out)	hd		0.20	0.20
Yearling (given-out)	hd		0.99	0.99
Straw output	kg	56575	71402	14827
Forage transfer	kg	48000	54536	6536
Sold wheat	kg	40682	51487	10805
Sold lambs	hd	7.00	12.20	5.20
Sold straw	bales	80.00	80.00	
Sold yearling (June)	hd		1.24	1.24
Sold yearling (July)	hd		3.30	3.30
Sold yearling (Aug.)	hd		6.86	6.86
Sold yearling (Oct.)	hd	13.00		-13.00
INDAP loan	$	802020	1002525	200505
Working capital	$	1226195	593529	-632666
Monthly hired labour (Sep.)	d		14.93	14.93

Note: Actual GM does not consider interest earned

8.11.2.6 Validation of the FSM-F

The feasibility experiment violated the wheat/chickpea ties for given-out land, while under-achieving them for own land. As the eucalyptus trees were only one and two years old, the over three year old trees tie was unbalanced. The dam-offspring ties were violated as this farmer had a higher than average fertility rate. Both own and taken-in cow/yearling ties showed small differences with the target levels.

In this FS labour use and availability were one of the major issues. The initial model with the farmer working every day on-farm and with up to five man/days per month of hired labour showed that no land was given out and that a large surplus of labour occurred. To reduce this surplus two alternative labour scena-

Table 8.16 Comparison between observed and predicted values for main decision variables of FSM-F under three labour availability scenarios

	Unit	Observed	100%	75%	50%
GM	$	3024653	3532474	3313611	2998430
Flat wheat	ha	2.50	4.91	5.00	5.00
Flat fallow	ha	2.50	4.91	5.00	5.00
Flat chickpea	ha		1.64	1.67	1.67
Flat oats & clover	ha	0.50			
Flat rough grazing	ha	9.56	9.81	10.00	10.00
Flat wheat (given-out)	ha	2.09			
Flat fallow (given-out)	ha	2.35			
Flat chickpea (given-out)	ha	2.35			
Flat vineyard	ha	0.50	0.38		
Flat rough grazing (taken-in)	ha	12.00	12.00	12.00	12.00
Hilly wheat	ha	1.25	2.50	2.50	1.37
Hilly fallow	ha	1.25	2.50	2.50	1.37
Hilly chickpea	ha		0.83	0.83	0.46
Hilly rough grazing	ha	4.79	5.00	5.00	5.00
Hilly oats & clover	ha	0.50			
Hilly wheat (given-out)	ha	1.04			1.13
Hilly fallow (given-out)	ha	1.17			1.13
Hilly chickpea (given-out)	ha	1.17			0.38
Mountain pasture	ha	10.00	12.00	12.00	12.00
Mountain eucalyptus (year 1)	ha	1.00			
Mountain eucalyptus (year 2)	ha	1.00			
Ewe	hd	50.00	87.09	88.23	88.23
Lamb	hd	45.00	70.54	71.47	71.47
Cow	hd	6.00	0.00	0.00	0.00
Yearling	hd	4.80	0.00	0.00	0.00
Cow (taken-in)	hd	5.00	5.00	5.00	5.00
Yearling (taken-in)	hd	4.00	3.70	3.70	3.70
Sold yearling (Aug.)	hd		0.00	0.00	0.00
Sold yearling (Oct.)	hd	3.90			
Produced charcoal (Aug.)	bags	100.00	157.22	141.50	102.50
Produced charcoal (Sep.)	bags	100.00	42.78	19.00	
INDAP loan	$	318571	356435	361005	334660
Working capital	$	1095899	834051	899147	899147
Monthly hired labour (Aug.)	d	5.00	5.00	5.00	5.00
Monthly hired labour (Sep.)	d	5.00	5.00	5.00	5.00

rios, with 75% and 50% of the initial available labour level, were modelled, and the model's predictive validity for each scenario tested (Table 8.16). The results showed that a sequence of changes occurred as labour became scarcer. First eucalyptus planting and growing was abandoned, due to the high labour demand for planting, which coincides with fallow preparation. Then vineyards were excluded as they had a high demand for labour, which in fact was a possibility being considered by this farmer. Finally land was given-out for wheat and as a result the area of own grown wheat was reduced. Throughout this process the production of charcoal was first reallocated and later reduced.

The model using 50% of available labour was used for policy analysis, as three empirical reasons suggest that is was the most suitable model. First, the farmer gave land out for cropping and took grazing land in, an indication that there was an effective labour deficit. Second the model showed that he should get rid of the vineyard, which was something he had in mind. And third there is reduced charcoal production, which also could be the case for the year 95-96. As data collection was done in mid season (July to August), it was possible that in that year the farmer did not produce as much charcoal as in the previous year, because of the amount of labour he had committed to wheat, pastures and vineyard. Halving his charcoal production would save him 20 days labour, so that he could match labour supply with demand.

8.11.2.7 Validation of the FSM-G

The crop-fallow restraint for flat land and the ewe-lamb ties were violated in the feasibility test. The underachievement of the remaining land use ties allowed to expect an improvement of the FSs' GM through optimisation. The optimal farm plan was based on wheat and maximum use of greenhouse tomatoes, while hilly land was almost entirely planted with eucalyptus (Table 8.17). No use was made of artificial pastures and the number of sheep was kept as the maximum possible given the forage availability. Charcoal production was reallocated from months with high labour demand to months with low labour demand.

Table 8.17 Comparison between observed and predicted values for main decision variables of FSM-G

	Unit	Observed	Model	Change
GM	$	2101844	2862654	760810
Flat wheat	ha	1.87	3.59	1.72
Flat fallow	ha	1.87	3.59	1.72
Flat oats	ha	1.00		-1.00
Flat oat & phalaris	ha	1.50		-1.50
Flat rough grazing	ha	11.70	10.76	-0.94
Lemon	trees	9.00		-9.00
Early tomato (Aug.)	500m²	0.50	1.20	0.70
Late tomato (Sep.)	500m²	0.50		-0.50
Hilly wheat	ha	1.25	0.45	0.80
Hilly fallow	ha	1.25	0.45	0.80
Hilly rough grazing	ha	5.50	1.34	4.16
Hilly eucalyptus year 1	ha	2.00	0.49	1.51
Hilly eucalyptus year 2	ha	2.00	0.49	1.51
Hilly eucalyptus years 3-20	ha		8.80	8.80
Ewe	hd	6.00	19.64	13.64
Lamb	hd	5.40	15.90	10.50
Charcoal production (Feb.)	bags	50.00	34.84	15.16
Charcoal production (Mar.)	bags	50.00	64.84	14.84
Charcoal production (Apr.)	bags	50.00	64.77	14.77
Charcoal production (May)	bags	50.00	68.10	18.10
Charcoal production (June)	bags	50.00	64.77	14.77
Charcoal production (July)	bags	50.00	37.77	12.23
Charcoal production (Aug.)	bags	50.00	38.88	11.12
Charcoal production (Sep.)	bags	50.00	26.03	23.97
INDAP loan	$	253733	214884	38849
Working capital	$	741476	702524	38952

8.11.2.8 Validation of the FSM-H

Only the ewe-lamb constraint was violated in the feasibility test, mainly because of the small number of ewes. There was also enough labour available to crop all the wheat taken-in. The model's optimisation achieved a slight improvement in GM by increasing flat wheat and reducing hilly wheat (Table 8.18). Part of the available land and labour remained unused, as working capital was a limiting resource.

Table 8.18 Comparison between observed and predicted values for main decision variables of FSM-H

	Unit	Observed	Model	Change
GM	$	1512814	1529106	16292
Flat wheat (taken-in)	ha	4.69	4.75	0.06
Flat fallow (taken-in)	ha	4.69	4.75	0.06
Hilly wheat (taken-in)	ha	4.69	4.41	-0.28
Hilly fallow (taken-in)	ha	4.69	4.41	-0.28
Ewe (given-out)	hd	5.00	5.00	
Lamb (given-out)	hd	5.00	4.05	-0.95
Cow (given-out)	hd	3.00	3.00	
Yearling (given-out)	hd	2.00	2.22	0.22
Sold wheat	kg	12425	10146	-2279
Charcoal (May)	bags	25.00		-25.00
Charcoal (June)	bags	25.00		-25.00
Charcoal (July)	bags	25.00		-25.00
Charcoal (Aug.)	bags	25.00	100.00	75.00
Own labour sold	days	26.00	26.00	
Transferred labour (May)	days	5.00	1.00	-4.00
Transferred labour (Aug.)	days		9.00	9.00

8.12 SUMMARY

In this chapter the processes of data collection, model construction, and model validation were described. With regard to data collection, it was found that the sequential semi-structured survey was a simple method of collecting in-depth data from a reduced number of farms. Its main advantages compared to single visit methods were that a series of visits allows validation of the information and enables collection of missing information. Its stepwise structure enabled the researcher to match data collection with model construction, a very useful feature when the data was used to construct whole farm models. Nevertheless it is not to be recommended when the number of farms is large, due to the time required to adjust individual questionnaires. A further problem is that as the number of visits increases so does travelling time and time loss due to failed visits.

The construction of the operational models was, despite the use of a spreadsheet base model for all farms, a time consuming task. It was necessary first to summarise the data to compute the input-output coefficients and then to construct the actual cash flows to estimate the household's expenses and working capital. In peasant economies the aggregation of data is not always straightforward. The lack of records means that data are frequently vague and need to be validated and cross-checked with values of other farms, e.g. livestock coefficients like lambing or calving rates. Lack of secondary data is also a major problem which has to be resolved with future research and appropriate record keeping systems.

Agricultural models are not meant only to simulate, to optimise or to predict the behaviour of systems but should also contribute, amongst other things, to an increased understanding of the total system. Further they should be able to pinpoint areas where knowledge is lacking, highlight economic benefits of methods suggested by research, summarise data and provide a method to interpolate and cautiously extrapolate, and make a more complete use of available data (France and Thornley, 1984). These contributions were all recognised during the model construction phase. The following points should be highlighted:

i. Even with scarce information available it was possible to build operational FS models according to the previously defined framework, although various assumptions and simplifications had to be made.

ii. Although livestock systems were simpler than cropping systems from the point of view of input use and output generation, their modelling is far more complex due to the absence of fixed time schedules. Only through the use of assumptions was it possible to model these sub-systems.

iii. Also from the point of view of data availability livestock systems were more complex to model. Only estimates of dry matter intake and output were available to establish forage balances. No account could be given of animals' growth or weight, which may be especially important for cattle.

iv. As forage balances were based on dry matter production and intake, it is probable that carrying capacities were overestimated due to low forage quality of some resources, especially straw.

v. It was recognised during validation that both labour and cash constraints were effectively binding, and thus fundamental in peasant FS models.

vi. Although a method to estimate working capital and monthly cash expenses was developed, these values could not be validated.

vii. Estimated soil loss for each activity was obtained, but no validation of this data was possible. Nevertheless it has to be kept in mind that for this particular research relative values are of greater importance than absolute ones. As the aggregate effect will be minimised it is more important to use proper relative values than exact values (the solution is independent of the scale of the objective function).

During the next stage model coefficients as well as activities were adjusted to increase the similarity between the observed and the optimal farm plan. During this process it was realised that:

i. Flat, hilly and mountain land should show differences in productivity.

ii. For some farms pasture productivity had to be improved to sustain the observed stocking rates.

iii. Fixed sale of steers resulted in additional cash constraints, which were lifted when monthly sale was allowed. This also meant that the presence of livestock (especially cattle) reduced working capital restraints of these FSs.

iv. Using the estimated working capital and cash expenses a feasible solution for each FS could be found, which suggests that the estimates used were not far from reality.

v. As most of the initial solutions showed that farmers used own capital to purchase seeds and fertilisers, working capital was further reduced to reflect the fact that most farmers used only a loan for these purchases.

Finally, as from an agricultural point of view the FSs were rather simple due to few available crops (mainly wheat) the base solution for most of the models was similar to reality. Nevertheless a recurrent problem was the violation or under-achievement of rotational constraints when the actual farm plan was used for the feasibility test. The fixed size of the plots was the main cause of these differences.

This chapter concludes Part Two of this thesis. It began by showing the background of the sustainability issue for peasant farmers in the Coastal Dryland of Central Chile and finished with the construction and validation of linear models. In Part Three these models will be used to analyse the impact of development alternatives for that area.

PART THREE

THE ANALYSIS OF THE SUSTAINABILITY OF PEASANT FARMING SYSTEMS IN CENTRAL CHILE

9. OPTIMAL SOLUTIONS FOR THE BASE MICRO-REGIONAL MODEL

9.1 INTRODUCTION

The last part of this thesis deals with the evaluation of local development policies using a micro-regional model (MRM) derived from the farming systems models (FSMs) described in Chapter 8. Although the model specified in Chapter 7 established that four criteria would be used to evaluate the sustainability of the FSs (or the micro-region), so far only GM, risk and soil loss have been considered. In this chapter the need for including a measure of income distribution (the fourth criterion) will be analysed. To achieve this first the MRM is constructed and optimised under a base scenario of no intervention. This base scenario which depicts the optimal situation under present conditions will then be used throughout as the standard for comparison. Next the development policies are defined and included into each of the FSMs. A development policy is understood as any action by a policy maker (i.e. the government or a governmental institution) with the purpose of affecting the production system of a peasant farmer. Although the model will be used to evaluate a limited number of new technologies any of the following alternatives can be evaluated through the appropriate modifications of the optimisation models:

i. Introduction of new technologies: comparing the introduction of new activities into the FSMs (e.g. strawberries or pines)
ii. Change in existing technologies: the input/output relations of certain activities are changed (e.g. seeds or fertilisers)

iii. Change in farmers' production constraints: the right hand side of the FS restraints are changed (e.g. available loan or irrigation)

iv. Change in micro-regional constraints: the right hand side of the micro-regional restraints are changed (e.g. total micro-regional output or available loan)

v. New micro-regional constraints: new restrictions are added at the aggregate level (e.g. soil loss or product sale)

In addition to the base scenarios, the impact of four technologies is evaluated. Five efficient solutions (maximising GM, minimising risk, minimising soil loss, L_1 compromise solution, and L_∞ compromise solution) were computed for each policy and compared. Then the impact of the policies at both the farm and the micro-regional levels is analysed. Finally the best solution is determined, according to its impact on the three optimisation criteria (GM, risk and soil loss).

9.2 CONSTRUCTION OF THE BASE MICRO-REGIONAL MODEL

The eight FSMs were brought together into a super-matrix to form the base MRM, as shown in Figure 9.1. Accordingly, the FSMs objective functions were added into the micro-regional objective functions of maximising micro-regional GM (Eq. [9.1]), minimising micro-regional risk (Eq. [9.2]) and minimising micro-regional soil loss (Eq. [9.3]).

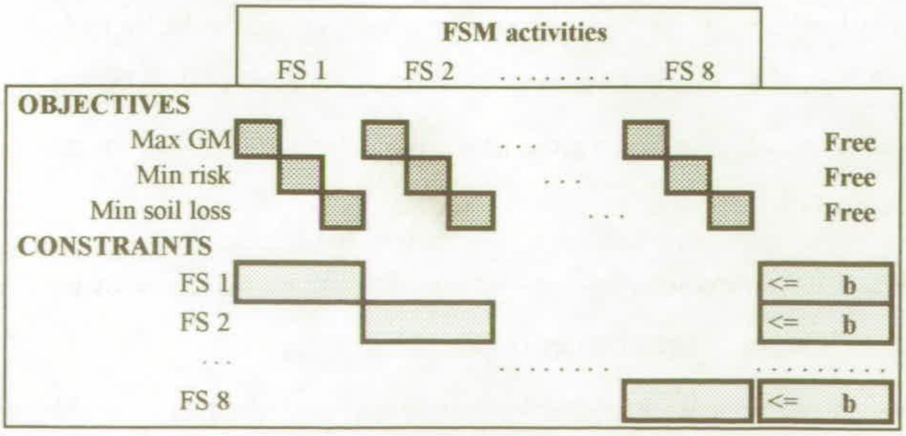


Figure 9.1 The matrix skeleton of the base micro-regional model

$$Max\ Y_1 = \sum_{i=1}^{8} w_{1i} Z_{1i} \qquad [9.1]$$

$$Min\ Y_2 = \sum_{i=1}^{8} w_{2i} Z_{2i} \qquad [9.2]$$

$$Min\ Y_3 = \sum_{i=1}^{8} w_{3i} Z_{3i} \qquad [9.3]$$

where w_{1i} is the weight given to GM of farm i in objective function 1; w_{2i} is the weight given to risk of farm i in objective function 2; w_{3i} is the weight given to soil loss of farm i in objective function 3; Z_{1i} is the total GM of farm i (Eq. [7.1]); Z_{2i} is the total underachievement of risk target for farm i (Eq. [7.15]); and Z_{3i} is the total estimated soil loss observed on farm i (Eq. [7.16]).

It was assumed that the micro-regional GM equals the sum of the GMs of all farms, and that the micro-regional risk equals the sum of the negative deviations from the target income for all farms' GM over the period of ten years. In both cases the same importance was given to each household. The weights used in these objective functions were equal to the number of farms belonging to each FS. A different approach was made for the soil loss objective, as the contribution of each farm to the micro-regional soil loss is related to the area covered by the FS, and not to the number of households. As each representative farm had to estimate the soil loss of all farms belonging to that FS the weights used were the total FSs area divided by the area covered by the representative farm. As a result the contribution of each FSM to the micro-regional soil loss was different from its contribution to the micro-regional GM or risk (Table 9.1). Compared to the GM and risk objectives, farm-A and farm-H approximately doubled their contribution to the soil loss objective, while farm-F halved it.

Table 9.1 Weights used in the construction of the micro-regional objective functions

Objective function	Farming system							
	A	B	C	D	E	F	G	H
GM and risk	4	4	11	7	5	4	7	11
Soil loss	10.95	4.09	15.53	7.02	4.84	2.18	10.76	19.08

The MRM's constraints were constructed through the aggregation of the eight sets of FS constraints. No modification or additional restraints were included, as the farms were assumed to be independent entities. Therefore, the micro-regional results, obtained through the optimisation of each of the three objective functions, are the same as the weighted addition of the farm level results, obtained through the optimisation of the farming system models. Nevertheless this is not necessarily true for the compromise solutions, as these minimise the distance between the micro-regional *ideal* and the micro-regional objective functions, and not between the *ideal* and the FS objective functions.

Finally, this simple base MRM should be seen as a stage in the development of the methodology. Its main purpose is to analyse the impact of the development policies on each FS and their objective functions and especially on the farms' GM, so that if necessary other restraints are added (Chapter 10).

9.2.1 OPTIMAL SOLUTIONS FOR THE BASE SCENARIO

Optimal solutions for the three criteria (GM, risk and soil loss) were determined for the MRM and each of the FSMs under the base scenario of no intervention (Table 9.2). Although the micro-region is constituted by an estimated 2,496 peasant farmers, the micro-regional results are expressed in terms of the 53 farms represented by the eight FSs which were analysed here. Therefore, multiplying the results by 47.1 generates the values of the objectives for the whole micro-region. To simplify the analysis all other results are expressed as a percentage of the base solution, a value which is not affected by the number of farms considered in the calculation of the results.

For the base as well as the policy scenarios the *ideal* (*nadir*) solutions were determined by the highest (lowest) GM and the lowest (highest) risk and soil erosion. As the base MRM was built by simple addition of the FSMs, the micro-regional solution as well as the *ideal* and *nadir* values could be obtained by weighting each FSM solution with the weights shown in Table 9.1.

Table 9.2 Trade-off matrix for the micro-regional model and each of the farming system models

Model	Objective	Function optimised Max GM	 Min risk	 Min soil loss
MRM	GM	$ 107,498,814	$ 107,215,200	$ 77,312,407
	Risk	$ 188,935,900	$ 187,454,010	$ 455,716,699
	Soil loss	39,978.9 t	39,938.7 t	20,067.6 t
A	GM	$ 554,038	$ 550,552	$ 425,193
	Risk	$ 1,523,442	$ 1,521,097	$ 2,683,494
	Soil loss	730.2 t	730.2 t	328.7 t
B	GM	$ 2,764,290	$ 2,702,708	$ 1,388,802
	Risk	$ 2,143,907	$ 1,850,812	$ 14,809,190
	Soil loss	706.9 t	700.4 t	297.1 t
C	GM	$ 1,808,217	$ 1,808,217	$ 1,641,731
	Risk	$ 7,258,982	$ 7,258,982	$ 9,003,014
	Soil loss	847.4 t	847.4 t	731.6 t
D	GM	$ 443,400	$ 443,400	$ 144,000
	Risk	$ 1,486,201	$ 1,486,201	$ 4,605,910
	Soil loss	198.1 t	198.1 t	34.4 t
E	GM	$ 4,475,771	$ 4,468,665	$ 3,310,884
	Risk	$ 4,626,775	$ 4,566,741	$ 14,763,830
	Soil loss	1159.8 t	1156.9 t	593.0 t
F	GM	$ 2,998,430	$ 2,998,430	$ 2,476,152
	Risk	$ 7,463,889	$ 7,463,889	$ 12,703,840
	Soil loss	316.6 t	316.6 t	172.6 t
G	GM	$ 2,862,654	$ 2,862,654	$ 2,347,866
	Risk	$ 343,538	$ 343,538	$ 1,944,717
	Soil loss	101.3 t	101.3 t	37.5 t
H	GM	$ 1,529,106	$ 1,529,106	$ 735,936
	Risk	$ 2,601,831	$ 2,601,831	$ 10,565,810
	Soil loss	374.6 t	374.6 t	0.0 t

Note: shaded values represent the *ideal* solution while underscored values represent the *nadir* solution

From these results two conclusions were drawn. First, the GM efficient and the risk efficient solutions were very similar at both the micro-regional and the FS level. In fact, five farms (C, D, F, G, and H) showed identical farm plans under these two optimisation criteria. Although a trade-off between both objectives was observed under this scenario (i.e. a reduction in risk can be achieved if GM is also reduced), it could only be done over a very small range of GMs. This was an unexpected result as both are normally found as highly conflicting objectives (see e.g. Hazell and Norton, 1986; Berbel, 1988; Maino, Pittet and Köbrich, 1993;

Fiske *et al.*, 1994; López-Pereira *et al.*, 1994; Millán and Berbel, 1994). One possible reason for it was that the FSMs included only activities observed on the farm and it is reasonable to believe that risk inefficient activities had already been discarded from observed farm plans. The inclusion at this level of unobserved activities may have changed these results. A second cause could have been that the farm models were structurally highly risk averse, as cash flow restrictions, and to a lower extent consumption thresholds, impose burdens on the inclusion of certain activities. Third, when information on price variation was unknown, estimates were obtained based on variation of observed gross margins. These activities were then highly correlated to the activities which determined to a higher degree the farm's GM (i.e. wheat). Finally, the model defined as the risk target, 120% of the maximum farm GM obtained during the last ten years (Section 8.8). This determined that a risk efficient plan was not only related to a stable income, but also to a minimum income ('safety first approach'). In other words activities with low GM and low GM variation may not be included in a risk efficient plan, as they do not contribute enough towards the achievement of the expected income.

The second conclusion came from the comparison of the GM and risk with the soil loss efficient plans. It was seen that there was considerable scope for the reduction of soil loss, but the impact of such a reduction was large on both income and risk. In fact, the maximum soil loss reduction of 50% is achieved when GM is reduced by 28% and risk increased by 240%. In other words trade-offs exist between the environmental objective and both economic objectives. For these farms, a reduction in soil loss of one tonne implies that the farmer's yearly income will be reduced by $ 321 to $ 8,057 (or 0.05% to 0.41% of his maximum income) while risk will increase by between $ 2,890 and $ 36,409 (Table 9.3). This means that the impact of a reduction in soil loss will depend on the farm being analysed, highlighting the need to consider different farms when environmental-economic analyses are carried out.

Table 9.3 Trade-off between GM and soil erosion and between risk and soil erosion for each model ($/t)

Model	GM/soil erosion	Risk/soil erosion
MR	1,516	7,887
A	321	2,890
B	3,357	30,910
C	1,437	15,056
D	1,829	19,063
E	2,055	17,885
F	3,629	36,409
G	8,057	25,062
H	2,117	21,260

9.2.2 COMPARISON OF TWO APPROACHES TO RISK ANALYSIS

In the previous section it was suggested that one reason behind the similarity between a risk efficient and a profit efficient farm plan was that target-MOTAD models implicitly generate a solution which establishes a compromise between income variation (i.e. total absolute deviations) and expected income level (i.e. target). To test this hypothesis a MOTAD model (Hazell, 1971) was constructed for farm F. This farm was selected because an identical plan was generated under profit and risk criteria. Also, as the model of this farm included a greater variety of activities compared to other farms, it was expected that it would be more appropriate to show differences between both approaches to risk analysis.

In the MOTAD model the coefficients of the risk vectors were the difference between the yearly GM and the average GM over the series of ten years. The objective function then minimised the deviation of these values from zero (Eq. [9.4]). Instead, the target-MOTAD model calculated the deviation of the yearly GMs from the target income (Eq. [9.5])[1].

$$\sum_{j=1}^{n}\left(GM_{jr} - \overline{GM}_j\right)x_j + n_r \geq 0 \qquad [9.4]$$

$$\sum_{j=1}^{n} GM_{jr}x_j + n_r \geq t \qquad [9.5]$$

[1] See also Section 7.3.2

where GM_{jr} is the expected GM for activity x_j during year $r=1,\ldots,s$; $\overline{GM}_j$ is the average GM for activity x_j; n_r is the negative deviation of expected GM for year $r=1,\ldots,s$; and t is the target level.

As the rest of the model was the same, including the objective functions, no differences were observed in the profit and erosion efficient plans (excluding of course, the values of variables associated to risk). Nevertheless the risk efficient plans showed differences between both models (Table 9.4). The MOTAD model generated a risk efficient plan which had a GM 17.3% lower than that from the target-MOTAD model. The new risk efficient plan showed that the total flat area under wheat was reduced and that an increased share of flat and hilly land was given out for both wheat and chickpeas. The labour saved was then used to

Table 9.4 Comparison of main decision variables obtained using the MOTAD and the target-MOTAD models for farm F

Decision variable[a]	Unit	target-MOTAD	MOTAD	Difference
Gross margin	$	2,998,430	2,479,584	-518,846
Risk	$	7,463,889	800,123	---[b]
Soil erosion	t	316.57	316.07	-0.50
Flat fallow	ha	5.00	1.02	-3.98
Flat wheat	ha	5.00	1.02	-3.98
Flat chickpeas	ha	1.67	0.34	-1.33
Flat fallow(given out)	ha		2.53	+2.53
Flat wheat (given out)	ha		2.53	+2.53
Flat chickpeas (given out)	ha		0.84	+0.84
Flat oats & clover	ha		1.91	+1.91
Flat rough grazing	ha	10.00	10.94	+0.94
Flat vineyard	ha		0.04	+0.04
Hilly fallow	ha	1.37		-1.37
Hilly wheat	ha	1.37		-1.37
Hilly chickpeas	ha	0.46		-0.46
Hilly fallow (given out)	ha	1.13	2.50	+1.37
Hilly wheat (given out)	ha	1.13	2.50	+1.37
Hilly chickpeas (given out)	ha	0.38	0.83	+0.46
Ewes	hd	88.23	104.90	+16.67
Ewe-lambs	hd	17.65	20.98	+3.33
Lambs	hd	71.47	84.97	+13.51
Charcoal production (Aug.)	bags	102.50	98.74	-3.76
Charcoal production (Sep.)	bags		82.56	+82.56

a: Only decision variables showing differences between both plans are presented

b: values are not comparable

increase the production of charcoal, and more livestock (sheep) were reared as land could be devoted to a forage crop (clover and oats).

These results showed that the optimal solution of both models was different and that the selection of the model significantly affects the results. Nevertheless, it is not possible to determine which model is better suited to farmers' decision making as their risk preferences were not known.

9.2.3 Compromise solutions for the base MRM

Using the *ideal* micro-regional values for each objective the compromise solutions were obtained, for both L_1 and L_∞ metrics (Table 9.5). It was observed that compared to the GM efficient both L_1 and L_∞ compromise solutions reduced soil loss in a significant amount (27.8% or 36.0% respectively) and with minor effect on micro-regional GM. Nevertheless the increase in micro-regional risk is notoriously larger (19.5% and 38.7%). These results suggest that not achieving the minimum income level is a major burden to a reduction in soil loss.

Also the individual FSs show a different response when the compromise solutions are computed. Under the L_1 scenario farms A, D and H show the largest reductions in GM and soil loss, while FS-G has a small reduction in GM and a larger reduction in soil loss, and farms B, C, E, and F remain unchanged (compared to the GM efficient solution). Under the L_∞ scenario, again farms A, D, and H show the largest reductions in GM and soil loss (in fact their solutions are the same as under the L_1 scenario), but there are also significant changes in farms B, C, and E. Farm G shows the same solution as under L_1 and farm F continues without contributing towards a reduction in soil loss (i.e. continues with the GM efficient plan).These results highlight the different contribution made by each FS towards a reduction in soil loss, and therefore also the different costs (in terms of foregone GM) faced by each to achieve such a reduction.

Table 9.5 L_1 and L_∞ optimal solutions for the base MRM and change with respect to the GM efficient solution

Model	Objective	L_1	Change	L_∞	Change
MRM	GM	$ 103,667,458	-3.6%	$ 99,107,527	- 7.8%
	Risk	$ 225,864,470	19.5%	$ 262,025,193	38.7%
	Soil loss	28,845.9 t	-27.8%	25602.6 t	-36.0%
A	GM	$ 425,193	-23.3%	$ 425,193	-23.3%
	Risk	$ 2,683,494	76.1%	$ 2,683,494	76.1%
	Soil loss	328.7 t	-55.0%	328.7 t	-55.0%
B	GM	$ 2,764,290	0.0%	$ 2,701,535	-2.3%
	Risk	$ 2,143,907	0.0%	$ 1,884,881	-12.1%
	Soil loss	706.9 t	0.0%	698.8 t	-1.1%
C	GM	$ 1,808,217	0.0%	$ 1,641,731	-9.2%
	Risk	$ 7,258,982	0.0%	$ 9,003,014	24.0%
	Soil loss	847.4 t	0.0%	731.6 t	-13.7%
D	GM	$ 366,631	-17.3%	$ 366,631	-17.3%
	Risk	$ 2,321,473	56.2%	$ 2,321,473	56.2%
	Soil loss	67.2 t	-66.1%	67.2 t	-66.1%
E	GM	$ 4,468,665	-0.2%	$ 3,973,152	-11.2%
	Risk	$ 4,566,741	-1.3%	$ 8,169,236	76.6%
	Soil loss	1156.9 t	-0.2%	865.4 t	-25.4%
F	GM	$ 2,998,430	0.0%	$ 2,998,430	0.0%
	Risk	$ 7,463,889	0.0%	$ 7,463,889	0.0%
	Soil loss	316.6 t	0.0%	316.6 t	0.0%
G	GM	$ 2,837,103	-0.9%	$ 2,837,103	-0.9%
	Risk	$ 449,520	30.9%	$ 449,520	30.9%
	Soil loss	75.0 t	-26.0%	75.0 t	-26.0%
H	GM	$ 1,295,996	-15.2%	$ 1,295,996	-15.2%
	Risk	$ 4,965,441	90.8%	$ 4,965,441	90.8%
	Soil loss	85.3 t	-77.2%	85.3 t	-77.2%

9.3 DEFINITION OF DEVELOPMENT POLICIES

During the last years different governmental institutions like INDAP, INIA, CONAF[2] and FIA[3] have been involved with the development of productive alternatives for this area. The first policy is establishing woods, specifically eucalyptus on mountainous land. CONAF has been encouraging the plantation of euca-

[2] National Forestry Corporation or 'Corporación Nacional Forestal'
[3] Agricultural Research Fund or 'Fundación Fondo de Investigación Agropecuaria'

lyptus (*Eucaliptus globulus*) and pine (*Pinus radiata*) on the Coastal Mountains. This alternative is introduced into the MRM to analyse possible causes of its small success at peasant level, despite the technical and financial support behind this policy (Section 8.4). It is suggested that one cause is the lack of income during a long period of time. Therefore a second development policy is introduced which considers planting eucalyptus and giving the farmer yearly cash payments before the trees are actually cut. The third alternative is introducing irrigation for small plots and planting strawberry on them. Although the introduction of this crop into the micro-region has been actively promoted by INDAP and FIA, there is little available information on the impact of their introduction on the sustainability of the FS. The fourth policy is to improve the pasture which follows wheat, by sowing associated to wheat a mixture of phalaris (*Phalaris tuberosa*) and subterranean clover (*Trifolium subterraneum*). This alternative has been proposed by INIA to improve pasture production, but so far it has not been adopted by small farmers.

Therefore to test the suitability of the MRM for the evaluation of sustainability, these four alternatives were included in the farming system models. This set of policies consisted of rather different alternatives in terms of land use, labour demand and cash flow. It must be noted that these policies will be formulated from the farmer's point of view and not from the policy maker's. This means that the costs of implementing such a policy will not be analysed.

9.3.1 PLANTING OF EUCALYPTUS

The first alternative was to encourage the planting of eucalyptus trees. Although CONAF had been doing this for some time, only a few farmers were growing them. In fact two of the surveyed farms had eucalyptus, and both had planted them during the last two years. As mentioned before (Section 8.4) a small farmer is currently able to plant trees without any capital cost to himself.

As done previously in farms F and G, three activities were defined (first year eucalyptus, second year eucalyptus and third to twentieth year eucalyptus), with two ties to bind their relations. GM for each was defined as its net present value times the number of years under each category (i.e. one, one, and eighteen years for each activity). This crop was limited to the steepest land type in each farm (mountains or hills), and thus not suitable for FS-H as it had no hilly land or mountains.

9.3.2 Planting of eucalyptus and yearly cash payments

One of the problems of growing eucalyptus is the long period in which no income is obtained. In fact, only after 20 years are the trees cut and sold. To overcome this difficulty a second alternative is analysed by which the farmer who plants eucalyptus receives a certain amount of money (five percent of the expected sale value) during each of the years previous to harvest. Such an alternative can be attractive for forestry enterprises, as the land would simply be rented and there would be no need to pay for labour, and for farmers as capital restriction would not limit planting. It is also highly possible that in the near future private companies would establish these tree growing contracts with smallholders.

This policy was modelled in the same way as the previous one, but a cash input was specified in April of each year. Although such an alternative would have an impact on the farmer's perception of the economic risk of growing this crop, its effect could not be modelled and included into the MRM.

9.3.3 Introduction of strawberries

During the last years a programme has been carried out by which small farmers in the dryland of the VIth Region receive from INDAP advice and loans to help them introduce strawberries in small areas (less than 0.2 ha) of their farms. The main restraint to such a crop is water availability. Although most farms have a well, some need improvement and all require proper irrigation systems[4].

The main feature of this alternative, was its high demand for labour. As strawberries are kept for two years, a separate activity for each year was defined. One tie specifies the relationship between both these activities (Eq. [9.6]) and another one establishes the maximum total area under this crop (Eq. [9.7]).

$$st1 - st2 \geq 0 \quad [9.6]$$

$$st1 + st2 \leq 0.2 \quad [9.7]$$

where *st1* represents first year strawberries; and *st2* represents second year strawberries.

9.3.4 ESTABLISHMENT OF PHALARIS AND CLOVER PASTURES

During March 1995 the Chilean government announced a series of measures to help farmers whose survival could be threatened by the free trade agreements which Chile intended to sign, principally MERCOSUR and NAFTA (Ministerio de Agricultura, 1995). The purpose of these measures is to encourage the use of modern technologies in traditional sectors of Chile's agriculture. To subsidise new pastures is one of the measures which aims to enhance productivity and to improve the competitiveness of the livestock sector. Specifically 30% of the sowing costs for up to 30 ha will be subsidised, with a maximum of $ 30,000 per hectare (Ministerio de Agricultura, 1995). The introduction of artificial pastures has long been advocated by INIA to improve livestock productivity and it is hoped that the financial incentives would encourage the uptake of this crop.

For this area a mixed pasture of phalaris with subterranean clover is recommended. As shown in Figure 9.2 an output of over seven tonnes can be expected (Rodríguez, 1991; Chacón, Rodríguez and Squella, 1988), although direct grazing may produce a loss of up to 25% of the available forage (Crempien and Squella,

[4] Future research should determine the impact of the increased water extraction on salinisation.

1987). A simple and recommended way to establish such a pasture is by sowing it with wheat.

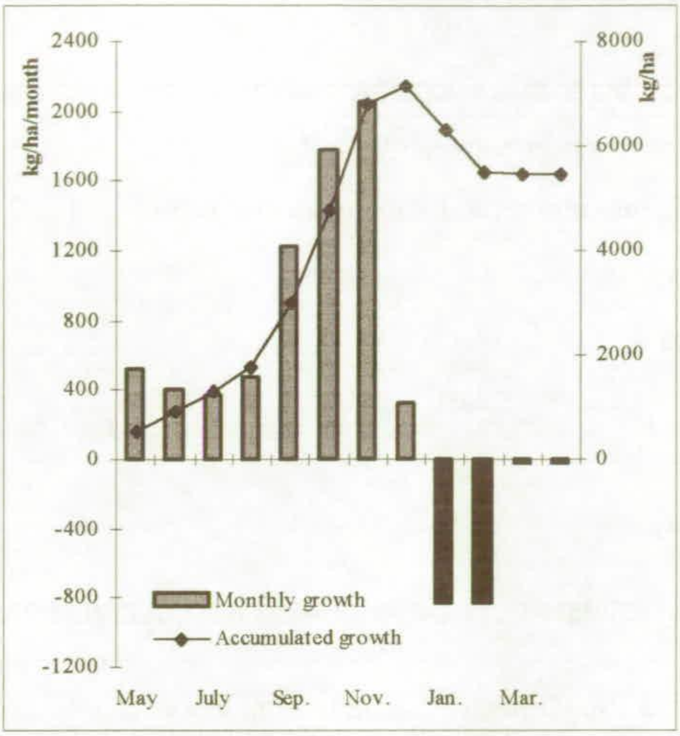


Figure 9.2 Dry matter production and accumulation of a mixed phalaris and subterranean clover pasture in the coastal dryland of the VIth Region, Chile (Rodríguez, 1991)

Based on this information the alternative of sowing phalaris and clover with wheat was included into the FSMs (Chacón et al., 1988; INIA, 1991). It is expected that such management will not reduce wheat output, as more fertiliser is used and as the 'normal' dose used by farmers is lower than the one recommended for the micro-region. During the first year an extra 1,000 kg of dry matter will be available as forage. Although the amount of forage produced during the first year would probably be higher, it is expected that consumption of straw will be significantly reduced. From the second to the fifth year the pasture's output is 3,750 kg. The difference between this figure and the observed output should reflect management differences between a farm and a research station and the losses due to direct grazing.

As this pasture was limited to flat and hilly land, four activities were included into each FSM to model this policy. The first two are flat and hilly first year pasture, and the other two flat and hilly second to fifth year pasture. A set of constraints specified the relation between first and subsequent year pastures (Eq. [9.8]), defined the relation between wheat and artificial pasture (Eq. [9.9]), and limited the maximum area under new pastures to 30 ha (Eq. [9.10]). The purchase of seeds and fertilisers was through the available INDAP loan.

$$-4\,fphc1 + 1\,fphc2 \leq 0 \quad [9.8]$$

$$-fphc1 + fwh1 \leq 0 \quad [9.9]$$

$$fphc1 + hphc1 \leq 30 \quad [9.10]$$

where *fphc1* is the flat area with first year phalaris and clover pasture; *fphc2* is the flat area with second to fifth year phalaris and clover pasture; *fwh1* is the flat area with wheat; and *hphc1* is the hilly area with first year phalaris and clover pasture.

9.4 EVALUATION OF DEVELOPMENT POLICIES USING THE BASE MICRO-REGIONAL MODEL

The four previously described policies were included into the eight FSMs, which were then added to construct the MRMs. Again no further constraints were imposed on the MRMs. For each of these MRMs five criteria were used to generate the set of efficient solutions: maximise GM, minimise risk, minimise soil loss, and the L_1 and L_∞ compromise solutions. For the sake of simplicity each combination of policy and efficient solution was identified as a scenario (e.g. base-GM, eucalyptus-risk, strawberries-soil loss, etc.). The base model under a GM maximising objective (i.e. base-GM scenario) was used as reference point for the comparison of the results, as this scenario represented the initial situation in the best way.

9.4.1 EFFICIENT SOLUTIONS WITH EUCALYPTUS

As in the base model the introduction of eucalyptus produced few differences between risk and GM efficient solutions and large differences between these two and the minimum soil loss solution (Table 9.6). Compared to the base-GM solution at the micro-regional level (Table 9.2) only a slight improvement in GM, risk and soil loss was achieved under the eucalyptus-GM and eucalyptus-risk scenarios. This was a result of over 70 ha of new plantations, requiring almost 140 man/days of additional labour.

These changes were a result of the introduction of these trees in FS-A and FS-B, and to a lower extent in FS-C and FS-E. The other three farms did not change their optimal plans as they already had the possibility of planting them (farms F and G) or they had no land to plant them (farm-H). Thus only FS-D did not introduce them despite the possibility of doing so, because the hired labour required to grow them determined that existing alternatives were more profitable. FS-A now gave all its livestock out, and transformed 2.37 ha of the mountain permanent pasture into a plantation. It required hired labour during August, taking a small loan from INDAP. Farm B planted 7.14 ha with eucalyptus, reducing the mountain permanent pasture as well as the sheep flock. This FS now required hired labour during January, June, and August and increased the demand for labour in September. FS-C reduced the hilly land under wheat and plants 2.91 ha of eucalyptus. This meant that less loan was required and more alfalfa to feed the same amount of livestock. Finally, FS-E only reduced slightly its hilly area under wheat to plant 0.20 ha of trees.

An important result was that under the soil loss scenario, the solution remained unchanged compared to the minimum soil loss solution for the base scenario. A reason for this was the presence of cash flow constraints; these coupled with the monthly cash expenses imposed restraints to further reductions in GM and thus also in soil loss. Nevertheless, the compromise solutions, and specially L_{∞}, had a significant impact on GM, risk and soil loss (Table 9.6). Compared to the base-

GM scenario L_1 (L_∞) could reduce soil loss in 30.5% (37.6%) while reducing GM in 1.6% (5.6%) and increasing risk in 12.9% (30.7%). The problem of L_1 solution is the large increase in the aggregated demand for hired labour, 282.2%, compared to the base-GM solution.

Table 9.6 Change in micro-regional single objective and compromise solutions (L_1 and L_∞ metrics) compared to the base solution. Scenario: Introduction of eucalyptus trees in the base MRM

		Function optimised			Compromise solution	
Model	Objective	Max GM	Min risk	Min soil loss	L_1	L_∞
MR	GM	2.4%	2.3%	-28.1%	-1.6%	-5.6%
	Risk	-8.1%	-8.2%	141.2%	12.9%	30.7%
	Soil loss	-2.8%	-2.8%	-49.8%	-30.5%	-37.6%
A	GM	28.4%	28.4%	-23.3%	-15.7%	-15.7%
	Risk	-70.1%	-70.1%	76.1%	48.2%	48.2%
	Soil loss	0.4%	0.4%	-55.0%	-53.8%	-53.8%
B	GM	12.3%	12.3%	-49.8%	12.3%	-3.8%
	Risk	-69.3%	-69.3%	590.8%	-69.3%	30.6%
	Soil loss	-0.6%	-0.6%	-58.0%	-0.6%	-40.3%
C	GM	2.7%	2.7%	-9.2%	2.7%	2.7%
	Risk	-6.2%	-6.2%	24.0%	-6.2%	-6.2%
	Soil loss	-8.5%	-8.5%	-13.7%	-8.5%	-8.5%
D	GM			-67.5%	-17.3%	-17.3%
	Risk			209.9%	56.2%	56.2%
	Soil loss			-82.6%	-66.1%	-66.1%
E	GM	0.2%	-0.1%	-26.0%	0.2%	-10.9%
	Risk	-1.0%	-1.4%	219.1%	-1.0%	107.3%
	Soil loss	-0.3%	-0.3%	-48.9%	-0.3%	-30.4%
F	GM			-17.4%		
	Risk			70.2%		
	Soil loss			-45.5%		
G	GM			-18.0%	-0.9%	-0.9%
	Risk			466.1%	30.9%	30.9%
	Soil loss			-63.0%	-26.0%	-26.0%
H	GM			-51.9%	-15.2%	-15.2%
	Risk			306.1%	90.8%	90.8%
	Soil loss			-100.0%	-77.2%	-77.2%

As a conclusion, under a GM maximising scenario the introduction of eucalyptus does not significantly improve the sustainability of FSs in this area, as only small improvements in the three indicators can be achieved.

9.4.2 EFFICIENT SOLUTIONS WITH EUCALYPTUS AND YEARLY CASH PAYMENTS

The combination of eucalyptus and cash meant that under the GM scenario an additional 300 ha of trees were planted compared to the base-GM situation. This equals 12.8% of the area covered by this study (2,378.7 ha) and a sevenfold increase in hired labour. At a micro-regional level GM increased by 10.3%, risk decreased by 30.3% and soil loss was reduced by 21.7% (Table 9.7). These changes were induced by trees planted in farms A, B, C, E , and G. Both FS-A

Table 9.7 Change in micro-regional single objective and compromise solutions (L_1 and L_∞ metrics) compared to the base solution. Scenario: Introduction of eucalyptus with yearly cash payments in the base MRM

		Function optimised			Compromise solution	
Model	Objective	Max GM	Min risk	Min soil loss	L_1	L_∞
MR	GM	10.3%	9.5%	-32.2%	4.2%	0.3%
	Risk	-30.3%	-30.7%	161.3%	-1.0%	14.3%
	Soil loss	-21.7%	-21.7%	-80.0%	-57.1%	-66.3%
A	GM	28.6%	28.6%	-23.2%	-23.2%	-23.2%
	Risk	-70.1%	-70.1%	77.0%	77.0%	77.0%
	Soil loss	0.4%	0.4%	-61.3%	-61.3%	-61.3%
B	GM	23.8%	23.3%	-37.0%	23.7%	15.5%
	Risk	-90.8%	-96.5%	407.9%	-96.2%	-74.4%
	Soil loss	-1.4%	-1.3%	-67.3%	-1.2%	-19.0%
C	GM	19.2%	17.5%	-9.0%	9.5%	-2.2%
	Risk	-35.5%	-35.5%	28.8%	-17.9%	11.8%
	Soil loss	-44.5%	-44.5%	-83.1%	-62.2%	-81.2%
D	GM			-66.7%	-17.3%	-17.3%
	Risk			135.2%	56.2%	56.2%
	Soil loss			-88.2%	-66.1%	-66.1%
E	GM	17.2%	15.5%	-24.7%	16.7%	12.3%
	Risk	-72.4%	-73.8%	210.1%	-72.2%	-57.0%
	Soil loss	-49.9%	-49.9%	-85.6%	-53.5%	-64.9%
F	GM			-17.4%		
	Risk			71.9%		
	Soil loss			-45.9%		
G	GM	0.6%	0.6%	-49.0%	-0.4%	-0.4%
	Risk			2923.3%	30.6%	30.6%
	Soil loss			-63.6%	-26.1%	-26.1%
H	GM			-51.9%	-15.2%	-15.2%
	Risk			306.1%	90.8%	90.8%
	Soil loss			-100.0%	-77.2%	-77.2%

and FS-F planted the same area with trees as when only eucalyptus was introduced, but with a higher GM as the loan taken from INDAP was lower. In FS-B 15.5 ha of mountains were planted, with a further reduction in its sheep flock. FS-C planted 14.46 ha of eucalyptus reducing the area of hilly wheat and reducing the size of the sheep flock. In farm E 29 ha of hilly wheat were replaced by trees and the number of cattle was reduced.

Again the results obtained under the risk scenario were similar to those of the GM scenario. Also large differences were observed when the soil loss scenario was compared to the base-soil loss scenario. Soil loss was reduced by 60.1% with a loss of only 5.7% in GM and an increase of 8.3% in risk. The risk scenario considered 250 new hectares with trees and a large increase in hired labour, while under the soil loss scenario a total of 600 ha were planted with a demand for almost 3,500 man/days of hired labour.

For this policy case both compromise solutions achieved a significant reduction in soil loss compared to the base-GM scenario. The L_1 metric solution reduced it by 57.1% while it increased GM by 4.2% and reduced risk by 1.0%. The L_∞ metric solution only improved GM by 0.3%, but reduced soil loss by 66.3% and increased risk by 14.3%.

This policy was thus effective in reducing soil loss on the assumption that the farmers maximise GM or minimise risk. An even larger reduction was achieved when the L_1 compromise solution was selected.

9.4.3 EFFICIENT SOLUTIONS WITH STRAWBERRIES

The possibility of growing strawberries changed the optimal farm plans of all farms. Only FS-D did not grow the maximum area of 2,000 m^2. At an aggregate level, 4.69 ha were planted, with an additional demand of 110 man/days of hired labour. The GM scenario improved the micro-regional GM by 34.1% compared to the base-GM scenario, while risk and soil loss were reduced by 81.4% and 8.0% respectively (Table 9.8). The large reduction in risk is because four FSs (A, B, G, and H) achieved their income target in each year, and were thus in a 'non-risk situation'.

The optimal farm plan of FS-A was the same as its base-GM plan, except that it replaced all the vineyards with strawberries. Farms B, C, D, E, and F reduced marginally flat wheat to accommodate the strawberries, adjusting their livestock stocking rate and their capital borrowing when necessary. FS-E increased the amount of hilly wheat, as the capital restraint had been relaxed. FS-F increased the land given out, to reduce its labour demand, as it still had a restriction in labour availability. Major changes were induced in FS-G. Less tomatoes and flat

Table 9.8 Change in micro-regional single objective and compromise solutions (L_1 and L_∞ metrics) compared to the base solution. Scenario: Introduction of strawberries in the base MRM

		Function optimised			Compromise solution	
Model	Objective	Max GM	Min risk	Min soil loss	L_1	L_∞
MR	GM	34.1%	34.1%	-18.2%	29.7%	20.0%
	Risk	-81.4%	-81.5%	107.6%	-73.6%	-30.6%
	Soil loss	-8.0%	-8.0%	-76.6%	-35.0%	-58.1%
A	GM	148.8%	148.8%	-23.3%	102.7%	102.7%
	Risk	-100.0%	-100.0%	89.2%	-100.0%	-100.0%
	Soil loss			-68.2%	-68.2%	-68.2%
B	GM	29.3%	29.3%	-42.0%	29.3%	28.0%
	Risk	-100.0%	-100.0%	503.4%	-100.0%	-99.2%
	Soil loss	-0.2%	-0.2%	-63.1%	-0.2%	-2.7%
C	GM	47.5%	47.5%	-9.0%	37.9%	-3.4%
	Risk	-78.3%	-78.3%	41.9%	-65.3%	28.0%
	Soil loss	-0.1%	-0.1%	-76.6%	-14.4%	-75.1%
D	GM	18.7%	18.7%	-57.4%	4.8%	4.8%
	Risk	-47.2%	-47.2%	183.8%	-3.9%	-3.9%
	Soil loss			-83.1%	-66.1%	-66.1%
E	GM	19.6%	19.5%	-24.7%	19.5%	10.3%
	Risk	-79.5%	-80.2%	233.5%	-80.2%	-50.9%
	Soil loss	1.3%	1.3%	-68.5%	1.3%	-19.6%
F	GM	24.8%	24.8%	-17.4%	24.8%	24.8%
	Risk	-74.7%	-74.7%	87.2%	-74.7%	-74.7%
	Soil loss	-0.3%	-0.3%	-62.3%	-0.3%	-0.3%
G	GM	26.2%	26.2%	-18.0%	24.0%	24.0%
	Risk	-100.0%	-100.0%	640.7%	-100.0%	-100.0%
	Soil loss	26.1%	26.1%	-63.5%	-23.5%	-23.5%
H	GM	44.3%	44.3%	2.0%	38.9%	38.9%
	Risk	-100.0%	-100.0%	23.5%	-100.0%	-100.0%
	Soil loss	-49.5%	-49.5%	-100.0%	-77.6%	-77.6%

wheat were grown, eucalyptus was partially replaced by hilly wheat, lemon trees were grown, charcoal production was rescheduled, and more sheep were kept on the farm. Finally, FS-H reduced the land taken in to grow wheat (especially on hills), contributing most to the reduction in soil erosion. On aggregate, extra labour was hired during all months, except September when less was demanded.

The strawberry-risk solution again was very similar to the strawberry-GM solution. The strawberry-soil loss scenario compared to the Base-soil loss scenario achieved a reduction in soil loss (76.6%) while worsening both GM (18.2%) and risk (107.6%).

Under this policy the L_1 compromise solution improved all three criteria simultaneously compared to base-GM. Specifically GM increased by 29.7%, while risk and soil loss were reduced by 73.6%, and 35.0% respectively. The L_∞ compromise solution also improved the three criteria, namely GM by 20.0%, risk by 30.6% and soil loss by 58.1%.

These results show that at the micro-regional level this policy improved GM while reducing both risk and soil loss, except under the soil loss scenario.

9.4.4 EFFICIENT SOLUTIONS WITH PHALARIS AND CLOVER PASTURES

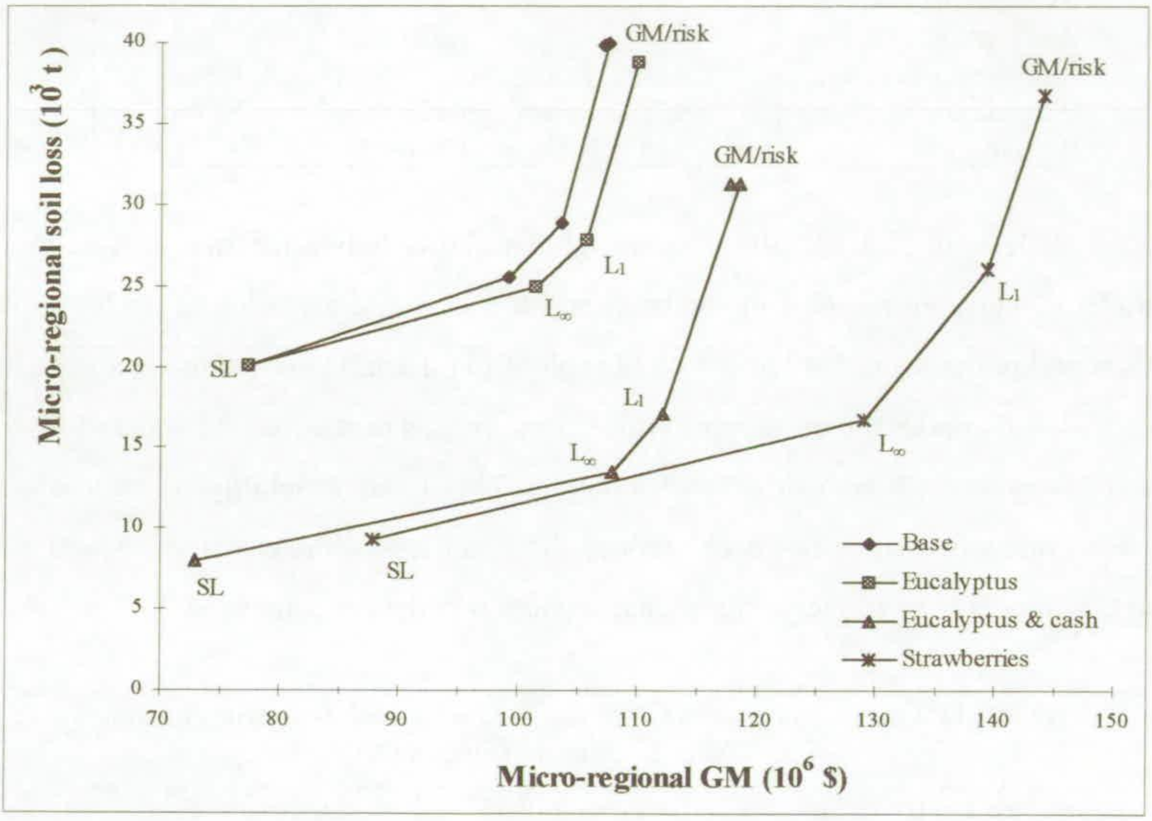
The introduction of artificial pastures had a limited effect under all three scenarios, with changes of less than one percent in each objective (Table 9.9). Under the pastures-GM scenario, on an aggregate level only 52 ha were sown, all in farms of type D. The reason for this is that it is not profitable to extend the wheat pasture rotation to a five year one nor to reduce the wheat-phalaris rotation to a three year one. Under the artificial pastures-minimum soil loss scenario the figure was less than ten hectares, but this time in farms of FS-E. Compared to the base-GM scenario, both compromise solutions reduced soil loss (26.2% in L_1 and 36.0% in L_∞ respectively), reduced GM (3.0% and 7.8%), and increased risk (15.9% and 38.4%). This policy failed to improve either GM or risk to any significant extent under any optimisation scenario. This probably explains why this technology has not been adopted so far and there is little likelihood of it being adopted in future, even considering the newly available subsidy.

Table 9.9 Change in micro-regional single objective and compromise solutions (L_1 and L_∞ metrics) compared to the base solution. Scenario: Introduction of phalaris and clover pastures in the base MRM

		Function optimised			Compromise solution	
Model	Objective	Max GM	Min risk	Min soil loss	L_1	L_∞
MR	GM		-0.2%	-27.8%	-3.0%	-7.8%
	Risk	-0.7%	-1.4%	139.4%	15.9%	38.4%
	Soil loss	0.1%		-50.2%	-26.2%	-36.0%
A	GM		-0.1%	-23.3%	-23.3%	-23.3%
	Risk		-0.2%	76.1%	76.1%	76.1%
	Soil loss			-55.0%	-55.0%	-55.0%
B	GM		-2.2%	-49.8%		-2.6%
	Risk		-13.7%	590.8%		-6.6%
	Soil loss		-0.9%	-58.0%		-2.1%
C	GM			-9.2%		-9.2%
	Risk			24.0%		24.0%
	Soil loss			-13.7%		-13.7%
D	GM	1.5%	1.5%	-67.5%	1.1%	-15.8%
	Risk	-12.1%	-12.1%	209.9%	-10.8%	44.1%
	Soil loss	2.2%	2.2%	-82.6%	-18.5%	-63.8%
E	GM		-0.2%	-24.6%	-0.2%	-11.4%
	Risk		-1.3%	204.5%	-1.3%	77.7%
	Soil loss		-0.2%	-51.8%	-0.2%	-25.7%
F	GM			-17.4%		
	Risk			70.2%		
	Soil loss			-45.5%		
G	GM			-18.0%	-0.9%	-0.9%
	Risk			466.1%	30.9%	30.9%
	Soil loss			-63.0%	-26.0%	-26.0%
H	GM			-51.9%	-15.2%	-15.2%
	Risk			306.1%	90.8%	90.8%
	Soil loss			-100.0%	-77.2%	-77.2%

9.5 Trade-offs between objectives

As seen before (Section 9.2.1), there was little or no trade off between the objectives of maximising GM and minimising risk. This meant that an improvement in one objective did not have an adverse effect on the other. The absence of conflict between them meant that almost the same solution was achieved when GM was maximised or risk was minimised. The way risk was modelled and the treatment of missing data explained why this occurred. Nevertheless, a conflict between GM and soil loss was seen when the values obtained under different optimisation criteria (GM, L_1, L_∞, and soil loss) were plotted in the same space (Figure 9.3). It must be noticed that a positive slope represents the existence of a trade-off, as GM is a maximising objective and soil loss is a minimising objective. An increase in GM (improvement) is accompanied by an increase (worsening) of soil loss.



Notes: GM/risk, SL, L_1, and L_∞ represent the efficient solutions when GM or risk, soil loss, income difference, L_1 and L_∞ are respectively optimised

Introduction of phalaris was not plotted as its results overlapped the base scenario.

Figure 9.3 Trade-off curve between GM and soil loss for four policy scenarios

As seen in Table 9.10 the trade-offs between policies are quite similar. Changing from a GM to a L_1 scenario means that for each Chilean Peso of GM lost between 2.2 kg and 3.2 kg of soil can be saved (i.e. the cost of saving one kg of soil is \$ 0.31 to \$ 0.46), while moving from the L_∞ to the minimum soil loss solution means that each additional Chilean Peso lost in GM saved only 0.16 kg to 0.27 kg of soil (i.e. the cost of saving one kg of soil is $ 3.77 to $ 6.39). Therefore, assuming that the present situation is one of GM maximisation, these results suggest that there is scope for saving large amounts of soil, without the farmer having to incur large costs in terms of foregone GM.

Table 9.10 Trade-offs between GM and soil loss ($/t)

	Trade-off for the segment between		
Policy	GM and L_1	L_1 and L_∞	L_∞ and SL
Base model	344	1,406	3,938
Eucalyptus	385	1,504	4,948
Eucalyptus & cash	457	1,155	6,387
Strawberries	438	1,127	5,564
Phalaris	315	1,316	3,771

Nevertheless, these trade-offs have a high variability between farms. In fact the trade-off between the GM maximising and the L_1 scenario varies depending on farm and policy from $ 47 to $ 2,462 (Table 9.11). Farm B even showed absence of trade-offs under the eucalyptus with cash policy as in it both GM and soil loss were worsened (though in a small amount). This large variability of trade-offs means that while some farms can reduce their soil loss without a large reduction in GM others have to face a significant reduction in their incomes.

Table 9.11 Trade-offs between GM and soil loss for each farm when moving from GM to L_1 efficient solution ($/t)

FS	Base	EU	E&C	ST	P&C
A	321	618	637	513	321
B	---	---	-1,887	654	---
C	---	---	1,168	1,438	---
D	587	587	587	471	47
E	2,462	---	532	---	2,462
F	---	---	---	---	---
G	969	969	1,023	1,295	969
H	806	806	806	777	806

EU: introduction of eucalyptus; E&C: introduction of eucalyptus with cash payments; ST: introduction of strawberries; P&C: introduction of phalaris and clover pastures

--- represents absence of trade-off as the scenario does not affect the optimal farm plan

9.6 Comparison of Policies

The previous policy analysis generated a total of 25 solutions each with dissimilar effects on any of the three evaluation criteria. Table 9.12 summarises the impact on GM, risk, and soil loss of the five solutions for each policy, compared to the base-GM scenario. Eucalyptus, eucalyptus with cash, and strawberries had always had a positive effect on the three criteria when GM or risk was optimised. The introduction of artificial pastures had none or only a very small impact. When soil loss was minimised the effect was always negative on both GM and risk, meaning that under these scenarios any measure forcing minimal soil loss will have negative effects on the FSs economic survival. Nevertheless compromise solutions improve GM and risk (compared to the base-GM scenario) and further reduce soil loss compared to solutions under purely economic criteria (GM and risk).

Table 9.12 Percentage change for each policy scenario under the base MRM compared to the base-GM scenario

		Solution				
Criterion	Policy	GM	Risk	Soil loss	L_1	L_∞
GM	EU	2.4%	2.3%	-28.1%	-1.6%	-5.6%
	E&C	10.3%	9.5%	-32.2%	4.2%	0.3%
	ST	34.1%	34.1%	-18.2%	29.7%	20.0%
	P&C		-0.2%	-27.8%	-3.0%	-7.8%
Risk	EU	-8.1%	-8.2%	141.2%	12.9%	30.7%
	E&C	-30.3%	-30.7%	161.3%	-1.0%	14.3%
	ST	-81.4%	-81.5%	107.6%	-73.6%	-30.6%
	P&C	-0.7%	-1.4%	139.4%	15.9%	38.4%
Soil loss	EU	-2.8%	-2.8%	-49.8%	-30.5%	-37.6%
	E&C	-21.7%	-21.7%	-80.0%	-57.1%	-66.3%
	ST	-8.0%	-8.0%	-76.6%	-35.0%	-58.1%
	P&C	0.1%		-50.2%	-26.2%	-36.0%

EU: introduction of eucalyptus; E&C: introduction of eucalyptus with cash payments; ST: introduction of strawberries; P&C: introduction of phalaris and clover pastures.

As observed already the five solutions for each policy scenario are necessarily Pareto efficient, this means that within a policy scenario no optimal solution dominates another optimal solution. Nevertheless it is possible that an optimal solution for one policy scenario dominates an optimal solution for a different policy scenario. In fact, the set of 25 solutions was reduced to an efficient set of seven when dominance between policy-scenarios was considered. These, shown in bold in Table 9.13, were the five solutions under the strawberry scenario and two alternatives within the eucalyptus with cash policy (minimum soil loss and L_∞).

Table 9.13 Value of the objective function and distance from the ideal solution for every optimal solution under the sixteen possible policy scenarios

	Value of objective function			Distance	
Scenario	GM (mill)	Risk (mill)	Soil loss (thousand)	L_1	L_∞
Base-GM	$ 107.5	$ 188.9	40.0 t	1.850	1.000
Base-Risk	$ 107.2	$ 187.5	39.9 t	1.849	0.999
Base-Soil loss	$ 77.3	$ 455.7	20.1 t	2.232	0.938
Base-L_1	$ 103.7	$ 225.9	28.8 t	1.636	0.652
Base-L_∞	$ 99.1	$ 262.0	25.6 t	1.677	0.632
EU-GM	$ 110.1	$ 173.6	38.9 t	1.745	0.965
EU -Risk	$ 110.0	$ 173.5	38.9 t	1.746	0.965
EU -Soil loss	$ 77.3	$ 455.7	20.1 t	2.232	0.938
EU -L_1	$ 105.8	$ 213.4	27.8 t	1.546	0.619
EU -L_∞	$ 101.5	$ 247.0	25.0 t	1.591	0.598
E&C-GM	$ 118.5	$ 131.8	31.3 t	1.299	0.729
E&C-Risk	$ 117.8	$ 130.9	31.3 t	1.309	0.729
E&C-Soil loss	**$ 72.9**	**$ 493.7**	**<u>8.0 t</u>**	2.000	1.000
E&C-L_1	$ 112.1	$ 187.0	17.1 t	1.067	0.450
E&C-L_∞	$ 107.8	$ 216.0	13.5 t	1.075	0.510
ST-GM	**<u>$ 144.1</u>**	**$ 35.1**	**36.8 t**	0.900	0.900
ST-Risk	**<u>$ 144.1</u>**	**<u>$ 34.9</u>**	**36.8 t**	0.900	0.900
ST-Soil loss	**$ 87.9**	**$ 392.3**	**9.4 t**	1.610	0.789
ST-L_1	**$ 139.4**	**$ 49.8**	**26.0 t**	0.661	0.562
ST-L_∞	**$ 129.0**	**$ 131.2**	**16.7 t**	0.695	0.273
P&C-GM	$ 107.5	$ 187.7	40.0 t	1.848	1.001
P&C -Risk	$ 107.3	$ 186.2	40.0 t	1.847	1.000
P&C -Soil loss	$ 77.6	$ 452.3	19.9 t	2.215	0.933
P&C -L_1	$ 104.2	$ 218.9	29.5 t	1.634	0.672
P&C -L_∞	$ 99.1	$ 261.5	25.6 t	1.676	0.632

EU: introduction of eucalyptus; E&C: introduction of eucalyptus with cash payments; ST: introduction of strawberries; P&C: introduction of phalaris and clover pastures

Bold values show the sub-set of efficient solutions, underlined values show the ideal values for each objective, and shadowed cells show the solutions closest to the ideal (L_1 and L_∞ metrics)

To determine which was the best compromise solution in a discrete setting (i.e. 25 possible solutions) the distance under the L_1 and L_∞ metric between each solution and the *ideal* solution was computed. First the *ideal* at the micro-regional (\$ 144 mill; \$ 35 mill; 8,000 t)[5] and the *nadir* (\$ 73 mill; \$ 494 mill; 40,000 t) were determined and then for each solution the L_1 and L_∞ metric compromise solutions were computed (Table 9.13). Under this discrete setting the scenario strawberries-L_1 had the minimum value for the L_1 metric and the scenario strawberry-L_∞ had the minimum value for the L_∞ metric. Thus it must be concluded that under present circumstances the introduction of strawberries is the policy with the best impact on the sustainability of the micro-region's FSs.

9.7 EFFICIENT SOLUTIONS AND FARM GROSS MARGIN

When only the GM maximising objective was considered then the introduction of any policy can obviously only maintain or improve the farm GM (Figure 9.4). The magnitude of the response to each policy varied between farms and according to the policy introduced: farm D only marginally adopted two policies (strawberries and artificial pastures); farms F, G, and H responded only to one policy (strawberry); farm E adopted two policies (eucalyptus with cash and strawberries); while the other three farms (A, B, and C) adopted three of them (eucalyptus, eucalyptus with cash, and strawberries).

Nevertheless under the soil loss minimising scenario, this was not so, as the ability to reduce soil loss varied between farms, so that different impacts on each FS's GM were observed. Specifically under such a scenario, the GMs of farms B and E, (and farms G and H under some policies) were reduced to a greater extent than the GMs of farms A, C and D (Figure 9.5).

[5] Vector of GM, risk, and soil loss respectively.

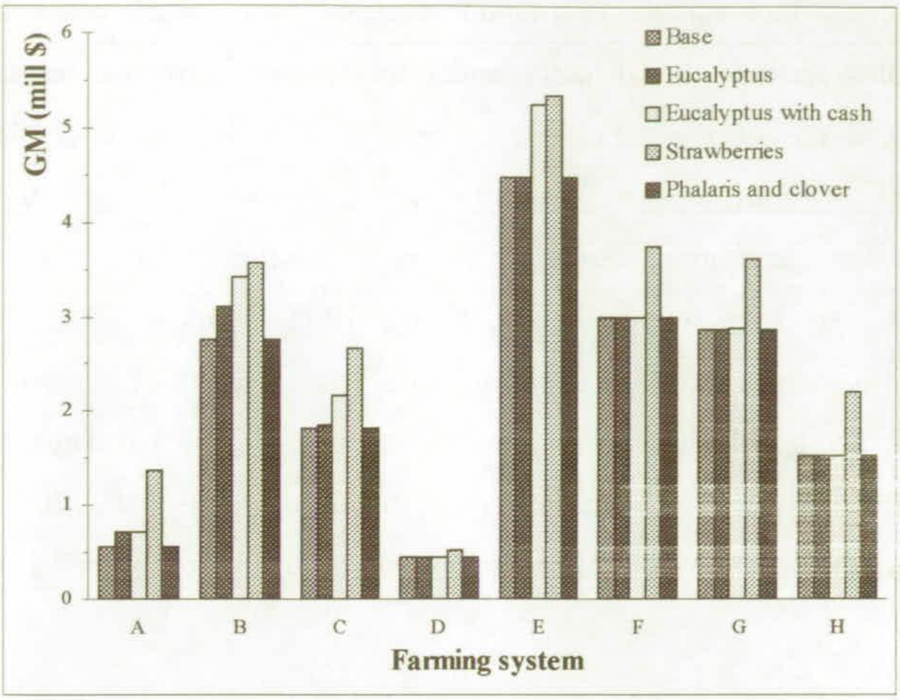


Figure 9.4 Farm level GMs under the five policy scenarios when GM was maximised

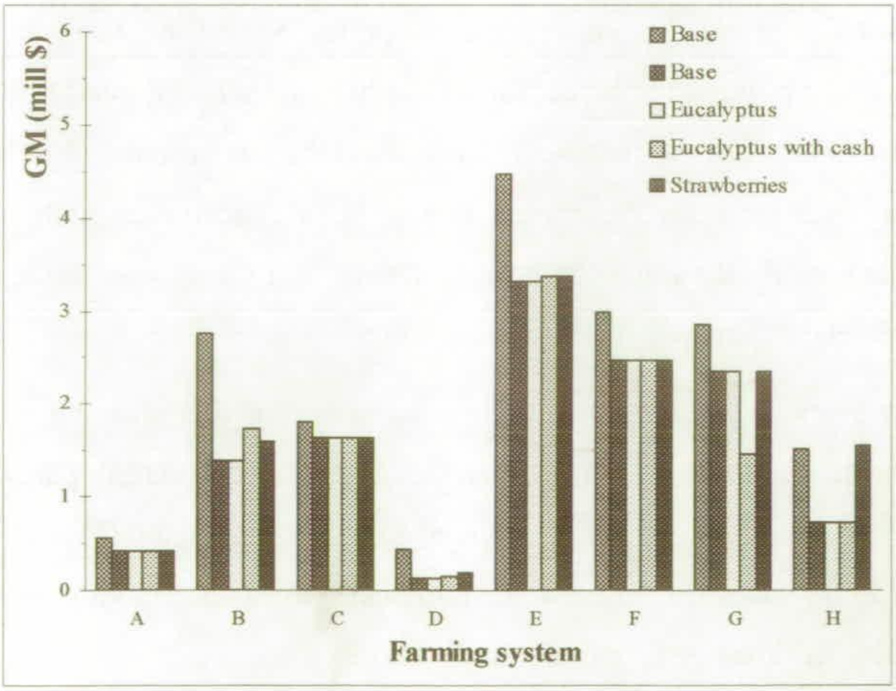


Figure 9.5 Farm level GMs under the five policy scenarios when soil loss was minimised

When the L_1 metric was optimised (Figure 9.6) the GM of farms B and C improved (except with the pasture policy), farms E and F improved or maintained their GM, while the GM of farms A, D, G, and H changed in any direction depending on the policy.

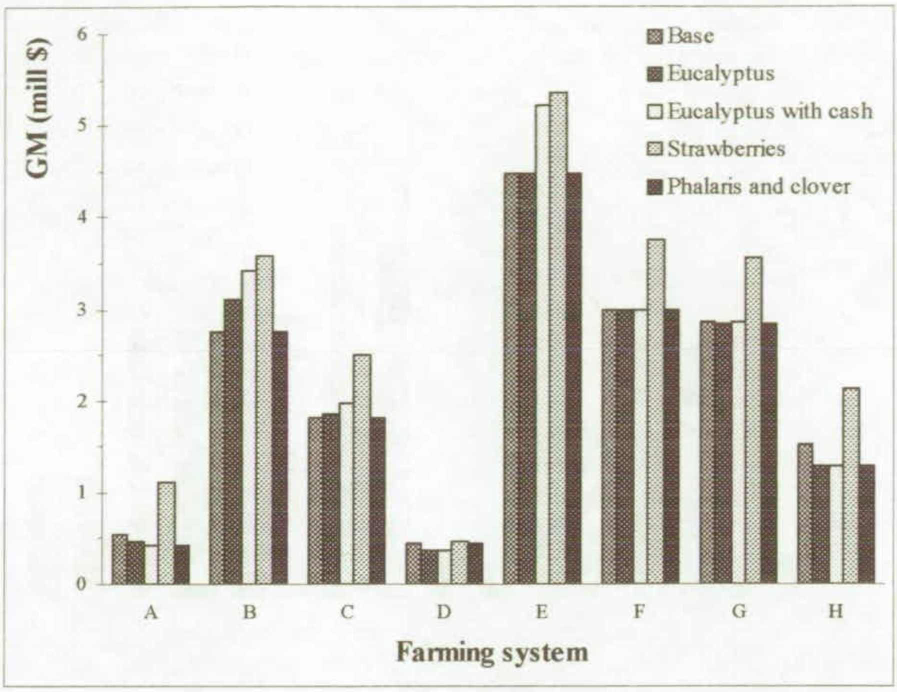


Figure 9.6 Farm level GMs for the five policy scenarios under L_1 compromise solution

Finally, when the L_∞ metric compromise solutions were computed (Figure 9.7) farms A, D, F, G, and H showed a response similar to that observed when L_1 was optimised. A different behaviour was shown by farms B and E, as they reduced their GM when eucalyptus or pastures were introduced, and by FS-C which reduced its GM when strawberries were introduced.

These results show that the response of each FS varies according to the policy and optimisation scenario, some farms showing a greater ability to respond to changes in the optimisation criteria (e.g. farms B and C under L_1 and L_∞ scenarios). It must be noted that even though some of these solutions would reduce the micro-region's soil loss, they are not likely to be acceptable to the farmers, as none would probably want to reduce his income, nor to the policy makers, as the share of their impact is not fairly distributed among different stakeholders, and therefore not in line with the policy of growth with equity.

Such results highlight the need to consider the differential effect of development policies across FSs, an issue which will be discussed in Chapter 10.

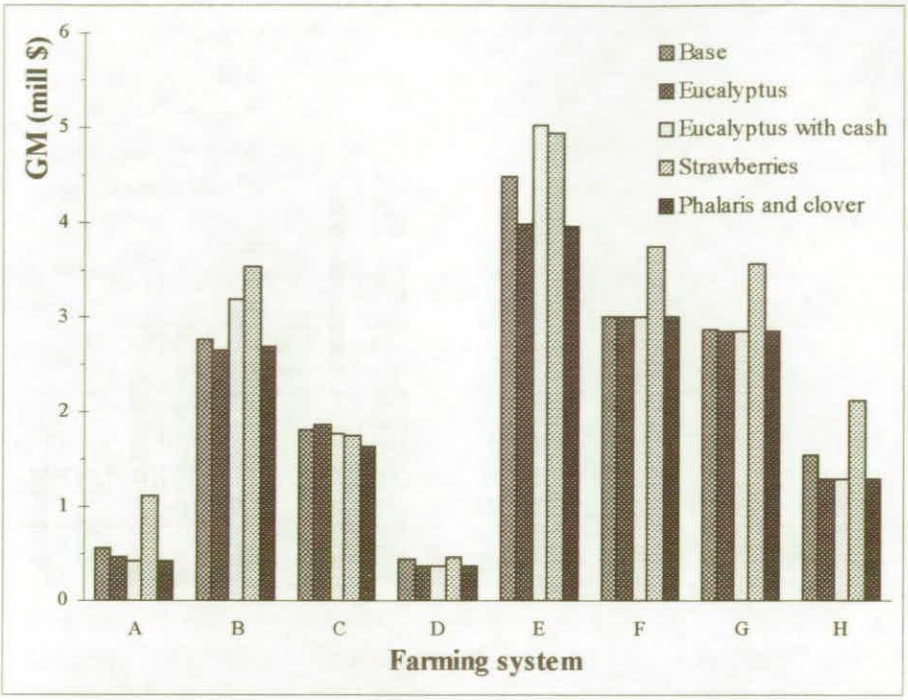


Figure 9.7 Farm level GMs for the five policy scenarios under L_∞ compromise solution

9.8 SUMMARY

This chapter began with the construction of the micro-regional model achieved by simple aggregation of the eight individual FSMs. The objective functions were obtained through a weighted sum of the FSs' objectives. Gross margin and risk were weighted by the number of farms in each FS and soil loss by taking into account the area covered by each system.

The model was then optimised for each possible combination of criteria (GM, risk, soil loss, and L_1 and L_∞ metric) and any of five policy scenarios. One was the base scenario in which no intervention was specified. The other included one of four new technologies: eucalyptus with or without yearly cash payments, strawberries, and artificial pastures. From the analysis of the solutions both within and between policies the following conclusions were drawn:

i. There was little or no trade-off between both economic criteria (GM and risk). The way in which risk was modelled explained most of this unexpected result.

ii. There was scope to reduce soil erosion within the base scenario, but this affected the economic viability of the FSs.

iii. The introduction of eucalyptus (with or without yearly cash payments) or strawberries improved all three evaluation criteria, when GM was used as the unique objective function.

iv. The establishment of phalaris and clover pastures had no major impact on the micro-region's FSs.

v. Different evaluation criteria achieved different solutions, especially from the point of view of changes in GM across FSs.

vi. From a discrete point of view, the best alternatives were the introduction of strawberries under an L_1 or L_∞ compromise scenario.

vii. The impact of each policy varied according to the FSs analysed; thus the evaluation of policies from a FSs point of view requires consideration of sets of homogenous FSs.

viii. When various FSs are considered simultaneously a measure of this differential impact has to be included into the MRM.

In the next chapter a method to evaluate the distributive effect of local development policies will be addressed. An extended MRM will be developed and used for policy evaluation.

10. Optimal solutions for the expanded micro-regional model

10.1 Introduction

In the previous chapter a simple micro-regional model was used to explore the impact of alternative development policies on a set of FSs. The development of such a model was based on three assumptions:

i. Each FS behaves as an independent entity; therefore its decisions are not influenced by the decisions of other FSs.

ii. At an aggregate level the farms within a micro-region are not able to change input or output prices.

iii. Implementing those policies does not imply additional restraints for the FSs or the micro-region.

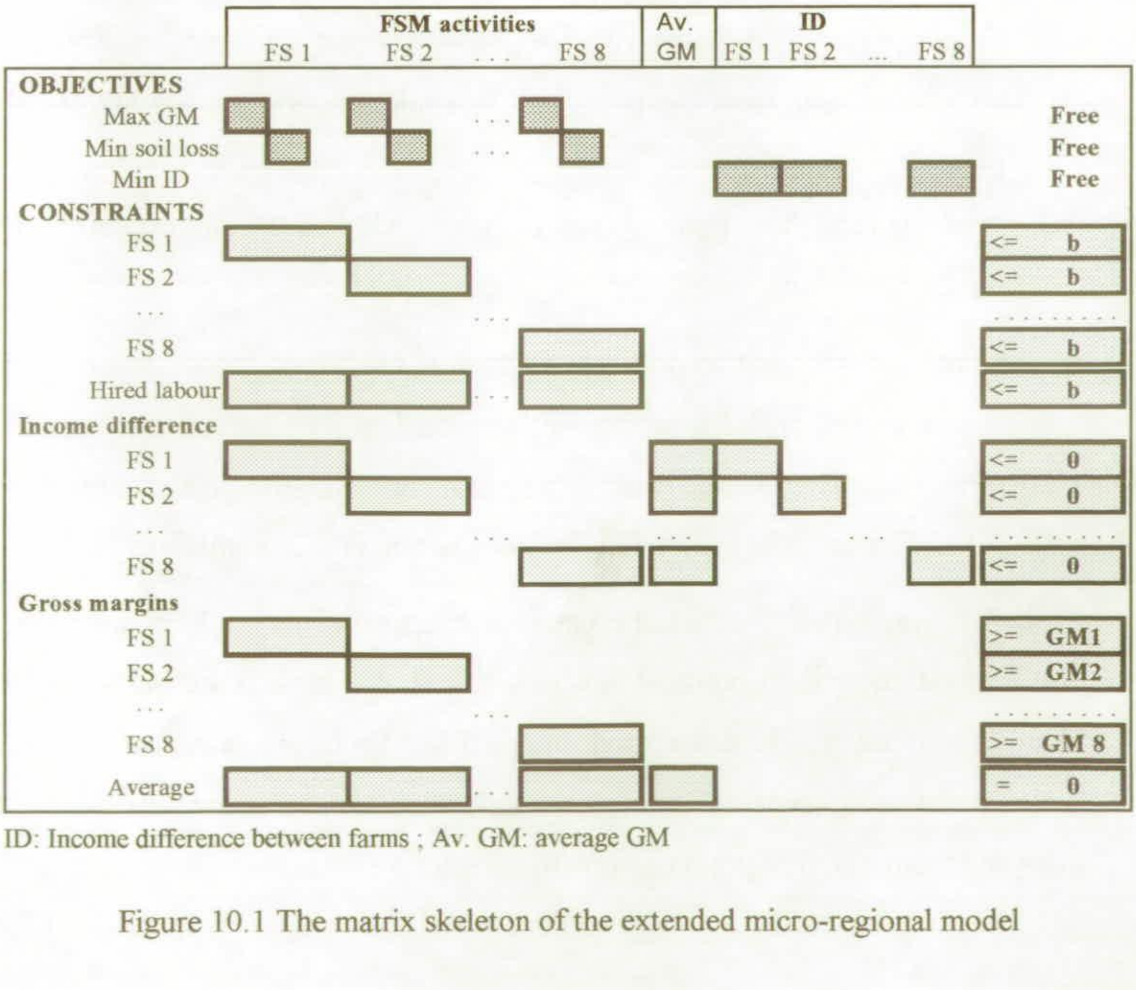
The results showed that an increased demand for labour under some scenarios was not compatible with the second and the third set of assumptions. In fact large increases in the demand for hired labour will increase the cost of labour as the aggregated demand will become higher than actual labour availability.

Further it was observed, that alternative scenarios did not only change GM and soil loss at the micro-regional level, but that the benefit or burden of these changes was unequally distributed among FSs. Therefore, a MRM requires the inclusion of some measure of income distribution, a need which has already been analysed from a policy point of view in Chapter 5.

This chapter deals with the problem of income and labour demand through the construction of an extended FSM. First the objective of minimising income differences between farms was included and then additional restraints were constructed. Finally this extended model was used to measure the impact of three development policies under different optimisation criteria, comparing the results generated under alternative policy scenarios.

10.2 Construction of the extended micro-regional model

The extended MRM showing the additional objective function and restraints is shown in Figure 10.1. The figure shows the columns computing the average GM and the income differences between farms. In addition to the FSM restraints, the



ID: Income difference between farms ; Av. GM: average GM

Figure 10.1 The matrix skeleton of the extended micro-regional model matrix includes rows specifying aggregated labour demand, and minimum gross margin levels, and ties to compute the deviations from the average GM. These modifications will be presented in more detail in the following sections.

10.2.1 THE INCLUSION OF A MEASURE FOR INCOME DISTRIBUTION

As discussed in Section 7.3.4, the income distribution problem can be incorporated into the MRM by minimising the sum of the negative differences between each FS's GM and the average GM. The snag with such a method is the above minimisation is achieved not only when the GM of low income groups is increased, but also (although to a lesser extent) when the GM of higher income groups is reduced. The latter is not fair to the individual farmer, as he has to reduce his already meagre earnings with no benefit, neither is this acceptable for the policy maker as what would be achieved is a simple averaging of the income of a group of poor farmers. Further, it is possible that if this method is used the model produces irrational farm plans. In fact, to reduce its GM a farm can embark on a plan which hires large amounts of labour but does not use them. No alternative modelling approach was found to prevent this from happening. To overcome this problem, a further restraint preventing any FS from reducing its actual GM was added. Therefore the model was extended by adding the following objective function and restraints to the base MRM:

$$\begin{aligned} & Min\ Z_4 = \sum_{i=1}^{n} w_i nid_i \\ & subject\ to \\ & \overline{GM} - GM_i - nid_i \leq 0_i \\ & GM_i \geq GM_{i0} \end{aligned} \qquad [10.1]$$

where nid_i is the negative difference between the average and the observed GM of farm i; w_i is the weight given to deviation nid_i in the objective function; $\overline{GM}$ is the average micro-regional GM for each scenario; GM_i is the GM of FS i; and GM_{i0} is the actual GM for FS i (this is GM in base solution). The weights used to calculate both income difference and average GM were the number of households in each FS. Thus it was assumed that each farm had the same importance in this objective function.

This combination of minimising income difference while setting a minimum income level determines that the optimal solution will be such that the income of lower income groups is raised, while achieving at least the current level for the higher income groups. This extended model also states that a reduction in the differences of income between farmer groups will imply an improvement in the sustainability of the micro-regional agriculture.

10.2.2 THE INCLUSION OF LABOUR RESTRAINTS

As seen in Chapter 9, the absence of micro-regional labour restraints allowed the generation of solutions requiring large amounts of hired labour. In fact one scenario demanded almost 3,500 man/days/year, while others had peak demands of over 600 man/days/month. These solutions are unrealistic as such high demands will probably increase labour costs. The best solution to this problem is to specify in the model an implicit labour supply function, i.e. the relationship between price and quantity of labour supplied (see Hazell and Norton, 1986). Further, it is probable that seasonality of labour demand also requires that such functions have to be specified for different seasons. Unfortunately, due to lack of data it was not possible to formulate these supply functions. As an alternative, maximum levels were set for hired labour at the micro-regional level. Specifically, an idle working force of 15 persons was defined for the 53 farms represented by the MRM. Part or all of this work force could be hired at each farmer's discretion and at a fixed cost. This labour was also made available to FS-F, for which the actual labour hiring restraints were lifted (see Section 8.11.2.6).

10.2.3 Scenarios analysed using the extended micro-regional model

Three policies and five evaluation criteria are analysed using the extended micro-regional model. The policies are derived from two of the policies analysed in the previous chapter. They are the introduction of eucalyptus with yearly cash payments and the introduction of strawberries. The introduction of eucalyptus without payments is not analysed further as it was clearly inferior to the alternative which considered cash payments. Artificial pastures are also discarded as they would be less effective in improving any sustainability criteria under a more restricted model. Despite this they are introduced as part of a combined policy which included also the introduction of strawberries and of eucalyptus with cash payments.

For all three policies maximum levels of adoption are imposed, as it is assumed that the government cannot give unlimited finance and that the technology transfer programmes can also give only a limited technical support to any of these new crops. To represent the scenario in which the adoption of eucalyptus with yearly cash payments is restricted it is specified that at the micro-regional level less than 15% of the area covered by the study could be planted with these trees. This meant a maximum of 357 ha of eucalyptus. When strawberries are introduced this maximum was set at eight hectares, corresponding to 40 farms with 0.2 ha of strawberries each.

The third policy, i.e. the simultaneous introduction of eucalyptus with cash, strawberries, and phalaris and clover pastures, includes the previous area restraints for eucalyptus and strawberries. The area sown with phalaris and clover is limited to 119 ha/year (5% of the total area).

These maximum planting levels as well as the hired labour restraint have the same effect as maximum demand or supply levels. There was no data available on the impact of changes in supply or demand prices, necessary to construct the implicit supply or demand functions, which would be able to reflect the price changes induced by an changes in supply or demand. The alternative of doing market research to gather that information was out of the scope of the thesis. Further it is expected that all policies will have a small impact on the product markets, even if adopted by a large number of peasant farmers. Specifically, strawberries will be exported and therefore compete in a very large market, the area with new eucalyptus plantations is minimal compared to over 14,000 ha of existing plantations, and the importance of the regional herds (which may increase due to a greater availability of forage) is very small at a national level.

The models including each of these three policies are solved according to the criteria of maximum GM, minimum soil loss, minimum income difference, and for both L_1 and L_∞ distance metrics compromise solutions. Risk is not considered as a fourth criterion in this extended MRM, as the trade-offs between risk and GM observed in the base model were very low or non-existent. Therefore the benefits from its inclusion would be outweighed by the additional difficulties of interpreting the results.

The introduction of these maximum adoption levels determine that the achievement levels of the optimisation criteria would necessarily be lower than the ones observed when the policy is introduced in an unrestricted way (Chapter 9).

Finally, the base scenario solution when GM is maximised (Sections 9.2.1 and 9.2.3) is again used as reference point for these 15 new scenarios (three policies and five solutions per policy).

10.3 Policy evaluation using the expanded micro-regional model

10.3.1 Efficient solutions with eucalyptus and yearly cash payments

At the micro-regional level the introduction of eucalyptus and yearly cash payments improved GM and soil loss but worsened income differences among farms of different types when GM was maximised (Table 10.1). Under this scenario 220.7 ha of eucalyptus were planted in farms of types A, B, C, E, and G. Although this scenario had its largest impact on the GMs of two farms with below average income (A and C) its overall effect on income difference was negative, as it failed to improve the GM in the other two low income farms (D and H) while improving it in all the above average income farms. Farm A transformed 2.37 ha of permanent pasture into woods and gave-out all the sheep and cows, with no changes in cropping activities. In FS-B 4.21 ha of permanent pasture were replaced with trees and the sheep flock was reduced, with no changes in other cropping activities. Farm C reduced the area under hilly wheat to plant 9 ha of eucalyptus. Farm E planted 15 ha of trees, reducing the area under hilly wheat and the number of cows. Farm G grew 2.91 ha of trees by changing from traditional eucalyptus to this alternative. Finally FS-F increased the GM by growing wheat instead of giving land out for growing it. This was a result of the relaxation of the farm's labour restraints; therefore the farmer could hire more labour than in the base model.

When the soil loss criterion was optimised, the minimum GM restraints became effective and no farm reduced its income. Despite this it was possible to generate a new efficient solution which compared to the base solution, had the same GM for each FS, and therefore the same income difference, but showed a soil loss 45.2% lower than the base scenario (Table 10.1). This soil loss reduction was the product of planting 339.5 ha of trees (i.e. 17 ha less than the maximum), mainly in farms of types B, C, and E.

The three remaining efficient solutions (minimisation of income difference, L_1 and L_∞) showed similar outcomes, improving at the aggregate level all three criteria (GM, income difference, and soil loss). Interestingly the solution which minimised income difference achieved also a rather large reduction in soil loss (Table 10.1). Under these three scenarios the introduction of eucalyptus with cash payments had is greatest impact on FSs A and C, while FS-D was unaffected[1]. Farms with above average income (B, E, F, and G) generally did not show

Table 10.1 Change in micro-regional single objective and compromise solutions (L_1 and L_∞ metrics) compared to the base solution. Scenario: Introduction of eucalyptus with yearly cash payments in the extended MRM

		Function optimised			Compromise solutions	
Model	Objective	GM	ID	Soil loss	L_1	L_∞
MR	GM	8.5%	3.6%		2.8%	5.1%
	ID	8.5%	-5.8%		-4.6%	-0.1%
	Soil loss	-12.6%	-28.2%	-45.2%	-36.0%	-32.1%
A	GM	28.6%	28.6%			
	ID	0.9%	-5.8%		3.9%	7.0%
	Soil loss	0.4%	0.4%	-35.7%	-35.7%	-35.7%
B	GM	9.1%				6.9%
	ID					
	Soil loss	-0.4%	-32.6%	-44.7%	-33.4%	-5.6%
C	GM	14.7%	16.2%		15.4%	17.1%
	ID	-42.8%	-100.0%		-100.0%	-94.2%
	Soil loss	-27.7%	-50.0%	-77.0%	-51.4%	-46.2%
D	GM					
	ID	10.8%	4.6%		3.6%	6.5%
	Soil loss					
E	GM	11.5%				
	ID					
	Soil loss	-25.1%	-63.4%	-63.4%	-63.4%	-63.4%
F	GM	15.4%				10.6%
	ID					
	Soil loss	-0.6%	-8.5%	-8.5%	-8.5%	0.1%
G	GM	0.6%				
	ID					
	Soil loss		-15.5%	-15.5%	-15.5%	-15.5%
H	GM					
	ID	34.4%	14.6%		11.5%	20.6%
	Soil loss					

ID: income difference between the farm and the micro-regional average
Note: no value is shown if there was no change in the objective function's value

[1] FS-H had no land for trees and was therefore also unaffected.

increases in GM although they responded with reductions in soil loss. When income difference was minimised three FSs (E, F, and G) showed maximum reductions in soil loss, and only one (FS-A) had a slight increase. The L_1 and L_∞ scenarios involved less soil loss for almost all farms.

Due to the way in which differences between farm income was modelled, two particular situations have to be kept in mind when comparing the impact of the policy at the farm level. First, change in a farm's deviation from the average income does not mean that the farm level solution changed (for example farms D and H in Table 10.1) as changes in this value may simply reflect changes in the micro-regional average GM. Second, the absence of change in income deviation does not mean that the solution remains unchanged (for example FS-B) as this value represents only the negative deviation from the average GM. As a result it may look as though under particular circumstances dominated solutions were obtained. An example of this were the FS-A solutions for the GM and income difference scenarios. In both GM increased by 28.6% and soil loss by 0.4%, while the deviation from the average income changed in opposite directions.

10.3.2 EFFICIENT SOLUTIONS WITH STRAWBERRIES

The introduction of strawberries also improved GM and soil loss under all optimisation criteria (Table 10.2), but the impact on them compared to the introduction of eucalyptus with cash was far larger. Under all scenarios the maximum amount of this crop was planted (8.00 ha) by farms of types A, B, C, E, and H (0.2 ha each) and a smaller area by FS-G (0.14 ha).

Under this policy when GM was maximised income difference increased, although FSs A, C, and H (below average income farms) improved their GMs. The reason was that the low income farm FS-D remained unchanged and that the four farms above average increased their GMs. From the point of view of soil loss the response was diverse; while most farms remained practically unchanged, FS-H reduced its soil loss while farm G increased it. The specific responses of each FS were as follows: farm A replaced all its vineyard with strawberries, and made no other change; farms B, C, E and G reduced their area under flat wheat to grow strawberries; and, farm H used part of its vegetable-garden to grow strawberries. Other changes required to satisfy land and labour demand included a reduced production of lentils (farm B), and less tomatoes and more lemons (farm G). Again farm F increased its GM as it could use additional hired labour.

Table 10.2 Change in micro-regional single objective and compromise solutions (L_1 and L_∞ metrics) compared to the base solution. Scenario: Introduction of strawberries in the extended MRM

		Function optimised			Compromise solutions	
Model	Objective	GM	ID	Soil loss	L_1	L_∞
MR	GM	32.0%	16.1%	0.3%	14.3%	19.3%
	ID	4.8%	-26.3%	-0.5%	-23.3%	-13.9%
	Soil loss	-8.3%	-27.9%	-69.5%	-48.4%	-45.0%
A	GM	148.8%	148.8%		118.8%	118.8%
	ID	-11.9%	-33.7%	0.4%	-25.0%	-18.1%
	Soil loss			-68.2%	-64.9%	-64.9%
B	GM	29.3%				2.7%
	ID					
	Soil loss	-0.2%	-51.3%	-51.4%	-51.4%	-50.2%
C	GM	47.5%	30.3%		28.2%	33.8%
	ID	-95.8%	-100.0%	2.9%	-100.0%	-100.0%
	Soil loss	-0.1%	-21.1%	-70.3%	-28.8%	-20.4%
D	GM		18.7%		18.7%	14.9%
	ID	40.9%	15.4%	0.4%	13.1%	20.5%
	Soil loss			-70.9%		-18.4%
E	GM	19.6%				
	ID					
	Soil loss	1.3%	-42.0%	-42.0%	-42.0%	-42.0%
F	GM	23.2%				23.4%
	ID					
	Soil loss	-3.4%	-50.1%	-57.7%	-50.1%	-3.4%
G	GM	18.7%				6.4%
	ID					
	Soil loss	18.6%	-60.4%	-63.0%	-60.2%	-43.7%
H	GM	44.3%	44.3%	2.0%	38.9%	38.9%
	ID	-5.8%	-70.1%	-4.8%	-61.2%	-40.8%
	Soil loss	-49.5%	-49.5%	-100.0%	-77.6%	-77.6%

ID: income difference between the farm and the micro-regional average

Note: no value is shown if there was no change in the objective function's value

Under the soil loss minimising scenario a large reduction in this objective was achieved without major impact on GM and therefore on income difference. The small change observed on GM was due to a slight increase in the GM of FS-H.

The large aggregate reduction of soil loss was a result of large reductions of soil loss in each FS (Table 10.2).

Again the solution obtained when income difference was minimised was similar to the ones achieved under compromise scenarios. In fact the solution with lowest income difference also represents at the micro-regional level a good compromise between the extreme GM and soil loss efficient solutions. Nevertheless a draw-back to this solution as well as of the L_1 and L_∞ compromise solutions is that some farms do not show a reduction in soil loss. In fact, no reduction in soil loss was observed in farms A and D when income difference was minimised, and in farm D when L_1 was optimised, while FS-F showed only a small reduction in soil loss when L_∞ was optimised.

10.3.3 Efficient solutions with the combined policy

As shown in Table 10.3 the maximisation of GM under the combined policy (i.e. the introduction of strawberries, of eucalyptus with yearly cash payments, and of phalaris and clover pastures) improved the GM (37.0%) and reduced soil loss (19.7%), but with an increase in the income difference between farms (10.7%). At the farm level, GMs increased from 1.5% (FS-D) to 176.5% (FS-A), while the change in soil loss ranged from a reduction of 49.5% (FS-H) to an increase of 23.8% (FS-G). The higher soil loss in farm G, due to a replacement of eucalyptus with wheat on hilly land, is probably for the policy maker a negative aspect of this solution.

Soil loss minimisation achieved a large reduction of this criterion (81.5%) without relevant changes in both GM and income difference. Due to the specification of minimum income restraints this was also so at the farm level, where the reduction in soil loss ranged from 50.7% (FS-F) to 100.0% (FS-H), while GM increased only in FS-H (2.0%).

Table 10.3 Change in micro-regional single objective and compromise solutions (L_1 and L_∞ metrics) compared to the base solution. Scenario: Introduction of all three policies in the extended MRM

		Function optimised			Compromise solutions	
Model	Objective	GM	ID	Soil loss	L_1	L_∞
MR	GM	37.0%	21.3%	0.3%	18.8%	25.4%
	ID	10.7%	-34.8%	-0.1%	-30.6%	-20.4%
	Soil loss	-19.7%	-49.8%	-81.5%	-70.1%	-62.0%
A	GM	176.5%	176.5%		118.8%	128.6%
	ID	-15.5%	-37.0%	0.1%	-18.8%	-13.3%
	Soil loss	0.4%	0.4%	-68.2%	-64.9%	-60.0%
B	GM	16.5%				18.9%
	ID					
	Soil loss	-0.4%	-53.6%	-61.1%	-56.5%	-50.9%
C	GM	59.9%	36.1%		33.2%	40.7%
	ID	-100.0%	-100.0%	0.8%	-100.0%	-100.0%
	Soil loss	-25.1%	-74.5%	-88.0%	-78.9%	-67.3%
D	GM	1.5%	141.6%		141.3%	141.3%
	ID	46.9%	-12.3%	0.1%	-15.5%	-7.0%
	Soil loss	2.2%	-9.2%	-80.7%	-26.1%	-26.1%
E	GM	29.3%				
	ID					
	Soil loss	-23.7%	-78.2%	-79.6%	-77.4%	-71.4%
F	GM	20.8%				26.2%
	ID					
	Soil loss	-0.6%	-38.4%	-50.7%	-39.7%	-0.4%
G	GM	27.6%				
	ID					
	Soil loss	23.8%	-26.1%	-63.0%	-26.1%	-26.1%
H	GM	44.3%	44.3%	2.0%	38.9%	40.4%
	ID	14.6%	-49.0%	-1.3%	-43.0%	-20.3%
	Soil loss	-49.5%	-49.5%	-100.0%	-77.6%	-70.1%

ID: income difference between the farm and the micro-regional average

Note: no value is shown if there was no change in the objective function's value

The other three scenarios (minimisation of income difference and both compromise solutions) were again similar, as they simultaneously improved all three criteria (Table 10.3). Also at the farm level these solutions maintained or improved the values for these criteria for all farms, except FS-A which increased its soil loss slightly (0.4%) when the income differences between farms were minimised.

Although the five solutions included maximum areas of strawberries, at the farm level the cropping pattern (area per farm type) varied between scenarios (Table 10.4). Farms C and H planted 0.2 ha under any scenario, FS-F never planted the maximum possible, while the other farms planted between nothing and 0.2 ha depending on the optimisation scenario.

Table 10.4 Adoption of strawberries at the farm level and under the five optimisation criteria (ha)

FS	GM	ID	Soil loss	L_1	L_∞
A	0.20	0.20	0.06	0.20	0.20
B	0.06	0.08	0.20	0.12	0.18
C	0.20	0.20	0.20	0.20	0.20
D		0.20	0.06	0.20	0.20
E	0.20	0.20	0.20	0.18	0.06
F	0.04		0.06		0.10
G	0.20		0.12		
H	0.20	0.20	0.20	0.20	0.20

The introduction of eucalyptus was complete in only three scenarios; when GM and L_∞ were optimised 208 ha and 337 ha of trees respectively were planted (Table 10.5). The largest amounts were planted in FS-E, where labour was readily available, while FS-D planted only a small number due to its lack of labour.

Table 10.5 Adoption of first year eucalyptus at the farm level and under the five optimisation criteria (ha)

FS	GM	ID	Soil loss	L_1	L_∞
A	0.12	0.12			0.02
B	0.19	0.52	0.56	0.57	0.44
C	0.41	0.56	0.56	0.56	0.56
D		0.08	0.02	0.08	0.08
E	0.71	1.31	1.51	1.34	1.42
F		0.17	0.21	0.22	0.04
G	0.17	0.19	0.13	0.18	0.15
Total	208.15	357.00	357.00	357.00	337.59

Phalaris and clover was a feasible alternative only for farm D, although not under the soil loss minimising scenario (Table 10.6). This highlights again the minor benefits derived from the introduction of this artificial pasture in the area.

Table 10.6 Adoption of flat and hilly phalaris and clover pastures in FS-D and under the five optimisation criteria (ha)

Type	GM	ID	Soil loss	L_1	L_∞
Flat	1.50	1.48	---	0.24	0.24
Hilly	5.99	5.90	---	0.96	0.96
Total	52.40	10.73	---	53.68	10.74

10.4 TRADE-OFFS BETWEEN OBJECTIVES

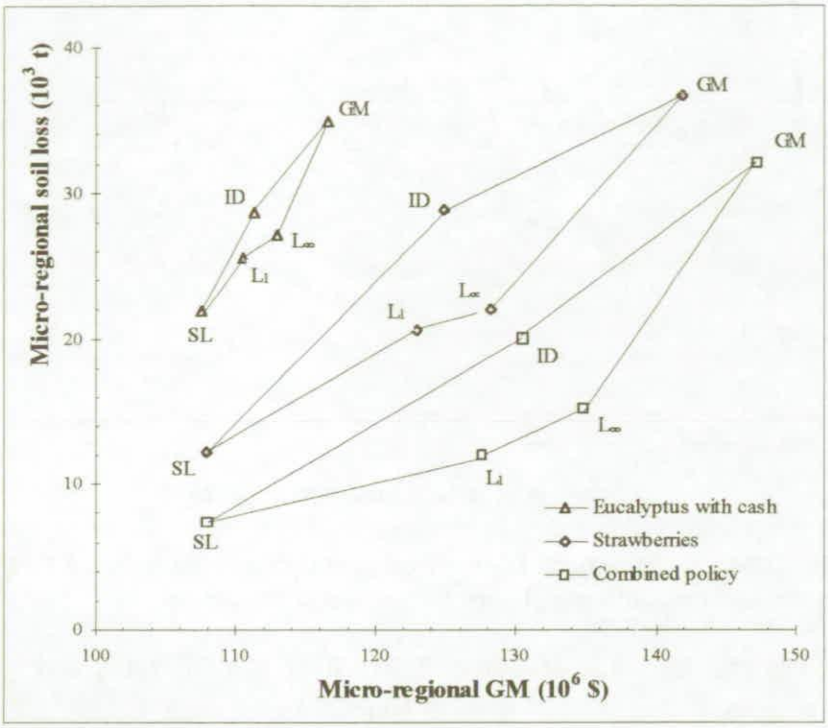
One problem when dealing with three or more conflicting objectives is the determination of trade-offs between these objectives. Even when only two of them are plotted in a two-dimensional space it is difficult to observe standard trade-off curves, such as the curves observed when GM and soil loss were optimised using the basic micro-regional model (Figure 9.2). The extreme points of a standard trade-off curve in a two dimensional space are found when each single objective is optimised; the remaining efficient solution occupy the points between these two. The slope of this curve is always decreasing (or increasing), as a constant reduction in the achievement level of one objective implies an ever diminishing marginal improvement of the other objective. The problem is that the specification of a third conflicting objective function displaces the intermediate efficient solutions and a polygon instead of a curve is observed. This problem can be overcome if a large set of efficient solutions is computed using some other MCDM technique (like MOP) and then plotted in a three-dimensional space, so that the surface representing the set of efficient solutions can be seen.

This problem happened when GM and soil loss were plotted using the set of five efficient solutions for each policy (Figure 10.2). Each polygon represents one policy and its corners the solutions generated when each of the five evaluation criteria were optimised. If only four scenarios for the combined policy are considered, a standard trade-off curve is observed: the GM and the soil loss efficient solutions represent the extreme points, and L_1 and L_∞ solutions represent intermediate points. Nevertheless when income difference was introduced as an optimisation criterion L_1 solutions were displaced[2]. Further, the solution for minimum income difference is dominated by both compromise solutions if only GM and soil loss are considered as measurement criteria (Figure 10.2)[3]. If the three policy

[2] L_∞ minimises the maximum distance from the ideal point, and was in this case unaffected by the introduction of a new criterion.

[3] The curve has been 'closed' joining the extreme point from both sides to highlight that instead of curves the extreme efficient points generate a surface.

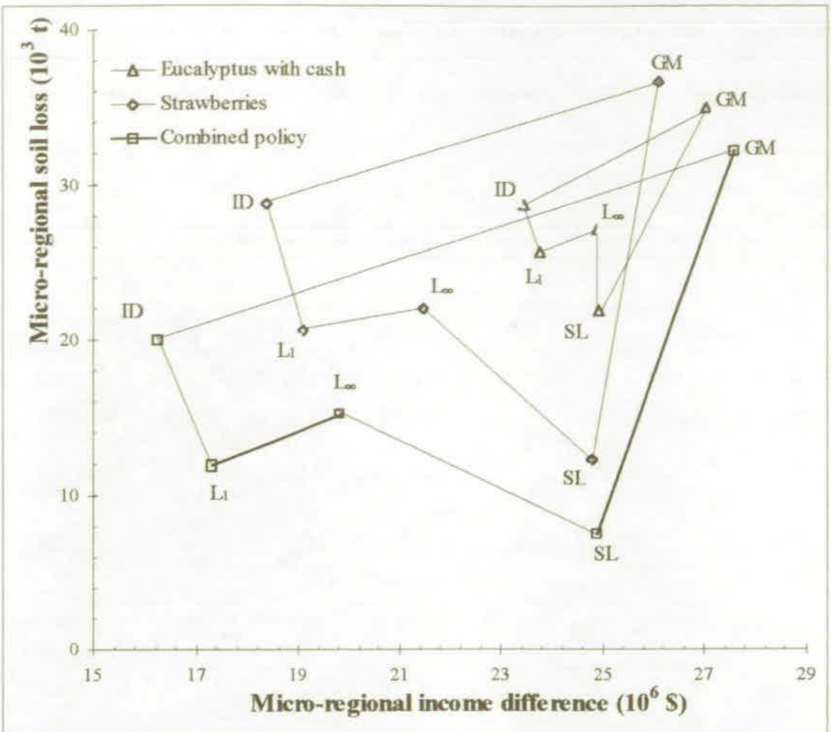
scenarios are compared then the curves clearly show the improvement obtained in both soil loss and GM when strawberries and especially the combined policy are introduced.



Note: GM, SL, ID, L_1, and L_∞ represent the efficient solutions when GM, soil loss, income difference, L_1 and L_∞ are respectively optimised.

Figure 10.2 Trade-off curves between GM and soil loss for all policies

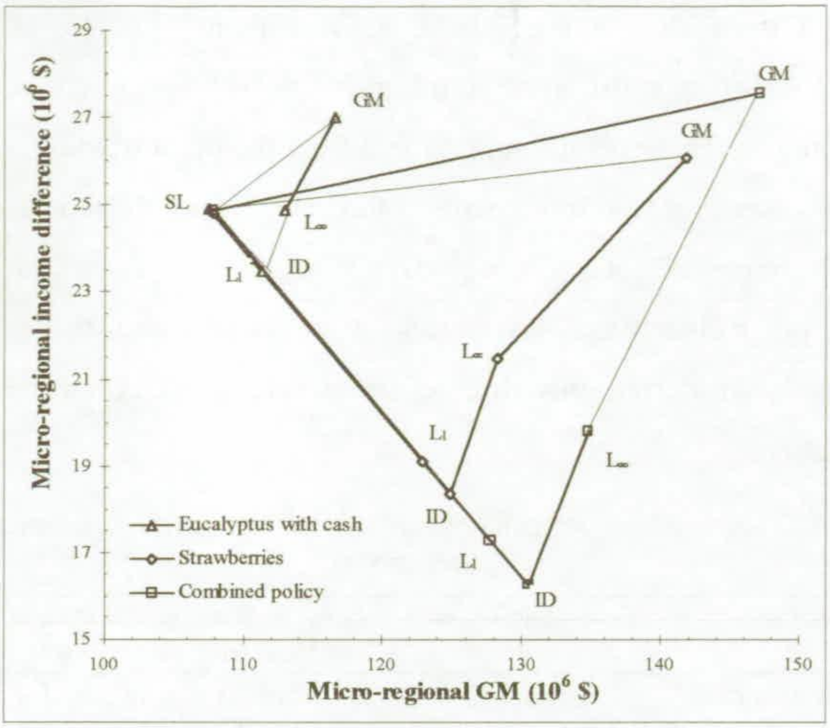
A curve with negative and decreasing slope (convex to the origin) is expected when income difference and soil loss are plotted, as both objectives are minimised. Nevertheless, it looked as if no conflict between income difference and soil loss does exist, as a positive slope between the L_1 and the L_∞ solutions is observed (Figure 10.3). This is again caused by L_∞ which is displaced away from the origin, giving the impression that L_∞ is dominated by L_1.



Note: GM, SL, ID, L_1, and L_∞ represent the efficient solutions when GM, soil loss, income difference, L_1 and L_∞ are respectively optimised

Figure 10.3 Trade-off curves between income difference and soil loss for all policies

When a conflict exists between a maximising and a minimising objective, the trade-off curve shows a positive and increasing slope, as between GM and soil loss under the combined policy (Figure 10.2). But when income difference and GM values are plotted the situation is more confusing as no diminishing marginal returns is observed over all the trade-off curve, because both L_∞ and specially L_1 are displaced (Figure 10.4). It must be noticed that in both Figures which include income difference in one of the axes (i.e. Figure 10.3 and Figure 10.4) the visualisation of the trade-off between objectives is more difficult than when this variable is not considered. The existing relation between income difference and GM (income difference depends on the values attained by GM) is probably a major cause of this.



Note: GM, SL, ID, L_1, and L_∞ represent the efficient solutions when GM, soil loss, income difference, L_1 and L_∞ are respectively optimised

Figure 10.4 Trade-off curves between GM and income difference for all policies

Nevertheless if only the polygons for each policy are compared it is seen that the impact of the introduction of strawberries, and especially of the combined policy on both GM and income difference is larger than when eucalyptus is introduced. This fact is reflected by the larger area covered by the polygons representing each policy in the previous three figures and by the dominance of the combined policy solutions over the eucalyptus solutions.

Due to the difficulties of analysing the values of trade-offs considering all efficient solutions, they were computed considering only the extreme solutions (i.e. optimising GM, soil loss, and income difference). Under such an approach, clear trade-offs between pairs of objectives are seen (Table 10.7). These results show that the eucalyptus policy has the lowest trade-offs between any of the three policies, especially between GM and soil loss and between differences in income and soil loss. Nevertheless, the range over which these trade-offs are relevant is smaller as this policy covers smaller areas in Figures 10.2 to 10.4. Compared to the introduction of strawberries, the combined policy has lower trade-offs between GM and income difference but higher trade-offs between income difference and soil loss. These results suggest that from the point of view of the trade-offs between objectives, the introduction of eucalyptus would represent the best alternative, as improvement in one objective is achieved with the lowest costs in terms of the other objectives. Nevertheless it has to be noted, that this analysis was performed considering only three efficient solutions and not a large set of efficient solutions.

Table 10.7 Trade-offs between pairs of extreme efficient solutions for each policy scenario

Policy	GM and soil loss	Income difference and soil loss	GM and income difference
Eucalyptus with cash	698 $/t	-214 $/t	1.47 $/$
Strawberries	1391 $/t	-386 $/t	2.20 $/$
Combined policy	1596 $/t	-682 $/t	1.48 $/$

10.5 Comparison between the three policies

The previous policy analysis generated 15 solutions with different effects on the three evaluation criteria. Table 10.8 summarises the impact on GM, income difference, and soil loss of these solutions compared to the base-GM scenario. All policy scenarios increase or maintain the GM, while simultaneously reducing

Table 10.8 Percentage change for each policy scenario under the extended MRM compared to the base-GM scenario

		Solution				
Criterion	Policy	Max GM	Min ID	Min SL	L_1	L_∞
GM	E&C	8.5%	3.6%		2.8%	5.1%
	ST	32.0%	16.1%	0.3%	14.3%	19.3%
	Combined	37.0%	21.3%	0.3%	18.8%	25.4%
Income difference	E&C	8.5%	-5.8%		-4.6%	-0.1%
	ST	4.8%	-26.3%	-0.5%	-23.3%	-13.9%
	Combined	10.7%	-34.8%	-0.1%	-30.6%	-20.4%
Soil loss	E&C	-12.6%	-28.2%	-45.2%	-36.0%	-32.1%
	ST	-8.3%	-27.9%	-69.5%	-48.4%	-45.0%
	Combined	-19.7%	-49.8%	-81.5%	-70.1%	-62.0%

ID: Income difference; SL: soil loss; E&C: introduction of eucalyptus with cash payments; ST: introduction of strawberries.

the soil loss. Income difference is also improved, but not under all scenarios; when GM is maximised this indicator increases its value. For the three policies, the minimum income difference as well as both compromise solutions produce the best outcome, as they improve simultaneously all three criteria.

Nevertheless if these 15 solutions plus the base-GM scenario (Chapter 9) are compared, it is seen that some of them are dominated by solutions obtained through other policies (Table 10.9). For example the L_1 solution for the combined policy dominates all the solutions of the eucalyptus with cash policy and three of the strawberry solutions (minimum income difference, minimum soil loss, and L_1 compromise solution). As a result under a discrete setting six non-dominated solutions were found. These were the five solutions under combined policy scenario and the GM-efficient solution for the strawberry policy. To select the

Table 10.9 Value of the objective function and distance to the ideal solution for every optimal solution under the sixteen possible policy scenarios

	Value of objective function			Distance	
Scenario	GM (mill)	ID (mill)	Soil loss (thousand)	L_1	L_∞
Base-GM	$ 107.5	$ 24.9	40.0 t	2.764	1.000
E&C-GM	$ 116.6	$ 27.0	34.9 t	2.566	0.950
E&C-ID	$ 111.4	$ 23.4	28.7 t	2.192	0.903
E&C-soil loss	$ 107.5	$ 24.9	21.9 t	2.209	1.000
E&C-L_1	$ 110.6	$ 23.8	25.6 t	2.144	0.923
E&C-L_∞	$ 112.9	$ 24.9	27.2 t	2.231	0.863
ST-GM	**$ 141.8**	**$ 26.1**	**36.7 t**	1.904	0.898
ST-ID	$ 124.8	$ 18.4	28.8 t	1.407	0.657
ST-soil loss	$ 107.8	$ 24.8	12.2 t	1.892	0.992
ST-L_1	$ 122.9	$ 19.1	20.6 t	1.271	0.613
ST-L_∞	$ 128.2	$ 21.5	22.0 t	1.385	0.478
ALL-GM	**<u>$ 147.3</u>**	**$ 27.6**	**32.1 t**	1.758	1.000
ALL-ID	**$ 130.4**	**<u>$ 16.2</u>**	**20.1 t**	0.811	0.423
ALL-soil loss	**$ 107.8**	**$ 24.9**	**<u>7.4 t</u>**	1.753	0.992
ALL-L_1	**$ 127.7**	**$ 17.3**	**12.0 t**	0.724	0.493
ALL-L_∞	**$ 134.8**	**$ 19.8**	**15.2 t**	0.865	0.315

Notes: Bold values show the sub-set of efficient solutions, underscored values show the ideal values for each objective, and shadowed cells show the solutions closest to the ideal (L_1 and L_∞ metrics)

ID: Income difference

best policy an *ideal* ($ 147.3 mill; $ 16.2 mill; 7,413 t)[4] and a *nadir* ($ 107.5 mill; $ 27.6 mill; 39,979 t) vector was constructed from all the solutions (Table 10.9), and the L_1 and L_∞ metric distance for each computed. The L_1 and the L_∞ solutions for the combined policy scenario were closest to the *ideal* solution when the L_1 and the L_∞ distance was respectively considered.

From this analysis it was concluded that the combined introduction of eucalyptus, strawberries, and artificial pastures is better than the introduction of eucalyptus with cash or strawberries alone. This policy is even better than the best policy under the unrestricted base scenario, i.e. the introduction of strawberries (Table 9.13)

10.6 THE EFFECT OF MINIMISING INCOME DIFFERENCE ON INCOME DISTRIBUTION

As mentioned before, as the Gini coefficient (G) could not be specified within an MCDM model to measure income distribution, differences in income between farms were used as an estimator of this distribution. To explore the suitability of using that estimator, G was computed for all efficient solutions (Table 10.10) and then compared to income difference. The Gini coefficient for the GM efficient solution under the base scenario (30.6%) was used as the reference point. It was seen that only in one scenario (GM efficient solution for eucalyptus with cash policy) did the value of G increase, while in eight it was improved (maximum GM, minimum income difference, and L_1 and L_∞ compromise solutions for both the strawberries and the combined policy). The unchanged Gini coefficient for all soil loss-efficient solutions was due to the inclusion of minimum income levels. These results also show that the five solutions for the eucalyptus policy did little to improve income distribution.

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[4] Vector of GM, income difference, and soil loss respectively

Table 10.10 Gini coefficient for each efficient solution (%)

	Efficient solution				
Policy scenario	Max GM	Min ID	Min SL	L_1	L_∞
Eucalyptus and cash	31.5	29.2	30.5	29.8	30.3
Strawberries	26.3	22.2	30.4	23.1	24.5
Combined policy	26.5	18.5	30.4	19.8	20.8

ID: Income difference; SL: soil loss.

The change in G can also be observed when the Lorenz curves for the minimum income difference scenarios were plotted (Figure 10.5). In that figure curves with higher G coefficients and therefore worse income distribution (like the base solution) are further away from the equality line while lower Gini coefficients (e.g. the combined policy) are closer to it.

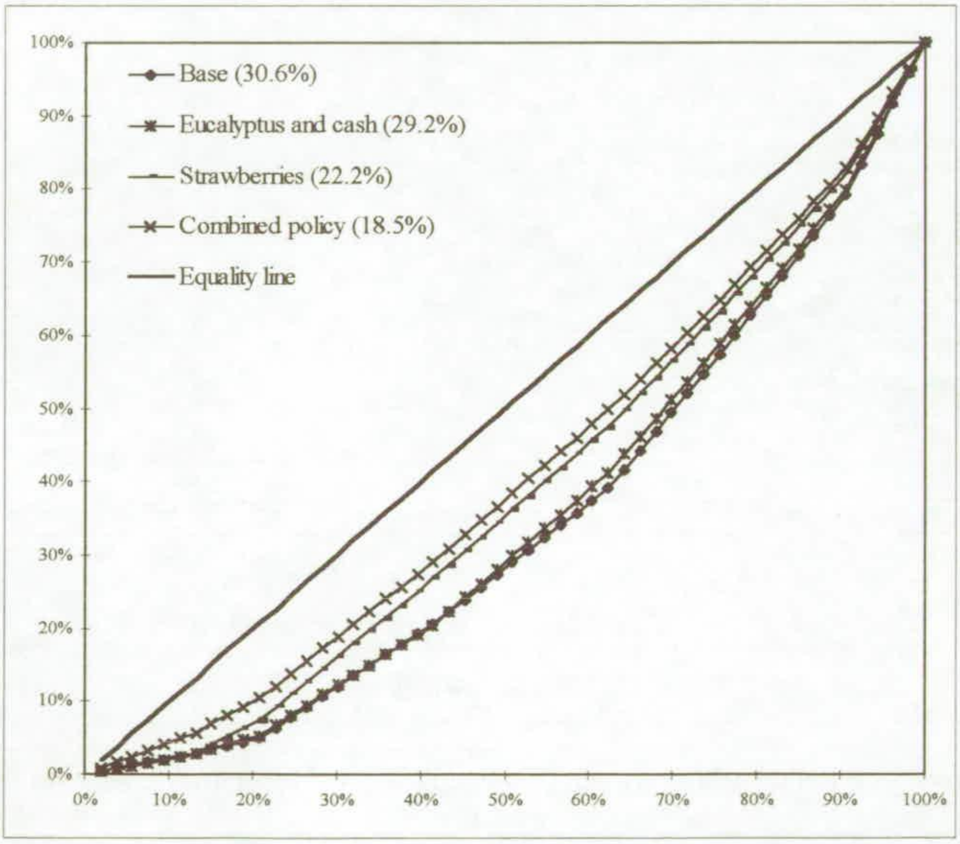

Figure 10.5 Lorenz curves and G coefficients for the base scenario and all income difference minimising scenarios

The high correlation between G and income difference ($R^2 = 75.2\%$) indicated that there was an adequate fit between both values. In fact, when efficient solutions within a policy scenario were compared, a lower income difference was associated with a lower G, except for the scenarios with the highest G for both the strawberry and the combined policies. In these cases income difference did underestimate the G coefficient (Figure 10.6). But when all solutions were compared this relationship was not always true, especially if the values for income difference were high. Thus the results suggest that income difference can be used to measure the impact of policies on income distribution. Nevertheless it must be kept in mind that the minimisation of income difference does not imply that the solution with the lowest G (i.e. the best income distribution) has been found. This can only be achieved if the model is optimised through the minimisation of the Gini coefficent. A way of modelling such an approach is still required.

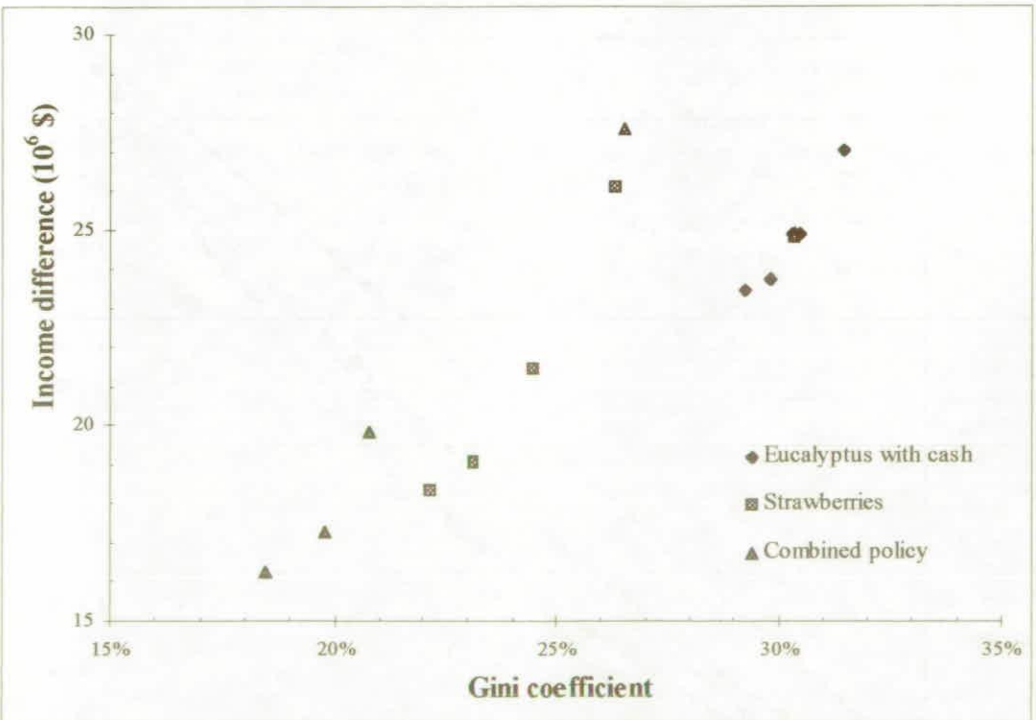

Figure 10.6 Relationship between Gini coefficient and income difference for all scenarios

10.7 EFFICIENT SOLUTIONS AND FARM GROSS MARGIN

At the farm level, each policy scenario had a different effect on GM, depending on the optimisation criterion. When the GM efficient solutions were computed, large changes were observed on all farms except on farm D (Figure 10.7). As expected the largest increase in GM is produced by the combined policy, except for farms B and F, where the introduction of strawberries produces a larger increase in GM.

Due to the specification of minimum income restraints, the minimisation of soil loss produced no impact on GM and all farms maintained their income level, except, as said before, FS-H which showed a small improvement.

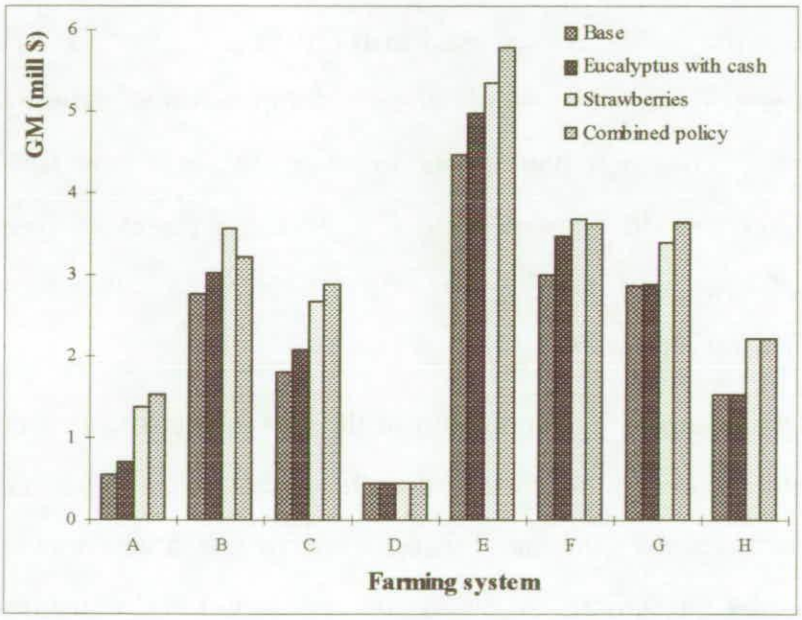

Figure 10.7 Farm level GMs under the base model and the three policy scenarios when GM was maximised

As expected, when the income difference was minimised (Figure 10.8) farms below average micro-regional income (farms A, C, D, and H) increased their GM, while farms above average were unaffected by the policies. The combined policy produced the highest increase in all farms.

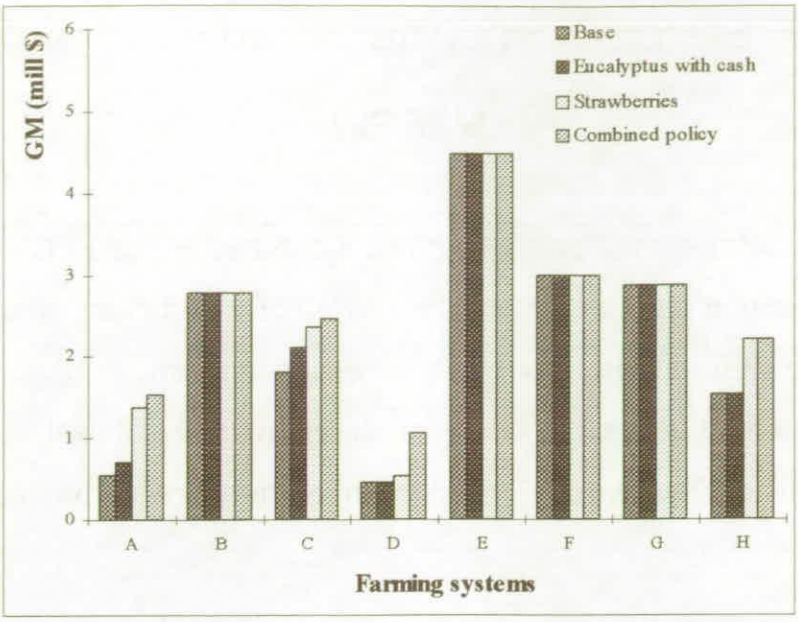

Figure 10.8 Farm level GMs under the base model and the three policy scenarios when income difference between farms was minimised

The L_1 compromise scenario increased also only the GM of farms with below average income (Figure 10.9), while the L_∞ solution showed improvements in farms B, F, and G which had above average GMs (Figure 10.10). The L_∞ solution also showed different ranking for the three policies. Specifically the introduction of strawberries in FS-B is not as good as for other farms, while in farm G it is the best alternative.

These results show how the introduction of the new objective function and of the income restraints changed the impact of each policy on the farms' GM. Farm E, which showed under the GM maximising scenario the largest increases in GM, was unaffected by the policies when any other solution was considered. Further, other farms with high incomes were less affected by each of the policies, while farms with low income could now benefit from the introduction of the development policies.

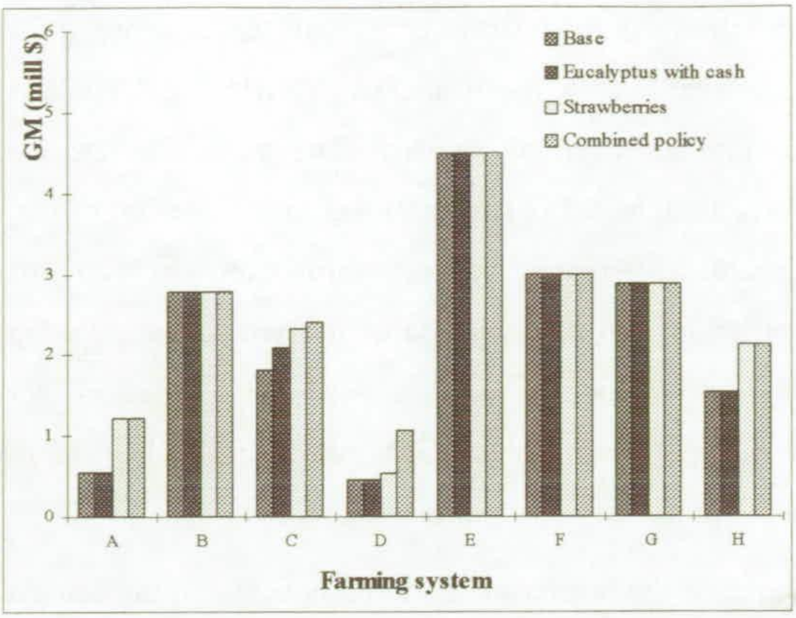

Figure 10.9 Farm level GMs under the base model and the three policy scenarios for the L_1 compromise solutions

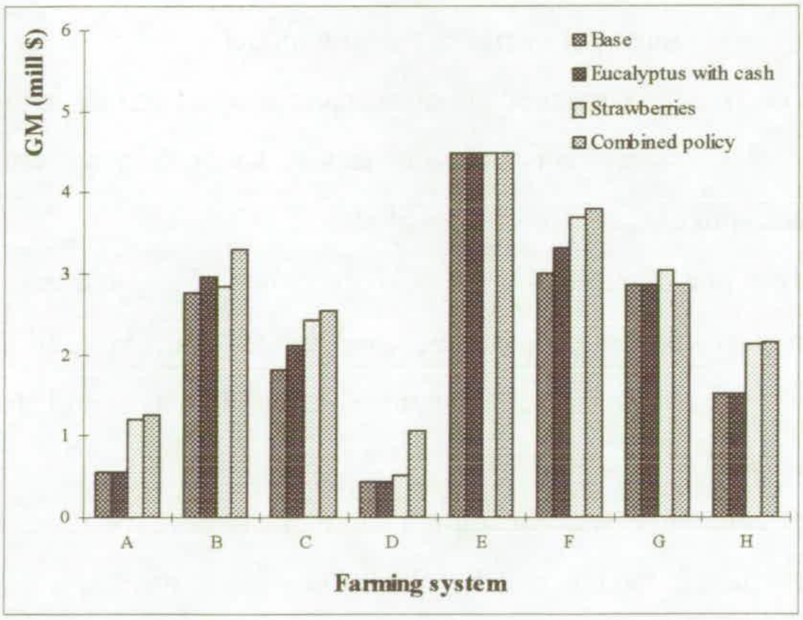

Figure 10.10 Farm level GMs under the base model and the three policy scenarios for the L_∞ compromise solutions

10.8 SUMMARY

In this chapter three policies were evaluated using an extended micro-regional model. The policies were the introduction of eucalyptus with yearly cash payments; the introduction of strawberries; and a combined policy, in which eucalyptus with yearly cash payments, strawberries, and phalaris and clover pastures were introduced simultaneously. The main differences between the extended and the base MRM (Chapter 9) were the inclusion of the objective of minimising income differences between farms, the exclusion of risk as an optimisation criterion, and the inclusion of restrictions on the adoption of each policy and the availability of labour. Again five efficient solutions were computed for each policy: maximum GM, minimum soil loss, minimum income difference, and both L_1 and L_∞ compromise solutions.

The measurement of the impact of the three policies on the achievement of the three objectives leads to the following observations:

i. As expected the eucalyptus and the strawberry policies had a lesser impact on GM improvement and soil loss reduction using the extended model when compared to the same policy run of the base model.
ii. On the contrary the combined policy scenario showed further improvement for GM and soil loss and was therefore clearly better than the introduction of eucalyptus with cash or strawberries alone.
iii. The introduction of eucalyptus did not reduce the soil loss to a large extent, as it mainly replaced permanent pastures, which already show low soil losses.
iv. Even under the expanded model the introduction of phalaris and clover pastures was not a good alternative, except for FS-D.
v. The best alternative was the introduction of all three policies, targeting its implementation in the FSs which make the best use of them.
vi. When only the extreme efficient solutions were considered, the eucalyptus policy showed the lowest trade-offs between objectives; therefore the cost of improving one objective in terms of the other objective would be lowest for this policy.
vii. The best compromise solutions within a discrete setting were, depending on the measurement criteria used, the L_1 and the L_∞ compromise solutions for the combined policy.

viii. The minimisation of income difference can be used to improve income distribution within an MCDM model. The results show that in addition to reducing GM differences between farms, the Gini coefficient of the efficient solutions was also improved.

ix. The simultaneous consideration of three criteria determined that a major problem was the analysis of trade-off and therefore of the degree of conflict between objectives. The inclusion of related objectives (income difference and GM) could be an additional reason for this difficulty.

The final chapter will summarise the results and conclusions of this thesis and highlight areas in which according to these results further research is required.

11. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

11.1 INTRODUCTION

This thesis has tried to gain new insights into the problem of agricultural sustainability. Having defined it, a methodological framework for the analysis of the sustainability of peasant farming systems is developed; this framework is later applied to measure the impact of local development policies on such agriculture in the coastal dryland of Central Chile. This chapter summarises the main findings of the research work in the light of the specific objectives of this thesis set out in Chapter 1. Finally the practical implications of the results are discussed and recommendations for future research are made.

11.2 OBSERVATIONS ON METHODOLOGY

11.2.1 THE DEVELOPMENT OF A FRAMEWORK TO ANALYSE THE SUSTAINABILITY OF PEASANT FARMING SYSTEMS

The main objective of this thesis is to develop a framework to analyse the sustainability of peasant farming systems. To do that, the first problem is to contend with the lack of a widely accepted definition of it (Chapter 2), which has led to an extensive use of the concept, frequently without any attempt at measuring it. It is not rare to find researchers who design production systems which, according to them, are sustainable because their environmental impact is lower than that of the current situation. Their total disregard of the economic and social aspects of farming systems can therefore lead to the prescription of systems which may be environmentally sound, but which are not necessarily sustainable. Thus any study related to sustainability has to resolve at the outset what is meant by the concept itself; otherwise there is no measure to judge if the system has improved.

The introduction of the concept of sustainability to agriculture is derived from the recognition of the conflicts which are intrinsic to the process of agricultural development. Two types of conflicts can be identified: first those that involve the economic, social, and environmental aspects of agriculture, and secondly those that exist between different decisions makers, specifically farmers and policy makers. Behind these conflicts is the issue of intergenerational equity, an aspect frequently stressed as being central to the problem.

Finally, it was concluded that the farming system has to be considered as the basic unit of analysis, because sustainability is related to resource use, and the decisions on how to use the resources are taken at this level. Nevertheless, for the policy maker it is not a single farm's problem and his analysis has to consider a larger unit within which normally policies are designed and implemented. Such an area has been defined as a micro-region. But the improvement of the sustainability of individual farming systems does not guarantee that a similar improvement is observed in the micro-region in which the FS is located, mainly because the various systems differ both in their production patterns and available resources, and can therefore respond differently to external stimuli. Therefore the analysis of sustainability has to consider not only the FS and the micro-region, but also the FS's heterogeneity within the micro-region.

11.2.2 THE INCLUSION OF SUSTAINABILITY ISSUES INTO AGRICULTURAL DECISION MAKING MODELS

The main challenge for including sustainability into agricultural decision models is how can it be modelled and optimised. This thesis exploits the strengths of multi-criteria decision making (MCDM) models to provide the framework within which important factors judged to determine the sustainability of an agricultural system are used as objectives to be optimised. As discussed in Chapter 3 economic and environmental criteria have frequently been used to evaluate farm plans, development alternatives, and policies; gross margin and net present value are used most commonly for economic evaluation, and soil loss, fertiliser use or leaching, and water use are the most common criteria for environmental assessment. Unfortunately, little effort has been devoted to the inclusion of objectives of social nature into such models; therefore, one of the challenges in using MCDM models is the definition, specification, and quantification of alternative objective functions to evaluate different dimensions related with sustainability.

Once adequate evaluation criteria have been defined and quantified, they have to be combined, or considered simultaneously, to obtain a single measure of a system's sustainability.

11.2.3 A METHODOLOGY TO MEASURE SUSTAINABILITY USING MCDM MODELS

With the foregoing background this thesis proposes a method to measure the impact of local development policies on the sustainability of peasant farming systems in the coastal dryland of Chile's VIth Region using MCDM models (Chapter 4). The aim is to determine which policy contributes most to the improvement of sustainability. Thus the essential stages are the definition of the local determinants of sustainability and how will they be measured (that is which indicators to use) and the identification and typification of various farming systems in the micro-region under study. Multivariate statistical analysis is used to create a typology of farming systems and for each area and for each of these farming systems MCDM models are constructed and optimised according to the sustainability criteria initially defined. An important result is the determination of a policy (or policies) which has (have) the 'best' overall effect on the micro-region and can therefore be recommended for implementation.

An additional feature of such an approach is that it avoids dealing with time, and therefore its data requirements are considerably lower. Sustainability is a problem of intergenerational equity, and therefore inter-temporal preferences should be considered. The problem is that the elicitation of such preferences from the actors would involve a subjective judgement. To avoid such problem the proposed method assumes that an improvement of the positive and a reduction of the negative impact of agriculture will benefit equally present and future generations.

Undoubtedly, although this methodology was only tested in one particular micro-region, its general applicability can be made extensive to areas in which a similar problem is to be analysed. The results show that it is possible to analyse the farming systems sustainability through the use of MCDM models.

11.3 RESEARCH FINDINGS

The contributions made by this thesis can be found in the process of constructing the MCDM models, in their use, and in the interpretation of the results. As discussed in the previous section, the main features of the models are their multiple objectives and their bi-level structure. Only after the optimisation criteria (Chapter 7) and the relevant FSs (Chapter 6) have been defined can the operational models be constructed (Chapter 8). These are then used to determine the impact of certain policies and the trade-offs between objectives (Chapters 9 and 10).

11.3.1 SELECTION OF CRITERIA FOR THE MEASUREMENT OF SUSTAINABILITY

The selection of economic criteria and their inclusion into the MCDM models is a straightforward procedure. Gross margin was chosen as the most suitable measurement criteria for profit of peasant FSs. Risk is estimated as the variation of this gross margin over a period of time, and computed using the target-MOTAD method (Tauer, 1983).

The selection of the environmental criterion is strictly dependent upon local circumstances. Based on some studies of soil degradation and the observation of the area under study, it was determined that accelerated soil loss is the most important threat to the environment posed by the area's agriculture. The Universal Soil Loss Equation (USLE) was used to estimate potential soil loss.

Finally the issue of social acceptability of various policies was analysed using the criterion of income distribution among different farm groups. Two arguments were behind the selection of this criterion. First a policy of the Chilean government is to achieve growth with equity, which means that the benefits of the economic growth should be fairly distributed amongst the whole population. Secondly it is expected that development policies aimed at improving the living standard of poorer sectors of the population are more acceptable than those improving the conditions of better-off farmers[1]. Thus it is assumed that, for both the policy maker and the farmer, acceptable policies are those which reduce differences in income, provided they do not reduce the actual income of any farmer. Unfortunately it was not possible to specify the minimisation of Gini coefficient, the most common measure of income distribution (Dovring, 1991), as an objective of the micro-regional model. Instead the model minimised the sum of the negative deviations between the expected income and the average income, using this value as an estimator of distribution.

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[1] The distinction between poorer and better-off farmers is relative, as all peasant farmers are poor according to INDAP's definition.

11.3.2 A TYPOLOGY OF PEASANT FARMING SYSTEMS IN THE COASTAL DRYLAND OF CENTRAL CHILE

In Section 11.2.3 it was defined that models for different FS would be required. The problem is that within a micro-region a large number of farms can be found, each different from the other. Therefore it is necessary to construct a typology which reduces this variation considering the similarities between the FSs. The typification process used in this thesis, consisted of six stages. During the first stage the specific context for typification was determined. As the objective was to analyse the response of different FSs to development policies, it was hypothesised that such response would depend on the available resources. Therefore the construction of a suitable typology had to consider variables related to labour, land and capital. During the second stage it was determined that the following information should be used to construct such a typology:

i. Labour availability: according to gender and months spent working on- and off-farm
ii. Land availability: according to source (own, sharecropped, etc.), use (crops, pasture, orchards, etc.), and use capability (arable, irrigated, non-agricultural, etc.)
iii. Capital: especially related to loans, savings and number of livestock (by species and type)

This information was then collected during the third stage from secondary sources for a random sample of 67 farms in the micro-region.

The fourth stage considered the selection of variables, the application of factor analysis on this reduced set of variables, and the use of cluster analysis for the construction of groups of similar farms. First using the criteria of relevance, variance, correlation, and absence of missing data the variable set was reduced from 33 to 11 variables. These variables were then used to construct seven factors through Principal Component Analysis. Such reduction from 33 variables to seven factors was seen as highly convenient as it was expected they would simplify the interpretation of the results and create a typology with a small number of FSs. The later is important as the aim of the typification process is to reduce the number of farms required to represent the whole micro-region. Using these seven factors five clusters were defined. Labour variables provided the major source of differences between clusters. One of the major difficulties encountered in multivariate analysis was the definition of the 'optimal' number of factors and clusters. Although rules have been developed to define the number of factors to retain, they produce different results and therefore a subjective decision is still involved in the selection of the 'optimal' number of factors. In cluster analysis most decision rules are based on a subjective analysis of the clustering process. In this thesis a set of rules was used for both factor and cluster analysis and the results of each compared to select the appropriate number of factors or clusters.

During the fifth stage the FS typology was defined by cross-tabulating the clusters with the farms' productive orientation. The resulting typology was therefore a combination of a new classification (clusters) based on continuous variables (available resources) and an existing classification (productive orientations) based on discrete variables (types of crops and livestock). Such a cross-tabulation gives equal weight to both classifications and makes use of existing and new knowledge about the farms and their households.

The sixth and final stage is probably the most difficult one, as it involves the validation of the typology. Common methods used to validate typologies are to compare the results with other relevant classifications and to analyse the suitability of the classification for the particular research project. In this thesis first the distribution of Counties and productive orientations along clusters was analysed. It was seen that the distribution of both Counties and productive orientations was not random and that therefore some underlying structure had been recognised, as none of these variables was considered in cluster analysis. Next and may be more important, the representative farms chosen from each FS type for in-depth survey did show large differences between them. These differences where related to cropping pattern, to resource availability, and to location within the micro-region.

As a result the models represented a variety of FSs and therefore significant differences in their response to the policies are expected. Finally, the optimisation of the MRMs showed that the response of each FSs to a given policy was in fact different; therefore the typology had been able to select substantially different farms, at least from the point of view of this research.

11.3.3 THE COLLECTION OF DATA FOR THE CONSTRUCTION OF THE FARMING SYSTEM MODELS

Next the representative farms were subject to in-depth surveying to collect the necessary data to construct the models (Section 8.2). Representative farms were defined as those which minimised the sum of the squared standardised differences between each farm and its FS average. The survey method used consisted of the sequential application of three questionnaires, each applied some two weeks after the previous one. The first questionnaire identified the farm's resources and activities. This information was used to construct a prototype FS model, showing the activities and constraints observed in all FSs. The next questionnaire characterised the production processes and assisted in the construction of FSMs in which the specific activities and constraints for each FS were specified. The last questionnaire collected data on inputs and outputs which was used to construct the operational FSMs. Such a stepwise surveying method was useful from two points of view. First, the modelling process was matched by the process of data collection, as information was collected when required and the data requirements were in turn defined by the model itself. The questionnaires were constructed according to the data requirements and therefore the collection of unnecessary information was minimised. In any case it was always possible to collect missing information in a next visit. Second, it was perceived that the quality of the information improved when collected over multiple visits. The reasons which explain this are that the farmer showed a progressive confidence towards the enumerator and that the enumerator gained a better comprehension of the FS and its limitations.

11.3.4 THE CONSTRUCTION OF THE FARMING SYSTEM MODELS

During the construction of the FSMs insights were gained in two aspects: the understanding of the total system and areas where knowledge is lacking. Understanding of the FSs was improved in aspects related to cash availability as an important restriction, livestock as a source of cash, flexibility of certain enterprises, and the reasons for sharecropping.

The principal sources of cash for the region's farmers are the sale of wheat and chickpeas during summer, and to a lesser extent the sale of one year old steers and of four to five month old lambs during late spring. This determines that during winter and early spring frequently lack of cash is observed, which affects necessarily the FS's expenses as there is no access to alternative sources of capital. In this sense INDAP's loan for the purchase of seeds and fertilisers plays a very important role, as it relaxes the working capital restrictions faced by these systems.

From the modelling point of view, it is of primary importance that these peasant FSMs include cash flow constraints and cash transfer activities. Nevertheless these restraints are not so important when the FSs have enterprises with a greater flexibility in the sale of outputs. It was seen that farmers who had cattle, which can be sold at any time of the year, could face greater capital restrictions. Specifically their working capital could be substantially reduced with a small impact on the farm's gross margin. Therefore it is reasonable to believe that development alternatives which generate income during winter have a good opportunity to be successful.

Further it was realised that sharecropping, an important practice in this area, was a result of an unbalanced distribution of land and labour, but not capital. In other words it is not farmers with capital which take-in land for cropping, but farmers who have an excess of labour and provide it to farmers who require it. Again INDAP's loan provides these farmers with the needed capital to work their land or use their labour.

Throughout model construction areas in which the lack of knowledge was important were found. These were related not only with specific coefficients but also with the specification of the model and its objectives[2]. Nevertheless, despite the problems of lack of information, it was possible to build the FS models within the methodological framework, making when required a series of assumptions and simplifications.

From the point of view of the farmer's objectives it was assumed that these are maximisation of profit and minimisation of risk, and that gross margin and target-MOTAD are the best way of operationalising them within an MCDM model. Further it was defined that the objectives of the micro-regional model were equal to the weighted addition of the FS models' objectives. This assumes that any household's farm plan does not affect the objective function of another household nor the contribution of third parties to the micro-regional gross margin, risk, or soil loss.

From the point of view of activities and restraints the farming system model had the following features. First both labour and cash flow were represented by monthly activities. Although it was possible to transfer cash between months, it was not possible to transfer labour between months. Second, only when strictly necessary yearly activities were specified for certain crops (e.g. strawberries and trees), whenever possible various years were represented by a single activity (e.g. growing eucalyptus or phalaris). Third data restrictions on forage consumption and output determined that only seasonal dry matter intake could be modelled. This meant that both forage quality and animal growth could not be included as decision variables.

Finally the estimation and validation of some coefficients was also troublesome, especially of soil loss, livestock activities, working capital, and risk coefficients. Although accelerated soil loss is an important problem in the micro-region, little is known about the magnitude of the problem. Nevertheless as the optimal solu-

[2] In this Section only the practical problems produced by lack of information will be discussed. The areas for future research are analysed in Section 11.4.

tion is unaffected by the scale of the objective function, an under or overestimation of an USLE coefficient for all activities does not affect the results. In other words for the purpose of this thesis it is far more important to obtain accurate relative soil losses than absolute values. In this sense the soil cover and management factor of the USLE is the most critical, as soil erodability was measured on farm, rain erosivity showed little variation between farms, and field length and slope, as well as soil conservation practices were assumed constant.

Problems with livestock coefficients arose from the lack of record keeping and the absence of a monthly management programme which determines monthly variations in the use of inputs and the generation of outputs. The validation of forage production and intake estimates could only be done by comparing the model's stocking rates with the observed ones. As in some farms the estimated forage output was not enough to feed the existing cattle the productivity of its natural pastures was increased.

During the calibration and the validation stages of the work it was realised that cash constraints were effectively binding, and therefore important in a model of a peasant FS. Both working capital and households' expenses were calculated from survey data as they could not be obtained directly from the farmers. It was assumed that working capital was equal to the amount of money required to carry out the observed farm plan and to cover the household's expenses without incurring in negative monthly cash balances, while households' expenses were one twelfth of the yearly farm gross margin .

A problem in the analysis of risk was to get the price series over the period of ten years of all relevant inputs and outputs (Section 8.8). To deal with the problem of missing data, two approaches were taken. First, if all the information on inputs or outputs for a certain activity was missing, then variation was artificially generated by weighting each activities expected gross margin with a factor representing the variation in the farm's gross margin. Otherwise, that activity would not be included in the optimal solution when risk is minimised, as it does not contribute towards the target income. Second, if the price series of a less important input (output) was missing, then the observed price of that input (output) was used as a constant value in the computation of the series of expected GMs. Otherwise the contribution of that activity towards the target income would have been overestimated (underestimated).

Finally, it was seen that these models could reach large dimensions. The problem of size was not so much related with the optimisation of the problem, as the available hardware and software could easily solve the micro-regional model (up to 554 rows; 765 variables; and 6,429 non-zero coefficients), but with the interpretation of the results, as the addition of variables or rows necessarily increases the amount of information generated through the optimisation process. As the micro-regional model was made by the aggregation of eight farming system models any increase in the size of one farming system model could represent a far larger size increase of the micro-regional model. Therefore throughout model construction a compromise between size and relevance of the results was sought, bearing always in mind the data required to include those variables or constraints and its availability.

11.3.5 CALIBRATION AND VALIDATION OF THE FARMING SYSTEM MODELS

One of the most important steps in model construction is its calibration and validation (Section 8.11). During calibration the model's performance is improved by adjusting some of its coefficients. Early results showed that the farmer showed no preference of using flat over hilly land (although the later involves more labour and less output), that large forage surpluses existed, and that own capital was used for the purchase of seeds and fertilisers. As these results were not rational or were in contradiction with observed values labour use and output coefficients for hilly and mountainous land, pasture productivity, and available working capital were modified to achieve a better representation of the observed reality.

These calibrated models were then validated by testing if the observed farm plan was feasible (feasibility experiment) under each particular farming system model and by comparing the optimal farm plan with the observed plan (prediction experiment). The feasibility experiment showed that the major inconsistencies were related to rotational constraints and weaner ties. The cause of this was respectively the irregular size of the plots and the small size of the herd or the flock. Although no measure of fit could be used for the prediction experiment, the results suggested that the models were suitable for predicting farmers' behaviour.

11.3.6 THE CONSTRUCTION OF THE MICRO-REGIONAL MODELS

Through simple addition of the eight FSMs a base and an extended micro-regional model were constructed. The base micro-regional model assumed that its restraints and objective functions were given by the summation of the FS's restraints and objective functions (Section 9.2). This model was used to measure the impact of four development policies: the introduction of eucalyptus with a single payment after 20 years (harvest of the trees); the introduction of eucalyptus with yearly payments; the introduction of strawberries; and the introduction of phalaris and clover pastures. These crops were chosen for evaluation as different agencies dealing with agricultural development have been recommending them for this area.

The extended micro-regional model was also constructed by adding the FSMs, but in this case new restraints and objective functions were considered (Section 10.2) to overcome some of the problems seen when the base micro-regional model was optimised. First, the results of the base micro-regional model showed very high demand for labour, which would probably not be satisfied by current supply. Therefore the micro-regional labour availability was restricted for each month. Second, maximum areas for each of the new crops were defined to avoid an unrestricted adoption of the policies. Third, the risk objective was dropped, because it did not conflict with the GM objective (Section 11.3.8) and because the way price series for some outputs had been estimated could have introduced bias into the results. Finally, the objective of minimising differences in farm income was added . It was seen that the development policies had a very different impact on each FS, confirming the importance of including the objective of minimising income differences between FSs (Section 7.3.4). This extended model was then used to evaluate three policies: the introduction of eucalyptus with cash payments, the introduction of strawberries, and the combined introduction of eucalyptus with cash payments, strawberries and artificial phalaris and clover pastures. The alternative of introducing only eucalyptus and only artificial pastures were not considered as the base model showed they were dominated by other policies.

For each micro-regional model the impact of the policies was measured by optimising each objective on its own and by computing two compromise solutions (Section 7.6.2). The first of them (L_1) represents the solution closest to the *ideal* in terms of the total geometric distance between both. The second compromise solution (L_∞) represents the solution for which the maximum distance between any objective and the ideal has been minimised. The solutions for each combination of policy scenario and optimisation criterion were then used to compute the trade-offs between objectives.

11.3.7 THE IMPACT OF THE DEVELOPMENT POLICIES AT THE MICRO-REGIONAL LEVEL

When the base micro-regional model was solved (Chapter 9) by maximising GM both the introduction of eucalyptus (with and without yearly cash payments) and strawberries improved the criteria of GM, risk and soil loss, while the establishment of phalaris and clover pastures had almost no effect on any of these three criteria. Compared to the base solution, the highest improvements in gross margin are achieved when strawberries are introduced and evaluated using the criterion of GM (34.1%), risk (34.21%), L_1 (29.7%) and L_∞ (20.0%). The highest reduction of soil loss (80.0%) is observed under the eucalyptus with cash-minimum soil loss scenario, while the lowest reduction was observed when eucalyptuses or strawberries were planted and evaluated under a GM criterion (2.8% and 8.0% respectively). Therefore from the farmer's point of view (assuming that he is a GM maximiser) the best solution is strawberries followed by eucalyptus with cash. From an environmental point of view the best solution is eucalyptus with cash followed by strawberries. The existence of such a conflict between economic and environmental objective is a valuable argument for the use of compromise solutions, in which solutions lying between these extreme solutions (i.e. obtained by maximising GM or minimising soil loss) are sought. From this point of view both compromise solutions for the policy of introducing strawberries provided the best alternatives.

As expected the specification of limits to the adoption of policies in the extended model (Chapter 10) determined that the policies had a lower impact on gross margin improvement and specially soil loss reduction compared to the same policy under the base model[3]. The implementation of the combined policy (i.e. eucalyptus with cash, strawberries, and artificial pastures) was clearly superior to the introduction of eucalyptus with cash or strawberries alone as both gross margin and soil loss were further improved. Compared to the base solution the gross margin increased by 37.0% and soil loss fell by 19.7% when gross margin was maximised. This increase was produced by the introduction of maximum areas of strawberries and eucalyptus (although for the later only in three out of five scenarios), while the establishment of pastures had little influence, as only a small area was sown.

The combined policy achieved even under the soil loss minimising scenario a large reduction in soil loss (81.5%) with almost no effect on gross margin (0.3% increase). The other two policies, introduction of strawberries and of eucalyptus with cash payments, also increased gross margin and reduced soil loss, but in a

[3] The effect of specifying a minimum income level for each FS and an objective function which minimises the income differences between farms will be discussed in the next Section.

lesser amount compared to the introduction of all policies, due to the limits specified for the adoption of these policies.

When all 15 combinations of policy and optimisation criteria were compared it was seen that the five solutions for the combined policy and the strawberries-GM scenario were not dominated by any other solution, thus defining the subset of efficient solutions. From this subset of efficient solutions, again both L_1 and L_∞ solutions provided the best alternatives if a compromise between the three objective functions is sought.

11.3.8 The impact of the development policies on the farming systems

The solutions for the base model showed that the farming system's response to each of the policies was different. Under a GM maximising scenario, eucalyptus were adopted by farms A and B; eucalyptus with cash by farms A, B, C and E; and strawberries by all farms. In the latter case farm A showed the highest increase in gross margin (148.8%) while farm D showed the lowest increase (18.7%). When soil loss was minimised, all farms adopted any of the three policies. For the specific case of strawberries, the reduction in soil loss varied between 62.3% (farm F) and 100.0% (farm H), while gross margin changed between 2.0% (farm H) and -57.4% (farm D). Thus it is clear that each farm responds differently to a given policy, and that this variability has to be considered in policy evaluation.

The specification of minimum income levels in the extended micro-regional model reduced this problem, as no farm could worsen its income. Despite these minimum income restraints all farms reduced their soil loss when any policy was evaluated under the soil loss minimising scenario (farm H even increased its gross margin). Further the compromise solutions achieved in most scenarios a large reduction of soil loss in each FS with large increases of gross margin in farms below average income

11.3.9 THE IMPACT OF THE DEVELOPMENT POLICIES ON THE FARMING SYSTEM'S INCOME DISTRIBUTION

The sum of the negative deviation of each farm's gross margin from the average gross margin was used as the estimator of income distribution, as the Gini coefficient, one of the most frequently used measures of inequality, could not be calculated and optimised within a mathematical programme. The minimisation of this estimator allowed to reduce gross margin differences between farms and to compute the Gini coefficient from its results (Section 10.5). It was concluded that the minimisation of income differences was an appropriate surrogate of the minimisation of the Gini coefficient, and therefore suitable for improving the income distribution between farms.

Under the base scenario Gini coefficient equalled 30.6%, while for the other policy scenarios its value ranged from 18.5% to 31.5%. It was seen that income distribution was not improved when soil loss was minimised for any policy or when eucalyptus with cash were introduced. But when strawberries or the combined policy were introduced under any scenario (except of course minimisation of soil loss) the distribution was improved. Therefore even assuming that the farmer maximises GM, the introduction of these policies will have a beneficial effect on the distribution of income. Nevertheless if the policy is introduced under an L_1, an L_∞ or an income minimising scenario, their effect will be even larger.

11.3.10 THE TRADE-OFFS BETWEEN THE OBJECTIVE FUNCTIONS OF THE MICRO-REGIONAL MODEL

It was seen in the base model that most of the times an increase in gross margin was associated to a reduction of risk. Only the minimisation of risk produced reductions in gross margin, and therefore some conflict between both objectives. Nevertheless as in this case both values showed only minor changes it was concluded that there is no trade-off between both; therefore the risk objective was not considered in further analysis and dropped from the extended micro-regional model. This result contradicts other studies which show a trade-off between gross margin and risk. The main reason explaining this is that as risk was measured as the deviation from a target income the 'best' farm plan is the one which comes as close to that income in as many years as possible, and not the one which shows the lowest variations in income, which is the case when MOTAD is used.

Next the trade-off between gross margin and soil loss was analysed for both the base and the extended micro-regional model. For the base model and under any of the five policies a clear conflict between the objectives was observed (Section 9.5). For each policy it was seen that an increase in gross margin was associated to an increase in soil erosion. In other words the cost of reducing soil loss (in terms of foregone gross margin) increases as the level of soil loss decreases. This conflict was also observed for the extended micro-regional model, although the specification of the third objective made the interpretation of results more difficult. Therefore it is concluded that in both models and for any policy scenario a reduction in soil loss necessarily implies a reduction of the micro-region's gross margin. Further the highest trade-off was observed between each extreme solution (i.e. maximum GM and minimum soil loss) and the compromise solution closest to it (i.e. L_1 and L_∞ respectively). Thus any solution located between both compromise solutions is seen as a good alternative from the point of view of both gross margin and soil loss.

Next the relationship between income differences, farm gross margin, and soil loss was analysed. It was seen that higher gross margins were associated to higher income differences and lower income differences with lower gross margin. In a similar way reducing (increasing) income differences implied an increase (reduction) of soil loss. In other words the three objectives were conflicting. Such a situation makes the analysis of the trade-offs difficult, because both the L_1 and the L_∞ compromise solutions are not located on a 'normal' convex or concave trade-off curve. In fact, the five efficient solutions belong to a three dimensional convex or concave surface and plotting them in a two-dimensional space does not help to analyse the results. Further as the number of efficient solutions is reduced a three dimensional graph is also of little use. This is an important disadvantage of compromise programming, compared to other MCDM methods which can find larger efficient sets, as for example multi-objective programming.

11.4 PRACTICAL IMPLICATIONS AND SUGGESTED AREAS FOR FUTURE RESEARCH

From the point of view of the application of the methodology for peasant farmers in the coastal dryland of Chile's VIth Region, a set of important implications were drawn.

First it is shown that under the present scenario a reduction of soil loss can only be achieved if gross margin is reduced. This is especially relevant considering that the farms' gross margin has been continuously falling. In fact for these eight farms the GM in 1994 was in real terms 18% to 35% lower than in 1985, mainly because the gross margin of wheat fell 39% to 46% between these years. This also means that there is little chance of reducing the area under wheat, and therefore the area under fallow which is the largest single contributor to soil loss, unless compensatory payments or more profitable crops are introduced. Nevertheless there are alternative practices, like zero-cultivation or contour ploughing, which can reduce soil loss without major impacts on profit. Their feasibility has to be explored from a farming system's perspective as labour and cash requirements may be different from the standard practice.

Second, the introduction of new crops made it feasible to reduce soil loss while improving gross margin. Specifically, the best alternatives are the introduction of strawberries under the base situation and the combined introduction of eucalyptus, strawberries, and a mixed phalaris and clover pasture under a more restricted situation.

Third, although no attempt is made to evaluate the social cost of introducing eucalyptus with yearly cash payments, it is shown that yearly cash payments increase considerably the plantation of trees, as these in advance incomes relax the farm's cash flow restrictions. Therefore the feasibility of this or other similar measures should be further analysed.

Fourth, under the present circumstances there seems to be little scope for the improvement of both cattle and sheep productivity. The results show that the introduction of artificial pastures, probably the best way of improving the forage output of these farms, has no economic advantage and therefore they are not an attractive alternative for these farmers. Further it was perceived that these farmers do not see livestock (and especially sheep) as a commercial enterprise and are therefore not very interested in investing capital into this enterprise. As a result the probability of succeeding in the introduction of changes to these sub-systems is very low.

The previous results, although obtained for a particular micro-region, can also be applied to the other parts of central Chile's coastal dryland, provided that its agro-climatic, social, and economic features are similar to the ones of the micro-region under study. This is probably valid for the counties located East (La Estrella) and South (Lolol, Paredones) of this micro-region.

From the point of view of the policy maker, although the proposed methodology allows to reduce the number of efficient solutions it was not possible to generate a single non dominated solution. Therefore it is still the policy maker's task to choose which of them suits better his objectives and how this will be implemented. If gross margin maximising solution is chosen, no restriction to policy adoption by individual farms should be specified; but if another solution is chosen, such restriction should be specified to achieve the desired results.

Although areas in which research is required have been mentioned elsewhere, the most important of them will be mentioned again. From a methodological point of view, three areas should be mentioned. The first is the definition of the objective functions and their specification, especially risk, and social and environmental objectives. Although the MOTAD-method or any of its variation have been extensively used, no research was found which linked these methods to actual behaviour. It is not clear if this measure of risk is related to how the farmer perceives risk, and therefore if its reduction is in line with a farmer perceiving a reduction in risk.

The second methodological problem is related to labour use, its measure and its opportunity cost. It was seen that labour restraints are important for the farming system. Due to data limitations it was assumed that the opportunity cost of own labour and of leisure was zero. Nevertheless it is clear that a farmer will not spend time to receive a small return, even if he has plenty of idle labour. Therefore the understanding of how the farmer perceives the cost and benefits of his labour has to be improved.

The third problem is related with time. This thesis constructed a single period micro-regional model, assuming that an improvement of all criteria (GM, risk, soil loss, and differences in income) represents an improvement on the micro-region's sustainability. Future changes in the farming systems constituting the micro-region would then further improve these indicators and in the long term satisfy all the conditions which determine that a system is sustainable. Nevertheless there is a large number of possible ways in which such a state can be achieved and this method is not able to select amongst all of them, the one which produces a sustainable system in the most efficient way possible. Undoubtedly then, a model considering a larger time frame and the dynamics of decisions over time (e.g. a dynamic programme model) would be of great value. Unfortunately the large amounts of information required in the construction of such models makes them for the time being a distant possibility. Further no attempt is made to analyse the dynamics of the adoption of the policies, neither within each farming system nor within the micro-region. The rate of uptake of each crop will not only depend on the farmers' economic rationality, but also on social and cultural aspects which could not be specified within an MCDM framework and on issues related to the policies' implementation (e.g. support and promotion).

Substantial research is required in areas related to secondary data validation. It was shown that many input-output coefficients were computed using estimates or values for other countries, and that there was no possibility of validating these data at the micro-regional level. This was considered particularly important for the soil cover and management factors used to estimate soil loss and for pasture production and consumption coefficients. Therefore considerable research is required to improve the understanding of these processes at the local level.

From a methodological point of view it would be of great value to make a similar analysis in a different micro-region and to construct the models for this micro-region using average values instead of real farm data. This would allow to test on one hand the general applicability of the method, and on the other how far could data collection and model construction be simplified. The latter is of extreme importance as a simplification would reduce the time requirements and therefore the costs of such a study.

At last, it is hoped that this thesis did provide a better insight into the question of sustainability and that the results presented for this particular micro-region, if implemented, are at least a step in the 'right direction', this is a long term improvement in the quality of life of the micro-region's peasant farmers.

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APPENDICES

1. FARMING SYSTEM SURVEY QUESTIONNAIRES

1.1 PHASE 1 QUESTIONNAIRE: THE SYSTEM'S RESOURCES

Farm: __________ County: ______________ Date: __________
Productive orientation ___________________ Cluster ____________
Observed enterprises ____

A. LAND

A.1. Sketch of the farm

A.2. Property and source of used land

	Area (ha)	Stability (years of use)
Own		
+ Inherited		
+ Community land		
+ Rented in		
+ Taken in		
+ Other land used		
- Rented out		
- Given out		
- Other lands		
		= Total available land

A.3. Land type

	Area (ha)	
Flat (0- 5%)		
+ Hilly (5-15%)		
+ Mountains (15% or more)		
		= Total available land

A.4. Availability of irrigation

Irrigated ha: _____
Irrigation type : (Canal/pump/....)
Irrigation costs:______

A.5 Land use (this season)

		Area (ha)				Irrigated	Land source[1]
		Total	Flat	Hill	Mount		
Crop:	Wheat						
+ Pasture:	TOTAL						
	Artificial						
	Improved						
	Natural						
Forage crop							
+ Woods	Pine						
	Eucalyptus						
+ Orchards							
+ Vineyard							
+ Vegetable garden							
+ Unproductive							
+ Other uses							
Total available land =							

A.6. Land use (previous season))

		Area (ha)				Irrigated	Land source[2]
		Total	Flat	Hill	Mount		
Crop:	Wheat						
+ Pasture:	TOTAL						
	Artificial						
	Improved						
	Natural						
Forage crop							
+ Woods	Pine						
	Eucalyptus						
+ Orchards							
+ Vineyard							
+ Vegetable garden							
+ Unproductive							
+ Other uses							
Total available land =							

[1] Own, rented, shared
[2] Own, rented, shared

B. LABOUR RESOURCES

B.1. Composition of the household

	Total	Work[3]
Males		
Females		

B.3. Activities by member and calendar month

	Gender	Age	Days[4]	On-farm labour			Off-farm labour	
				Agriculture	House	Unused	Agriculture	Other
Manager								
Partner								
Member 1								
Member 2								
Member 3								
Member 4								
Hired								

C. CAPITAL RESOURCES

C.1. Loan

Source	Loan type

Amount borrowed	Actual debt ($)	Monthly repayments

C.2. Investments

	Type	Current value ($)
Buildings		
Machinery		
Equipment		
Fences		
Other		

C.3. Cash and savings

Available cash ____________________

Savings ____________________

Type of savings ____________________

[3] On or off-farm
[4] Number of days worked per month (average)

C.4. Valuation of inputs and products

	Type	Quantity
Agro-chemicals		
Seeds		
Grains		
Wool		
Forage		
Foodstuff		
etc.		

C.5. Herd composition

Cows	Heifers	Calves	Bulls	Steers	Oxen

Ewes	Rams	Ewe-lambs	Lambs

Does	Bucks	Replacements	Kids

Mares	Stallions	Horses	Foals

1.2 PHASE 2 QUESTIONNAIRE: DESCRIPTION OF THE SUB-SYSTEMS

Farm: ___________ County: _______________ Date: ___________

A. CROPPING SUB-SYSTEM[5]

Crop: _________________

Area (ha)	[6]	Land origin	
Irrigation (ha)		Land type[7]	

Rotation ____

[5] Technical fiches for each crop during the previous season.

[6] Boxes with double borders were filled by the researcher before the questionnaire was applied

[7] Flat, hill or mountain

A.1. Activities

Stage	Activity	Description	Season/month
Pre-sowing	Soil preparation		
	Fertilisation		
Sowing	Fertilisation		
	Sowing		
Maintenance	Fertilisation		
	Irrigation		
	Agro-chemicals		
Harvest	Cutting		
	Threshing		
Post-harvest	Sale		
	Baling		

A.2. Origin of the resources

	Origin
Labour	
Machinery	
Draught power	

A.3. Output use

Product	Use[8]	Month	Quantity
Grains			
Straw			

B. LIVESTOCK SUB-SYSTEM

B.1. Pastures

Pasture type[9]		Area (ha)		Irrigation (ha)	
Land origin		Land type[10]			
Species					
Management					

B.2. Forages and foodstuff

Resource type[11]	Origin[12]	Quantity

[8] Sale, storage, consumption, seeds, etc.
[9] Natural, improved or artificial
[10] Flat, hill or mountain
[11] Forage crop, hay, straw, minerals, vitamins, etc.
[12] Own production, purchase, sharecropping, sale, etc.

B.3. Cattle

Herd size and its changes (last year)

		Cows	Heifers	Calves	Bulls	Steers	Oxen
Herd:	March'95						
	March'94						
Purchase:	Heads						
	Source						
Sale:	Heads						
	Destiny						
Death							
Calving							
Weaning							

Type of breeding [13] ____________ Breeding month ____________

Age of weaning ____________

Health management

Treatment	Season or month

Labour use

Activities	Origin	Season
General Care		
Reproductive management		
Health management		
Feeding		

Output

Product	Destiny	Season
Calves		
Steers		
Culled cows		

B.4 SHEEP

Herd size and its changes (last year)

		Sheep	Rams	Ewe-lambs	Lambs
Herd:	March'95				
	March'94				
Purchase:	Heads				
	Source				
Sale:	Heads				
	Destiny				
Consumption					
Death					
Calving					
Weaning					

Type of breeding ____________ Breeding month ____________

Age of weaning ____________

[13] Natural breeding, , artificial insemination, other

Health management

Treatment	Season or month

Labour use

Activities	Origin	Season
General Care		
Reproductive management		
Health management		
Feeding		

Output

Product	Destiny	Season
Lambs		
Wool		
Culled cows		

B.5. Horses

Herd size and its changes (last year)

		Stallions	Horses	Mares	Foals
Herd:	March'95				
	March'94				
Purchase:	Heads				
	Source				
Sale:	Heads				
	Destiny				
Death					
Calving					
Weaning					

Breeding month ____________ Age of weaning ____________

Health management

Treatment	Season or month

Labour use

Activities	Origin	Season
General Care		
Reproductive management		
Health management		
Feeding		

Output

Product	Destiny	Season

1.3 PHASE 3 QUESTIONNAIRE: PRODUCTIVE ACTIVITIES

Farm: ___________ County: ______________ Date: ___________

A. PRODUCTIVE ACTIVITIES FOR EACH CROP

Crop		Land origin	
Irrigation		Land type	

Rotation ____

A.1. Soil preparation

Activity				
Month				
MD/ha				
MH/ha				
AD/ha				

(MD: Man days; MH: Machinery hours; AD: Animal days)

Costs: Labour _____________$/ha Machinery _____________$/ha
Animals _____________$/ha Other _____________$/ha
Specify _____________

A.2. Sowing

Activity	Sowing	Fertilising		
Month				
Inputs	Seeds			
Dose				
Cost				
MD/ha				
MH/ha				
AD/ha				

Costs: Labour _____________$/ha Machinery _____________$/ha
Animals _____________$/ha Other _____________$/ha
Other costs _____________$/ha Specify _____________
Seed type: __own ___ordinary ___selected ___certified ___other

A.3. Maintenance

Activity	Fertilising			
Month				
Inputs				
Dose				
Costs				
MD/ha				
MH/ha				
AD/ha				

Does soil analysis before fertilising YES/NO
Why doesn't he fertilise _____________
Costs : Labour _____________$/ha Machinery _____________$/ha
Animals _____________$/ha Other _____________$/ha

A.4. Harvest

Activity				
Month				
Input				
Dose				
Cost				
MD/ha				
MH/ha				
AD/ha				

Productivity ____________ kg/ha
Total production ___________ kg
Shared ____________ kg
Other harvest costs ___________ $/ha
Costs Labour ____________ $/ha
Machinery ___________ $/ha
Animals ____________ $/ha
Other ___________ $/ha
Consumption ____________ kg
Sale ___________ kg
Seeds ____________ kg
Other ___________ kg
Sale price ____________ $/kg
Sale month ___________
Buyer ____________
Marketing & sale ___________ MD
Sale costs ____________

A.5. Post-harvest

Activity				
Month				
Input				
Dose				
Cost				
MD/ha				
MH/ha				
AD/ha				

Costs: Labour ____________ $/ha
Machinery ____________ $/ha
Animals ____________ $/ha
Other ____________ $/ha
Other post-harvest ____________ $/ha
Destination: Consumption ____________
Sale ____________
Sharecropper ____________
Other ____________
Sale price ____________
Month of sale ____________
Buyer ____________
Marketing & sale ____________ MD
Sale costs ____________

B. LIVESTOCK SUB-SYSTEM

B.1. Pastures

Type		Area (ha		Irrigation(ha)	
Land origin		Land type			

Activity				
Month				
Input				
Dose				
Cost				
MD/ha				
MH/ha				
AD/ha				

Costs: Labour ______________ $/ha Machinery ______________ $/ha
Animals ______________ $/ha Other ______________ $/ha
Other ______________ $ Specify ______________

B.2. Forages and foodstuff

Type				
Source				
Month of use				
Species fed with				
Quantity		kg	kg	kg
Total cost		$	$	$
Labour	Purchase	MD	MD	MD
	Feeding	MD	MD	MD

Other costs: ________________ $ Specify : ______________________

B.3. Cattle sub-system

Output (last year)

	Cows	Heifers	Calves	Bulls	Steers	Oxen
Herd (March '95)						
(March '94)						
Sale (n)						
Sale price						
Month of sale						
Purchase (n)						
Purchase price						
Purchase month						
Peso						
Month						
Deaths						
Births						
Weaning						

Reproductive management

Age of first breeding ______________
Calving rates ______________
Weaning rate ______________
Adult mortality ______________

Health management

Treatment				
Month				
Labour (MD)				
Dose				
Cost				

Other labour use

	Source	Month	Quantity
Care			
Feeding			
Reproductive management			

Other costs and incomes

Leather ________________
Other ________________

B.4. Sheep

Output (last year)

	Sheep	Rams	Ewe-lambs	Lambs
Herd (March '95)				
(March '94)				
Sale (n)				
Sale price				
Month of sale				
Purchase (n)				
Purchase price				
Purchase month				
Peso				
Month				
Consumption				
Deaths				
Births				
Weaning				

Wool production

	Sheep	Rams
Shorn (n)		
Wool weight		
Month		

Month shorn __________ Shearing cost ______________
Labour source ______________
Consumption ______________ kg Storage ______________ kg
Sale ______________ kg Sale price ______________ $/kg
Sale month ______________
Marketing ____

Reproductive management

Age of first breeding ______________
Calving rates ______________ Weaning rate ______________
Adult mortality ______________

Health management

Treatment				
Month				
Labour (MD)				
Dose				
Cost				

Other labour use

	Source	Month	Quantity
Care			
Feeding			
Reproductive management			

Other costs and incomes

Leather and by-products

B.5. Horses

Herd (last year)

	Stallions	Horses	Mares	Foals
Herd (March '95)				
(March '96)				
Sale (n)				
Sale price				
Month of sale				
Purchase (n)				
Purchase price				
Purchase month				
Deaths				
Foaling				

Breeding month ____________

Health management

Treatment				
Month				
Labour used				
Dose				
Dose cost				

Other labour uses

	Source	Month
Care		
Reproductive management		
Feeding		

C.1 CHARCOAL PRODUCTION

Activity				
Month				
Inputs				
Labour				
Output				

Sale ____________kg Sale price ____________ $/kg

Sale month ____________ Consumption ___________kg

2. FARM DATA

2.1 FARM A DATA

Fallow (sharecropped)

	Month	Output	Input	QQ	Px	Total	Other
Labour use	Aug.		Ploughing			5.76	
	Jan.-Mar.		Cleaning			2.56	

Wheat (sharecropped)

	Month	Output	Input	QQ	Px	Total	Other
Input/output	Apr.		Seeds	77	94	-$7,238	cash
	Apr.		Disinfectant			-$577	cash
	Apr.		Urea	64	120	-$7,680	cash
	July		Na nitrate	102	112	-$11,424	cash
	July		Herbicide	2	2500	-$5,000	cash
	Jan.		Combine			-$10,000	cash
	Apr.	Wheat		1400	65	$91,000	cash
GM						$49,081	
Labour use	Apr.-May		Sowing			1.28	
	July		Fertilising			1.28	
	July		Herbicide			1.92	
	Dec.		Harvest			0.20	
Consumption		800 kg					
Straw use factor[14]		50%					

Chickpea

	Month	Output	Input	QQ	Px	Total	Other
Input/output	Sep.		Seeds	64	300	-$19,200	cash
	Oct.		Pesticide	0.32	10000	-$3,200	cash
	Jan.	Chickpea		577	300	$173,100	cash
GM						$150,700	
Labour use	Sep.		Sowing			5.12	
	Oct.		Pesticide			0.80	
	Jan.		Harvest			9.62	
Consumption		80 kg					

[14] Amount of straw which can be used to feed livestock. It takes into account storage facilities and accessibility

Vineyard (cropped with his with brother)

	Month	Output	Input	QQ	Px	Total	Other
Input/output	Sep.		Urea	50	120	-$6,000	cash
	Nov.		Sulphur	8	200	-$1,500	cash
	Apr.	Wine (l)		1125	133	$149,625	cash
GM						$142,125	
Labour use	July-Aug.		Pruning			4.00	
	Sep.		Ploughing I			4.00	
	Nov.		Ploughing II			10.00	
	Apr.		Harvest			5.00	

Sheep

Item	Month	Number		Value	Total	Other
Culled ewes	Dec.-Apr.	0.30	15%	12000	$1,800	cash
Ewe-lambs		0.40	20%	-12000	-$2,400	
Lambs	Nov.	1.80	81%	12000	$9,720	cash
Wool			2 kg	150	$300	consumed
GM per ewe					$9,420	

Cattle (given out)

Item	Month	Number		Value	Total	Other	Weight
Culled cows	Dec.-Apr.	0.2	10%	155000	$15,500	cash	500 kg
Heifers		0.3	15%	39000	-$5,850		90 kg
Yearlings	Oct.	1.6	74%	39000	$28,860	cash	90 kg
GM per cow					$38,510		

Dry matter intake

	Season I	Season II
Ewe (pooled)	270 kg	193 kg

Farm's actual GM

Activity	QQ	GM	Total
Fallow	3.13	0	$0
Wheat	3.13	49081	$153,624
Chickpea	1.56	150700	$235,092
Vineyard	0.20	142125	$28,425
Sheep	2.00	9420	$18,840
Cattle	2.00	38510	$77,020
TOTAL			$513,001

Actual cash flow

Month	Wheat	Chickpea	Vineyard	Sheep	Cattle	Total	Balance
Apr.	$184,330		$29,925	$720	$6,200	$192,082	$192,082
May						-$29,093	$162,989
June						-$29,093	$133,896
July	-$51,408					-$80,501	$53,395
Aug.						-$29,093	$24,302
Sep.		-$29,952	-$1,200			-$60,245	-$35,943
Oct.		-$4,992			$46,020	$11,935	-$24,008
Nov.			-$300	$14,640		-$14,753	-$38,761
Dec.				$720	$6,200	-$22,173	-$60,934
Jan.	-$31,300	$246,036		$720	$6,200	$192,563	$131,629
Feb.				$720	$6,200	-$22,173	$109,456
Mar.				$720	$6,200	-$22,173	$87,283

Income less expenses	**$436,399**
Monthly cash expenses (-20%)	**$29,093**
Working capital	**$60,934**
Maximum loan	**$250,000**
Risk target	**$718,005**

Expected yearly GMs

	Wheat fl	Chickpea fl	Wheat hi	Chickpea hi	Wheat mo	Chickpea mo
'85	$73,955	$146,853	$67,903	$138,414	$61,852	$129,975
'86	$74,748	$158,857	$68,865	$149,743	$62,982	$140,629
'87	$57,179	$125,922	$52,342	$118,661	$47,505	$111,399
'88	$51,418	$110,686	$46,741	$104,281	$42,063	$97,877
'89	$51,201	$189,945	$46,505	$179,082	$41,810	$168,220
'90	$38,737	$201,949	$34,733	$190,412	$30,729	$178,874
'91	$39,039	$183,173	$34,907	$172,692	$30,776	$162,210
'92	$35,287	$135,002	$31,424	$127,230	$27,561	$119,458
'93	$34,105	$111,917	$30,428	$105,443	$26,752	$98,969
'94	$35,123	$142,851	$31,442	$134,638	$27,761	$126,424
Average	$49,079	$150,715	$44,529	$142,060	$39,979	$133,404

fl: flat; hi: hilly; mo: mountains

	Ewe	Lamb	Cow	Yearling	Wine	FGM
'85	$1,942	$8,408	$15,485	$36,192	$74,608	$641,591
'86	$2,240	$8,554	$17,577	$41,379	$174,797	$718,005
'87	$2,325	$9,613	$17,717	$43,524	$225,641	$510,136
'88	$2,406	$10,566	$16,182	$41,340	$86,787	$438,296
'89	$2,302	$10,925	$15,423	$39,780	$61,356	$550,099
'90	$2,060	$9,671	$13,315	$33,891	$77,122	$520,429
'91	$2,111	$9,574	$16,353	$40,833	$189,981	$528,201
'92	$2,258	$10,886	$16,973	$42,666	$285,557	$468,956
'93	$1,774	$9,885	$14,012	$36,972	$153,829	$389,616
'94	$1,582	$9,137	$11,935	$33,384	$91,567	$417,616
Average	$2,100	$9,722	$15,497	$38,996	$142,124	$518,295

FGM: total Farm GM

2.2 FARM B DATA

Fallow

	Month	Output	Input	QQ	Px	Total	Other
Labour use	Aug.		Ploughing I			2.56	
	Sep.		Ploughing II			1.92	

Wheat (after fallow)

	Month	Output	Input	QQ	Px	Total	Other
Input/output	May		Seeds	154	70	-$10,780	own
	May		Disinfectant			-$962	cash
	May		DAPh[15]	103	156	-$16,068	loan
	July		Na nitrate	91	101	-$9,191	loan
			Urea	64	176	-$11,264	loan
	Dec.		Combine	192	70	-$13,440	wheat
	Dec.	Wheat		2611	70	$182,770	cash
GM						$121,065	
Labour use	Apr.		Seed bed preparation			0.21	
	May		Sowing			1.92	
	July		Fertilising			0.57	
	Dec.		Harvest			0.20	

Consumption 800 kg
Straw use 80%

Chickpea (after fallow, before wheat)

	Month	Output	Input	QQ	Px	Total	Other
Input/output	Sep.		Seeds	100	300	-$30,000	own
			TSPh	100	135	-$13,500	loan
	Jan.		Tractor	1	5000	-$5,000	cash
		Chickpea		800	300	$240,000	cash
GM						$191,500	
Labour	Sep.		Sowing			2.00	
	Jan.		Harvest			9.00	

Lentils (after peas)

	Month	Output	Input	QQ	Px	Total	Other
Input/output	May		Seeds	45	500	-$22,500	own
	Jan.		Tractor	1	3000	-$3,000	cash
	Jan.	Lentils		400	500	$200,000	cash
GM						$174,500	
Labour	May		Sowing			3.00	
	Jan.		Harvest			10.00	

Consumption 200 kg (when sown)

[15] Di-Ammonic phosphate

Peas (after fallow)

	Month	Output	Input	QQ	Px	Total	
Input/output	May		Seeds	120	70	-$8,400	loan
			DAPh	80	160	-$12,800	loan
	Aug.		Na nitrate	125	176	-$22,000	loan
			Urea	100	176	-$17,600	loan
	Oct.	Peas		2000	140	$280,000	cash
GM						$219,200	
Labour	May		Sowing/fertilising			3.00	
	Aug.		Fertilising			0.50	
	Oct.		Harvest			4.00	

Consumption 200 kg

Oats

	Month	Output	Input	QQ	Px	Total	
Input/output	May		Seeds	120	70	-$8,400	loan
	July		Urea	100	176	-$17,600	loan
			Na Nitrate	160	101	-$16,160	loan
	Dec.	Oats, straw		2400			
GM						-$42,160	
Labour	May		Sowing			3.00	
	July		Fertilising			0.50	
	Dec.		Harvest			7.00	

Consumption 200 kg

Sheep

Item	Month	Number		Value	QQ	Other
Culled ewes	Dec.-Apr.	9	15%	12000	$1,800	cash
Ewe-lambs		12	20%	12600	-$2,520	
Lambs	Sep.	49	81%	12600	$10,206	cash
Wool (kg)	Nov.		2	150	$300	cash
Medicines	May				-$357	cash
GM per ewe					$9,429	
Labour	Nov.	Shearing			0.01	

Consumption 8 hd

Cattle

Item	Month	Number		Value	QQ	Other
Culled cows	Dec.-Apr.	0.70	10%	155000	$15,500	cash
Heifers		1.05	15%	85000	-$12,750	
Yearlings	Oct.	5.18	74%	85000	$62,900	cash
Medicines	May				-$540	cash
GM per cow					$65,110	

Alfalfa hay

	Month	Output	Input	QQ	Px	Total	Other
Alfalfa hay	Feb.	Purchase		3000 kg	43	-$129,000	Cash

Rough grazing productivity **110%**

Dry matter intake

	Season I	Season II
Ewe (pooled)	273 kg	195 kg
Cow (pooled)	1764 kg	1244 kg
Horse	1819 kg	1283 kg

Farm's actual GM

Activity	QQ	GM	Total
Fallow	7.03		$0
Wheat	7.03	$121,065	$851,087
Chickpea	2.34	$191,500	$448,110
Lentils	0.00	$174,500	$0
Peas	2.00	$219,200	$438,400
Oats	1.00	-$42,160	-$42,160
Sheep	61	$9,429	$575,169
Cattle	7	$65,110	$455,770
Alfalfa hay			-$129,000
Interest on loan			-$34,414
TOTAL			$2,562,962

Actual cash flow

	Wheat	Chickpeas	Peas	Oats	Alfalfa
Apr.	-$263,520	-$31,590	-$121,600	-$42,160	
May					
June					
July					
Aug.					
Sep.					
Oct.			$532,000		
Nov.					
Dec.	$1,058,606				
Jan.		$419,700			
Feb.					-$129,000
Mar.					

	Sheep	Cattle	Loan	Monthly	Balance
Apr.	$21,960	$21,700	$458,870	-$110,884	-$110,884
May	-$21,777	-$3,780		-$180,101	-$290,985
June				-$154,544	-$445,529
July				-$154,544	-$600,073
Aug.				-$154,544	-$754,617
Sep.	$368,046			$213,502	-$541,115
Oct.		$351,050		$728,506	$187,391
Nov.	$18,300			-$136,244	$51,147
Dec.	$21,960	$21,700		$947,722	$998,869
Jan.	$21,960	$21,700		$308,816	$1,307,685
Feb.	$21,960	$21,700		-$239,884	$1,067,801
Mar.	$21,960	$21,700	-$493,284	-$ 604,168	$ 463,633

Income less expenses	**$2,318,161**
Monthly cash expenses (-20%)	**$154,544**
Working capital	**$754,617**
Maximum loan	**$500,000**
Risk target	**$2,804,341**

Expected yearly GMs

Flat	Wheat	Chickpeas	Lentils	Peas	Oats
'85	$164,505	$184,171	$198,818	$153,665	-$47,787
'86	$164,762	$200,227	$273,190	$212,795	-$42,257
'87	$132,534	$156,205	$187,990	$254,294	-$40,166
'88	$121,714	$134,133	$128,528	$232,282	-$43,944
'89	$124,127	$243,687	$175,388	$218,322	-$44,189
'90	$102,598	$261,930	$208,580	$249,672	-$41,614
'91	$105,881	$236,553	$187,813	$283,659	-$44,854
'92	$99,345	$172,402	$121,605	$210,725	-$43,209
'93	$97,472	$141,982	$128,528	$203,552	-$37,190
'94	$97,723	$183,922	$134,563	$172,750	-$36,443
Average	$121,066	$191,521	$174,500	$219,171	-$42,165

Hilly	Wheat	Chickpeas	Lentils	Peas	Oats
'85	$152,351	$172,471	$187,448	$142,521	-$47,787
'86	$152,946	$187,591	$257,630	$199,089	-$42,257
'87	$122,820	$146,137	$177,230	$238,726	-$40,166
'88	$112,320	$125,253	$121,118	$217,456	-$43,944
'89	$114,696	$228,627	$165,338	$204,252	-$44,189
'90	$94,556	$245,934	$196,660	$234,104	-$41,614
'91	$97,584	$222,021	$177,063	$266,159	-$44,854
'92	$91,586	$161,626	$114,585	$197,173	-$43,209
'93	$90,089	$133,006	$121,118	$190,700	-$37,190
'94	$90,330	$172,534	$126,813	$161,550	-$36,443
Average	$111,928	$179,520	$164,500	$205,173	-$42,165

	Ewes	Lamb	Cows	Yearlings	FGM
'85	$1,585	$10,899	$14,945	$78,880	$2,631,534
'86	$1,883	$11,088	$17,037	$90,185	$2,804,341
'87	$1,968	$12,461	$17,177	$94,860	$2,668,685
'88	$2,049	$13,696	$15,642	$90,100	$2,545,927
'89	$1,945	$14,162	$14,883	$86,700	$2,633,604
'90	$1,703	$12,537	$12,775	$73,865	$2,429,468
'91	$1,754	$12,411	$15,813	$88,995	$2,592,263
'92	$1,901	$14,112	$16,433	$92,990	$2,429,316
'93	$1,417	$12,814	$13,472	$80,580	$2,216,332
'94	$1,225	$11,844	$11,395	$72,760	$2,106,806
Average	$1,743	$12,603	$14,957	$84,992	$2,505,828

2.3 Farm C Data

Fallow

	Month	Output	Input	QQ	Px	Total
Labour	July	Fallow	Ploughing I			2.56
	Sep.-Oct.		Ploughing II			1.28

Wheat

	Month	Output	Input	QQ	Px	Total	
	May		Seeds	179	172	-$ 30,788	loan
	May		TSPh	102	122	-$ 12,444	loan
	May		DAPh	51	154	-$ 7,854	loan
	May		Urea	32	158	-$ 5,056	loan
	July		Urea	96	158	-$ 15,168	loan
	Dec.		Combine	208	75	-$ 15,600	wheat
	Dec.	Wheat		3328	75	$ 249,600	cash
GM						$ 162,690	
Labour	Apr.-May		Seed bed preparation			0.32	
			Sowing			0.64	
	July		Fertilising			0.32	
	Dec.		Harvest			0.20	
Consumption	120 kg						
Straw use	20%						

Sheep

Item	Month	Number		Value	QQ	Other
Ewes		20				
Culled ewes	Dec.-Apr.	3	15%	12000	$ 1,800	cash
Ewe-lambs		4	20%	12000	-$ 2,400	
Lambs	Sep.	16	81%	12000	$ 9,720	cash
Wool (kg)	Nov.		2	150	$ 300	cash
GM per ewe					$ 9,420	
Consumption	5 hd					

Alfalfa hay

	Month	Output	Input	QQ	Px	Total	Other
Alfalfa hay	Mar.	Purchase		900 kg	$ 40	-$ 36,000	Cash

Dry matter intake

	Season I	Season II
Ewe (pooled)	273 kg	195 kg
Horse	1819 kg	1283 kg

Farm's actual GM

Activity	QQ	GM	Total
Fallow	7.03		$ 0
Wheat	12.00	$ 162,690	$ 1,952,280
Sheep	20	$ 9,420	$ 188,400
Hay	900	$ 40	-$ 36,000
Interest on loan			-$ 64,179
TOTAL			$ 2,040,501

Actual cash flow

	Wheat	Sheep	Alfalfa	Loan	Total	Balance
Apr.	-$ 855,720	$ 7,200		$ 855,720	-$ 124,233	-$ 124,233
May					-$ 131,433	-$ 255,666
June					-$ 131,433	-$ 387,099
July					-$ 131,433	-$ 518,532
Aug.					-$ 131,433	-$ 649,965
Sep.		$ 86,400			-$ 45,033	-$ 694,998
Oct.					-$ 131,433	-$ 826,431
Nov.		$ 6,000			-$ 125,433	-$ 951,864
Dec.	$ 2,799,000	$ 7,200			$ 2,674,767	$ 1,722,903
Jan.		$ 7,200			-$ 124,233	$ 1,598,670
Feb.		$ 7,200			-$ 124,233	$ 1,474,437
Mar.		$ 7,200	-$ 36,000	-$ 919,899	-$ 1,080,132	$ 394,305

Income less expenses	**$ 1,971,501**
Monthly cash expenses (-20%)	**$ 131,433**
Working capital	**$ 951,864**
Maximum loan	**$ 900,000**
Risk target	**$ 2,587,988**

Expected yearly GMs

	Wheat (fl)	Wheat (hi)	Ewes	Lambs	FGM
'85	$ 217,397	$ 200,798	$ 1,942	$ 10,380	$ 2,587,988
'86	$ 217,498	$ 201,362	$ 2,240	$ 10,560	$ 2,583,580
'87	$ 175,583	$ 162,317	$ 2,325	$ 11,868	$ 2,118,336
'88	$ 162,720	$ 149,891	$ 2,406	$ 13,044	$ 1,986,260
'89	$ 165,931	$ 153,052	$ 2,302	$ 13,488	$ 2,028,532
'90	$ 139,402	$ 128,419	$ 2,060	$ 11,940	$ 1,715,856
'91	$ 144,791	$ 133,460	$ 2,111	$ 11,820	$ 1,778,436
'92	$ 136,834	$ 126,239	$ 2,258	$ 13,440	$ 1,707,100
'93	$ 133,358	$ 123,275	$ 1,774	$ 12,204	$ 1,646,544
'94	$ 133,381	$ 123,284	$ 1,582	$ 11,280	$ 1,635,412
Average	$ 162,690	$ 150,210	$ 2,100	$ 12,002	$ 1,978,804

2.4 FARM D DATA

Wheat (given out)

	Month	Output	Input	QQ	Px	Total	
Input/output	May		Seeds	82	75	-$ 6,150	own
	May		Disinfectant			-$ 666	loan
	May		TSPh	123	125	-$ 15,375	loan
	July		Urea	77	175	-$ 13,475	loan
	Dec.		Combine	80	75	-$ 6,000	wheat
	Dec.		Transport	30	75	-$ 2,250	wheat
	Dec.	Wheat		1216	75	$ 91,200	cash
GM						$ 47,284	

Consumption	0 kg
Straw use	25%

Sheep

Item	Month	Number		Value	QQ	
Ewes	Dec.-Apr.	3	15%	12000	$ 1,800	cash
Ewe-lambs		4	20%	12000	-$ 2,400	
Lambs	Sep.	16.2	81%	12000	$ 9,720	cash
Wool (kg)	Nov.	2		150	$ 300	consumed
GM per ewe					$ 9,420	

Consumption	12 lambs

Alfalfa hay

	Month	Output	Input	QQ	Px	Total	Other
Alfalfa hay	Mar.	Purchase		1500 kg	40	-$ 60,000	Cash

Dry matter intake

	Season I	Season II
Ewe (pooled)	271 kg	193 kg
Horse	1819 kg	1283 kg

Off-farm income (Apr.-Mar.) $ 90,000

Farm's actual GM

Activity	QQ	GM	Total
Fallow	4.69		$ 0
Wheat	7.81	$ 47,284	$ 369,288
Sheep	20	$ 9,420	$ 188,400
Alfalfa hay	1500	$ 40	-$ 60,000
Interest on loan			-$ 17,289
TOTAL			$ 480,399

Actual cash flow

	Wheat	Sheep	Alfalfa	Loan	Off-farm	Total	Balance
Apr.	-$ 230,520	$ 7,200		$ 230,520	$ 90,000	$ 7,200	$ 7,200
May					$ 90,000	$ 0	$ 7,200
June					$ 90,000	$ 0	$ 7,200
July					$ 90,000	$ 0	$ 7,200
Aug.					$ 90,000	$ 0	$ 7,200
Sep.					$ 90,000	$ 0	$ 7,200
Oct.		$ 2,400			$ 90,000	$ 2,400	$ 9,600
Nov.					$ 90,000	$ 0	$ 9,600
Dec.	$ 599,808	$ 7,200			$ 90,000	$ 607,008	$ 616,608
Jan.		$ 7,200			$ 90,000	$ 7,200	$ 623,808
Feb.		$ 7,200		-$ 247,809	$ 90,000	-$ 240,609	$ 383,199
Mar.		$ 7,200	-$ 60,000		$ 90,000	-$ 52,800	$ 330,399

Income less expenses	**$ 330,399**
Monthly cash expenses (pension)	**$ 90,000**
Working capital	**$ 0**
Maximum loan	**$ 300,000**
Risk target	**$ 605,214**

Expected yearly GMs

	Wheat (fl)	Wheat (hi)	Sheep	Lambs	FGM
'85	$ 64,803	$ 58,738	$ 1,942	$ 10,380	$ 605,214
'86	$ 66,497	$ 60,601	$ 2,240	$ 10,560	$ 598,927
'87	$ 51,833	$ 46,985	$ 2,325	$ 11,868	$ 507,189
'88	$ 45,326	$ 40,638	$ 2,406	$ 13,044	$ 482,901
'89	$ 47,245	$ 42,540	$ 2,302	$ 13,488	$ 504,494
'90	$ 38,826	$ 34,813	$ 2,060	$ 11,940	$ 434,493
'91	$ 40,673	$ 36,533	$ 2,111	$ 11,820	$ 449,366
'92	$ 39,208	$ 35,336	$ 2,258	$ 13,440	$ 461,490
'93	$ 39,175	$ 35,491	$ 1,774	$ 12,204	$ 434,717
'94	$ 39,241	$ 35,552	$ 1,582	$ 11,280	$ 422,341
Average	$ 47,283	$ 42,723	$ 2,100	$ 12,002	$ 490,113

2.5 FARM E DATA

Fallow

	Month	Output	Input	QQ	Px	Total	Other
Labour	Sep.	Fallow	Ploughing I			3.84	
	Oct.		Ploughing II			2.56	

Wheat

	Month	Output	Input	QQ	Px	Total	Other
Input/output	May		Seeds	154	68	-$ 10,472	loan
	May		Disinfectant			-$ 1,460	loan
	May		DAPh	154	160	-$ 24,640	loan
	July		Urea	96	176	-$ 16,896	loan
	Dec.		Combine	154	68	-$ 10,472	wheat
	Dec.	Wheat		3072	68	$ 208,896	cash
GM						$ 144,956	
Labour	May		Sowing			1.28	
	July		Fertilising			0.32	
	Dec.		Harvest			0.20	
	Jan.		Balling	25 kg	16	-$ 400	cash
	Feb.	Sale		25 kg	40	$ 1,000	cash
GM		per bale				$ 600	

Consumption 2000 kg
Straw use 80%

Cattle

Item	Month	Number		Value	Total	Other
Culled cows	Dec.-Apr.	2.00	10%	155000	$ 15,500	cash
Heifers		3.00	15%	80000	-$ 12,000	
Yearlings	Oct.	16.00	74%	80000	$ 59,200	cash
Medicine	May				-$ 540	cash
GM per cow					$ 62,160	

Sheep (given out)

Item	Month	Number		Value	Total	Other
Culled ewes	Dec.-Apr.	3.00	15%	12000	$ 1,800	cash
Ewe-lambs		4.00	20%	6000	-$ 1,200	
Lambs	Sep.	18.00	81%	6000	$ 4,860	cash
Wool (kg)	Nov.		1	300	$ 300	consumed
GM per ewe					$ 5,760	

Horses

Item	Month	Number		Value	Total	Other
Sale	Dec.-Apr.	1		110000	$ 110,000	cash
GM per head					$ 13,750	

Alfalfa Hay

	Month	Output	Input	QQ	Px	Total	Other
Alfalfa hay	Mar.	Hay		3000 kg	-40	-$ 120,000	cash

Charcoal

	Month	Output	Input	QQ	Px	Total	Other
Input/output		Bags (40 kg each)		100	4000	$ 400,000	cash
GM						$ 400,000	
Labour	Aug.-Sep.		Cutting/trimming/burning			0.30	

Dry matter intake

	Season I	Season II
Cow (pooled)	1765	1245

Rough grazing productivity **110%**

Maize (fixed, for horses)

	Month	Output	Input	QQ	Px	Total	Other
Input/output	Oct.		Seeds	30 kg	70	-$ 2,100	cash
			DAPh	60 kg	182	-$ 10,920	cash
	Nov.		Urea	100 kg	176	-$ 17,600	cash
	Jan.-Feb.	Maize		8000 kg			
Labour	Apr.-Mar.		Feeding			1.00	
	Aug.		Seed bed			1.00	
	Oct.		Sowing			1.00	
	Nov.		Hacking I			1.00	
	Dec.		Hacking II			1.00	
	Jan.-Feb.		Harvest			1.00	

Farm's actual GM

Activity	QQ	GM	Total
Fallow	15.00		$ 0
Wheat	15.00	$ 144,956	$ 2,174,340
Charcoal	100	$ 4,000	$ 400,000
Cattle	20	$ 62,160	$ 1,243,200
Sheep	20	$ 5,760	$ 115,200
Straw	80	$ 600	$ 48,000
Horses	8	$ 13,750	$ 110,000
Interest on loan			-$ 60,152
TOTAL			$ 4,030,589

Actual cash flow

Month	Wheat/straw	Sheep	Cattle	Horses	Charcoal
Apr.	-$ 802,020	$ 7,200	$ 62,000	$ 22,000	
May			-$ 10,800		
June					
July					
Aug.					
Sep.					$ 400,000
Oct.		$ 73,200	$ 800,000		
Nov.		$ 7,200	$ 62,000		
Dec.	$ 2,946,360	$ 7,200	$ 62,000	$ 22,000	
Jan.	-$ 32,000	$ 7,200	$ 62,000	$ 22,000	
Feb.	$ 80,000	$ 7,200	$ 62,000	$ 22,000	
Mar.		$ 7,200	$ 62,000	$ 22,000	

Month	Alfalfa	Maize	Loan	Total	Balance
Apr.			$ 802,020	-$ 170,119	-$ 170,119
May				-$ 272,119	-$ 442,238
June				-$ 261,319	-$ 703,557
July				-$ 261,319	-$ 964,876
Aug.				-$ 261,319	-$ 1,226,195
Sep.				$ 138,681	-$ 1,087,514
Oct.		-$ 13,020		$ 611,881	-$ 475,633
Nov.		-$ 17,600		-$ 192,119	-$ 667,752
Dec.				$ 2,776,241	$ 2,108,489
Jan.				-$ 202,119	$ 1,906,370
Feb.				-$ 90,119	$ 1,816,251
Mar.	-$ 120,000		-$ 862,172	-$ 1,032,291	$ 783,961

Income less expenses	**$ 3,919,789**
Monthly cash expenses (-20%)	**$ 261,319**
Working capital	**$ 1,226,195**
Maximum loan	**$ 1,002,525**
Risk target	**$ 4,708,913**

Expected yearly GMs

	Wheat (fl)	Wheat (hi)	Sheep given out	Lambs given out	Cows	Yearlings
'85	$ 193,090	$ 179,199	$ 1,942	$ 2,595	$ 14,945	$ 74,240
'86	$ 194,036	$ 180,530	$ 2,240	$ 2,640	$ 17,037	$ 84,880
'87	$ 156,534	$ 145,431	$ 2,325	$ 2,967	$ 17,177	$ 89,280
'88	$ 143,771	$ 133,033	$ 2,406	$ 3,261	$ 15,642	$ 84,800
'89	$ 147,940	$ 137,161	$ 2,302	$ 3,372	$ 14,883	$ 81,600
'90	$ 123,747	$ 114,556	$ 2,060	$ 2,985	$ 12,775	$ 69,520
'91	$ 129,367	$ 119,884	$ 2,111	$ 2,955	$ 15,813	$ 83,760
'92	$ 121,985	$ 113,118	$ 2,258	$ 3,360	$ 16,433	$ 87,520
'93	$ 119,873	$ 111,433	$ 1,774	$ 3,051	$ 13,472	$ 75,840
'94	$ 119,250	$ 110,800	$ 1,582	$ 2,820	$ 11,395	$ 68,480
Average	$ 144,959	$ 134,514	$ 2,100	$ 3,001	$ 14,957	$ 79,992

	Horses	FGM
'85	$ 8,014	$ 4,544,957
'86	$ 10,208	$ 4,708,914
'87	$ 11,241	$ 4,157,428
'88	$ 10,310	$ 3,861,726
'89	$ 9,668	$ 3,875,611
'90	$ 8,002	$ 3,283,828
'91	$ 9,855	$ 3,650,480
'92	$ 12,554	$ 3,619,017
'93	$ 10,643	$ 3,333,573
'94	$ 8,717	$ 3,163,836
Average	$ 9,921	$ 3,819,937

2.6 FARM F DATA

Fallow

	Month	Output	Input	QQ	Px	Total	Other
Labour	Sep.	Fallow	Ploughing I	1.92			
	Oct.		Ploughing II	1.28			

Wheat

	Month	Output	Input	QQ	Px	Total	Other
Input/output	May		Seeds	179 kg	69	-$ 12,351	own
	May		Disinfectant			-$ 1,460	loan
	May		DAPh	51 kg	154	-$ 7,854	loan
	May		Urea	80 kg	158	-$ 12,640	loan
	July		Na Nitrate	154 kg	102	-$ 15,708	loan
	Dec.		Combine	192 kg	69	-$ 13,248	wheat
	Dec.	Wheat		3718 kg	69	$ 256,542	
GM						$ 193,281	
Labour	May		Sowing			1.92	
	July		Fertilising			0.32	
	Dec.		Harvest			0.20	

Self consumption 2000 kg
Straw use 80%

Wheat (given out)

	Month	Output	Input	QQ	Px	Total	Other
Input/output	May		Seeds	90 kg	69	-$ 6,176	own
	May		Disinfectant			-$ 1,460	loan
	May		DAPh	26 kg	154	-$ 4,004	loan
	May		Urea	40 kg	158	-$ 6,320	loan
	July		Na Nitrate	77 kg	102	-$ 7,854	loan
	Dec.		Combine	96 kg	69	-$ 6,624	wheat
	Dec.	Wheat		1859 kg	69	$ 128,271	
GM						$ 95,834	

Straw use 80%

Chickpeas (given out)

	Month	Output	Input	QQ	Px	Total	Other
Input/output	Sep.		Seeds	77	0	$ 0	
			Na Nitrate	154	102	-$ 15,708	loan
	Jan.		Harvest			-$ 28,846	cash
		Chickpeas		455	400	$ 182,000	cash
			Seeds	125	400	-$ 50,000	own
GM						$ 87,446	

Chickpeas (own)

Input/output Same data as given out chickpea but doubled.
Sowing labour estimated as average from farms A and B

Vineyard

	Month	Output	Input	QQ	Px	Total	Other
Input/output	Nov.		Sulphur	12	200	-$ 2,400	
	Apr.	Wine (l)		2300	150	$ 345,000	
GM						$ 342,600	
Labour use	Aug.		Trimming			4.00	
			Ploughing			8.00	
	Sep.		Vine shoot binding			8.00	
	Oct.		Hacking			7.00	
	Apr.		Harvest			6.00	

Oats-clover

	Month	Output	Input	QQ	Px	Total	Other
Input/output	May		Oat seeds	80 kg	70	-$ 5,600	Loan
			Clover seeds	20 kg	1330	-$ 26,600	Loan
			DAPh	80 kg	154	-$ 12,320	Loan
			Urea	50 kg	158	-$ 7,900	Loan
	Aug.		Na Nitrate	80 kg	102	-$ 8,160	Loan
	Dec.	Forage		3000 kg			
	Jan.-Feb.	Grazing		3000 kg			
GM						-$ 60,580	
Labour	May		Sowing			2.00	
	Aug.		Fertilising			0.15	
	Dec.		Balling			8.00	

Charcoal

	Month	Output	Input	QQ	Px	Total	Other
Input/output		Bags (35 kg each)		200	3150	$ 630,000	
GM						$ 630,000	
Labour	Aug.-Sep.		Cutting/trimming/burning			0.20	

Eucalyptus

	Month	Output	Input	QQ	Px	Total	Other
GM						73920	
Labour			Soil preparation			2.00	
	Sep.		Planting			6.00	
	Apr.-Mar.		Maintenance			2.00	

Cattle

Item	Month	Number		Value	QQ	Other
Culled cows	Nov.-Apr.	0.60	10%	155000	$ 15,500	Cash
Heifers		1.20	15%	95000	-$ 14,250	
Yearlings	Oct.	3.60	74%	95000	$ 70,300	Cash
GM per cow					$ 71,550	
total					$ 429,300	

Cattle (taken)

Item	Month	Number		Value	QQ	Other
Yearlings	Apr.-May	3.00	74%	47500	$ 35,150	Cash
GM per cow					$ 35,150	
total					$ 175,750	

Sheep

Item	Month	Number		Value	QQ	Other
Culled ewes	Nov.-Apr.	7.50	15%	12000	$ 1,800	Cash
Ewe-lambs		10.00	20%	14000	-$ 2,800	
Lambs	Aug.	40.00	41%	15000	$ 6,075	Cash
Lambs	Sep.		41%	13000	$ 5,265	Cash
Wool (kg)	Nov.		2.0	150	$ 300	Cash
Parasiticide	May				-$ 357	Cash
GM per ewe					$ 10,283	

Consumption 10 hd

Alfalfa hay

	Month	Output	Input	QQ	Px	Total	
Hay	Mar.		Alfalfa hay	2500 kg	40	$ 100,000	Cash

Dry matter intake

	Season I	Season II
Ewe (pooled)	258 kg	184 kg
Cow (pooled)	1764 kg	1244 kg

Rough grazing productivity 120%

Maximum hired labour 5 days/month

Farm's actual GM

Activity	QQ	GM	Total
Fallow	3.75		$ 0
Wheat	3.75	$ 193,281	$ 724,804
Wheat (given out)	3.13	$ 95,834	$ 299,480
Chickpea (given out)	1.00	$ 87,446	$ 87,446
Vineyard	0.50	$ 342,600	$ 171,300
Rough grazing	11.88		
Permanent grazing	12.0		
Cattle	6	$ 71,550	$ 429,300
Cattle (taken)	5	$ 35,150	$ 175,750
Sheep	50	$ 10,283	$ 514,150
Eucalyptus	1.00	$ 73,920	$ 73,920
Charcoal	200	$ 3,150	$ 630,000
Oats/clover	1.00	-$ 60,580	-$ 60,580
Interest on loan			-$ 20,917
TOTAL			$ 3,024,653

Actual cash flow

Month	Wheat	Oats&clover	Chickpea	Vineyard	Cattle	Sheep
Apr.	-$ 202,601	-$ 60,580	-$ 15,708		$ 15,500	$ 15,000
May						-$ 17,850
June						
July						
Aug.				$ 86,250		
Sep.				$ 86,250		$ 228,750
Oct.					$ 512,050	$ 133,250
Nov.				-$ 1,200	$ 15,500	$ 30,000
Dec.	$ 1,088,885				$ 15,500	$ 15,000
Jan.			-$ 28,846		$ 15,500	$ 15,000
Feb.			$ 132,000		$ 15,500	$ 15,000
Mar.					$ 15,500	$ 15,000

Month	Charcoal	Loan	Total	Balance
Apr.		$ 278,889	-$ 431,571	-$ 431,571
May			-$ 201,032	-$ 632,603
June			-$ 183,182	-$ 815,785
July			-$ 183,182	-$ 998,967
Aug.			-$ 96,932	-$ 1,095,899
Sep.	$ 315,000		$ 446,818	-$ 649,081
Oct.	$ 315,000		$ 777,118	$ 128,037
Nov.			-$ 138,882	-$ 10,845
Dec.			$ 936,203	$ 925,357
Jan.			-$ 181,528	$ 743,829
Feb.			-$ 20,682	$ 723,147
Mar.		-$ 299,806	-$ 152,682	$ 570,465

Income less expenses	**$ 2,747,733**
Monthly cash expenses (-20%)	**$ 183,182**
Working capital	**$ 1,095,899**
Maximum loan	**$ 500,000**
Risk target	**$ 3,819,395**

Yearly GMs

	Wheat (fl)	Wheat (hi)	Wheat given out (fl)	Wheat given out (hi)	Chickpea given out (fl)	Chickpea given out (hi)
'85	$ 261,388	$ 244,328	$ 129,865	$ 121,335	$ 84,617	$ 75,745
'86	$ 258,725	$ 242,139	$ 128,539	$ 120,246	$ 96,421	$ 86,839
'87	$ 208,658	$ 195,023	$ 103,516	$ 96,698	$ 68,974	$ 61,339
'88	$ 197,507	$ 184,321	$ 97,930	$ 91,337	$ 53,864	$ 47,130
'89	$ 198,396	$ 185,159	$ 98,385	$ 91,767	$ 121,075	$ 109,654
'90	$ 166,004	$ 154,716	$ 82,198	$ 76,555	$ 130,852	$ 118,722
'91	$ 170,419	$ 158,772	$ 84,409	$ 78,586	$ 112,392	$ 101,372
'92	$ 159,615	$ 148,725	$ 79,014	$ 73,569	$ 71,720	$ 63,548
'93	$ 155,709	$ 145,345	$ 77,071	$ 71,889	$ 53,538	$ 46,731
'94	$ 156,376	$ 145,998	$ 77,401	$ 72,212	$ 81,122	$ 72,487
Average	$ 193,280	$ 180,453	$ 95,833	$ 89,419	$ 87,458	$ 78,357

	Cow	Yearling	Yearling (taken)	Ewe	Lamb	Vineyard	FGM
'85	$ 15,485	$ 88,160	$ 44,080	$ 1,942	$ 12,975	$ 192,525	$ 3,552,700
'86	$ 17,577	$ 100,795	$ 50,398	$ 2,240	$ 13,200	$ 418,500	$ 3,819,395
'87	$ 17,717	$ 106,020	$ 53,010	$ 2,325	$ 14,835	$ 533,730	$ 3,561,308
'88	$ 16,182	$ 100,700	$ 50,350	$ 2,406	$ 16,305	$ 215,985	$ 3,254,368
'89	$ 15,423	$ 96,900	$ 48,450	$ 2,302	$ 16,860	$ 157,335	$ 3,503,362
'90	$ 13,315	$ 82,555	$ 41,278	$ 2,060	$ 14,925	$ 192,525	$ 3,162,097
'91	$ 16,353	$ 99,465	$ 49,733	$ 2,111	$ 14,775	$ 453,345	$ 3,421,800
'92	$ 16,973	$ 103,930	$ 51,965	$ 2,258	$ 16,800	$ 672,420	$ 3,446,306
'93	$ 14,012	$ 90,060	$ 45,030	$ 1,774	$ 15,255	$ 366,750	$ 2,922,712
'94	$ 11,935	$ 81,320	$ 40,660	$ 1,582	$ 14,100	$ 222,885	$ 2,816,426
Average	$ 15,497	$ 94,991	$ 47,495	$ 2,100	$ 15,003	$ 342,600	$ 3,346,048

2.7 FARM G DATA

Fallow

	Month	Output	Input	QQ	Px	Total	Other
Labour use	Aug.		Ploughing I			1.92	
	Sep.		Ploughing II			1.92	

Wheat

	Month	Output	Input	QQ	Px	Total	Other
Input/output	May		Seeds	179 kg	75	-$ 13,425	own
	May		Sowing (tractor)	1	20000	-$ 20,000	cash
	May		Disinfectant			-$ 1,460	loan
	May		TSPh	154 kg	137	-$ 21,098	loan
	May		Urea	96 kg	160	-$ 15,360	loan
	July		Urea	96 kg	160	-$ 15,360	loan
	Dec.		Combine	250 kg	75	-$ 18,750	cash
	Dec.	Wheat		3076 kg	75	$ 230,700	own
GM						$ 125,247	
Labour use	July		Fertilising			0.32	
	Dec.		Harvest			0.20	

Consumption 1600 kg
Straw use 80%

Oats

	Month	Output	Input	QQ	Px	Total	Other
Input/output	May		Seeds	120 kg	70	-$ 8,400	loan
	Aug.		Urea	96 kg	160	-$ 15,360	loan
	Dec.		Combine			-$ 14,103	cash
	Dec.	Oats		1500 kg		$ 0	cons.
GM						-$ 37,863	
Labour use	May		Sowing			1.92	
	Aug.		Fertilising			0.32	
	Jan.		Harvest			0.02	

Oats-Phalaris (2nd to fifth year only phalaris)

	Month	Output	Input	QQ	Px	Total	Other
Input/output	Aug.		Oat seeds	30 kg	70	-$ 2,100	loan
			Phalaris seed	11.5 kg	2460	-$ 28,290	loan
			TSPh	51 kg	137	-$ 6,987	loan
			Urea	32 kg	160	-$ 5,120	loan
	Nov.	Forage yr. 1		3000 kg		$ 0	
		Forage yr. 2-5	75%	2250 kg		$ 0	
Establishment cost						-$ 42,497	
Labour use	May		Ploughing			3.85	
	Aug.		Fertilising			0.32	
	Nov.		Soiling			5.12	

Lemons (per tree)

	Month	Output	Input	QQ	Px	Total	Other
Input/output	July-Sep.	Lemons		20	100	$ 2,000	
GM						$ 2,000	
Labour use	Sep.		Hacking			0.01	
	Dec.-Mar.		Irrigation			0.01	

Tomatoes (500m²)

	Month	Output	Input	QQ	Px	Total	Other
Input	July		Plastic	1080	60	-$ 64,800	
			Plants	700	55	-$ 38,500	
			Urea	4	160	-$ 640	
			TSPh	4	137	-$ 548	
			Fertiliser	5	1200	-$ 6,000	
			Pesticide			-$ 3,500	
	Mar.		Loan			-$ 60,000	

			Px	Early	Late	Early	Late
Output	Nov.	Tomatoes	$ 250	1200 kg	200 kg	$ 300,000	$ 50,000
	Dec.		$ 200	800 kg	1500 kg	$ 160,000	$ 300,000
	Jan.		$ 150	500 kg	800 kg	$ 75,000	$ 120,000
	Feb.		$ 50	400 kg	400 kg	$ 20,000	$ 20,000
GM						$ 381,012	$ 316,012
Labour use	July		Hacking			2.00	
			Plastic cover			2.00	
			Soil prep.			1.00	
			Planting			1.50	
	Aug.		Hacking				2.00
			Plastic cover				2.00
			Soil prep.				1.00
			Planting				1.50
	Sep.		Irrigation			0.75	0.75
	Oct.		Irrigation			1.00	1.00
	Nov.		Irrigation, harvest, sale			8.00	3.00
	Dec.		Irrigation, harvest, sale			7.00	10.50
	Jan.		Irrigation, harvest, sale			5.50	7.00
	Feb.		Irrigation, harvest, sale			5.00	5.00

Eucalyptus

	Month	Output	Input	QQ	Px	Total	Other
GM						$ 73,920	
Labour			Soil prep.			2.00	
	Sep.		Planting			6.00	
	Apr.-Mar.		Maintenance			2.00	

Sheep

Item	Month	Number		Value	QQ	Other
Culled ewes	Nov.-Apr.	0.80	15%	10000	$ 1,500	
Ewe-lambs		0.90	20%	12000	-$ 2,400	
Lambs	Oct.	5.50	81%	12000	$ 9,720	cash
Wool (kg)	Nov.		2	150	$ 300	cash
Treatment	May				-$ 200	cash
GM per ewe					$ 7,420	

Consumption	2 hd
Horses	5 hd

Alfalfa hay

	Month	Output	Input	QQ	Px	Total	
Hay	Mar.		Alfalfa hay	750 kg	40	-$ 30,000	Cash

Dry matter intake

	Season I	Season II
Ewe (pooled)	271 kg	193 kg

Charcoal (35 kg bags)

	Month	Output	Input	QQ	Px	Total
Input/output	Aug.-Sep.	Bags		1	2625	$ 2,625
GM						$ 2,625
Labour	Feb.-Aug.		Cutting, trimming, burning			0.30

Additional labour (brother) **8 days/month**

Farm's actual GM

Activity	QQ	GM	Total
Fallow	3.12		$ 0
Wheat	3.12	$ 125,247	$ 390,771
Oats	1.00	-$ 37,863	-$ 37,863
Oats/phalaris	1.50	-$ 42,497	-$ 63,746
Tomatoes (early)	0.50	$ 381,012	$ 190,506
Tomatoes (late)	0.50	$ 316,012	$ 158,006
Lemons	9.00	$ 2,000	$ 18,000
Eucalyptus	4.00	73920	$ 295,680
Charcoal	400	$ 2,625	$ 1,050,000
Sheep	6	$ 7,420	$ 44,520
Horses	5	$ 0	$ 0
Alfalfa	750	-$ 40	-$ 30,000
Interest on loan			-$ 19,030
TOTAL			$ 1,996,844

Actual cash flow

Month	Wheat/straw	Oat	Oat/phalaris	Lemon	Early tomato	Late tomato
Apr.	-$ 166,227	-$ 23,760	-$ 63,746			
May	-$ 62,400					
June						
July				$ 666	-$ 56,994	-$ 56,994
Aug.				$ 666		
Sep.				$ 666		
Oct.						
Nov.					$ 150,000	$ 25,000
Dec.		-$ 14,103			$ 80,000	$ 150,000
Jan.	$ 619,398				$ 37,500	$ 60,000
Feb.					$ 10,000	$ 10,000
Mar.					-$ 30,000	-$ 30,000

Month	Sheep	Charcoal	Loan	Total	Balance
Apr.	$ 1,500		$ 253,733	-$ 111,844	-$ 111,844
May	-$ 1,200			-$ 176,944	-$ 288,788
June				-$ 113,344	-$ 402,132
July				-$ 226,666	-$ 628,798
Aug.				-$ 112,678	-$ 741,476
Sep.		$ 1,050,000		$ 937,322	$ 195,846
Oct.	$ 19,920			-$ 93,424	$ 102,422
Nov.	$ 3,300			$ 64,956	$ 167,378
Dec.	$ 1,500			$ 104,053	$ 271,431
Jan.	$ 1,500			$ 605,054	$ 876,485
Feb.	$ 1,500			-$ 91,844	$ 784,641
Mar.	$ 1,500		-$ 272,763	-$ 444,607	$ 340,034

Income less expenses	**$ 1,700,162**
Monthly cash expenses (-20%)	**$ 113,344**
Working capital	**$ 741,476**
Maximum loan	**$ 500,000**
Risk target	**$ 2,379,993**

Yearly GMs

	Wheat (flat)	Wheat (hilly)	Tomatoes (early)	Tomatoes (late)	Lemons	Oats
'85	$ 175,070	$ 159,728	$ 328,652	$ 297,052	$ 1,206	-$ 43,067
'86	$ 178,400	$ 163,485	$ 327,352	$ 296,162	$ 1,200	-$ 39,904
'87	$ 138,628	$ 126,366	$ 453,332	$ 420,392	$ 1,916	-$ 38,962
'88	$ 124,299	$ 112,442	$ 386,412	$ 325,002	$ 3,316	-$ 40,247
'89	$ 127,319	$ 115,414	$ 347,607	$ 332,352	$ 2,836	-$ 39,703
'90	$ 102,635	$ 92,484	$ 281,712	$ 236,842	$ 1,842	-$ 36,783
'91	$ 107,252	$ 96,778	$ 509,272	$ 399,212	$ 2,218	-$ 37,502
'92	$ 100,895	$ 91,102	$ 480,757	$ 326,922	$ 1,578	-$ 36,730
'93	$ 98,744	$ 89,424	$ 369,387	$ 277,912	$ 2,328	-$ 32,690
'94	$ 99,197	$ 89,865	$ 325,102	$ 247,802	$ 1,560	-$ 33,074
Average	$ 125,244	$ 113,709	$ 380,959	$ 315,965	$ 2,000	-$ 37,866

	Ewe	Lamb	FGM
'85	$ 1,468	$ 10,668	$ 2,245,749
'86	$ 1,717	$ 11,712	$ 2,319,637
'87	$ 1,788	$ 12,840	$ 2,379,994
'88	$ 1,855	$ 13,236	$ 2,084,028
'89	$ 1,768	$ 13,392	$ 2,051,117
'90	$ 1,567	$ 11,892	$ 1,614,157
'91	$ 1,609	$ 11,784	$ 2,135,436
'92	$ 1,732	$ 12,996	$ 1,977,734
'93	$ 1,329	$ 10,980	$ 1,730,382
'94	$ 1,168	$ 10,500	$ 1,631,668
Average	$ 1,600	$ 12,000	$ 2,016,990

2.8 FARM H DATA

Fallow

	Month	Output	Input	QQ	Px	Total	Other
Input/output	Aug.		Ploughing I	1.00	8320	-$ 8,320	cash
	Oct.		Ploughing II	1.00	6400	-$ 6,400	cash
GM						-$ 14,720	

Wheat (taken)

	Month	Output	Input	QQ	Px	Total	Other
Input/output	May		Seeds	77	70	-$ 5,390	own
	May		Disinfectant			-$ 962	loan
	May		DAPh	77	166	-$ 12,782	loan
	Aug.		Urea	48	166	-$ 7,968	loan
	Dec.		Combine	96	70	-$ 6,720	own
	Dec.	Wheat		1536	70	$ 107,520	
GM						$ 73,698	
Labour use	May		Sowing			0.64	
	July		Fertilising			0.64	
	Dec.		Harvest			0.02	

Consumption 2000 kg

Sheep (given out)

Item	Month	Number		Value	QQ	Other
Culled ewes		1.00	15%	13000	$ 1,950	55 kg
Ewe-lambs		1.00	20%	10000	-$ 2,000	30 kg
Lambs		5.00	81%	10000	$ 8,100	30 kg
Wool (kg)	Nov.		2	150	$ 300	cash
GM per ewe					$ 6,400	
Shearing	Dec.				0.10	

Consumption 1 hd

Cattle (given out)

Item	Month	Number		Value	QQ	Other
Culled cows	Nov.-Apr.	0.00	10%	155000	$ 15,500	Cash
Heifers		0.00	15%	40000	-$ 6,000	
Yearlings	Oct.	2.00	74%	40000	$ 29,600	Cash
GM per cow					$ 23,600	

Charcoal (shared) (bag of 40 kg)

	Month	Output	Input	QQ	Px	Total	Other
Output	Sep.	Bags		100	1500	$ 150,000	Cash
Labour	May-Aug.					0.14	

Farm's actual GM

Activity	QQ	GM	Total
Fallow	9.38	-$ 14,720	-$ 138,074
Wheat	9.38	$ 73,698	$ 691,287
Sheep	5.00	$ 6,400	$ 32,000
Cattle	3.00	$ 23,600	$ 70,800
Charcoal	100.00	$ 1,500	$ 150,000
Off-farm labour	12.00	$ 58,900	$ 706,800
TOTAL			$ 1,512,814

Actual cash flow

	Wheat	Sheep	Cattle	Charcoal	Off-farm	Total	Balance
Apr.		$ 1,950	$ 9,300		$ 58,900	-$ 24,059	-$ 24,059
May					$ 58,900	-$ 35,309	-$ 59,368
June					$ 58,900	-$ 35,309	-$ 94,677
July					$ 58,900	-$ 35,309	-$ 129,986
Aug.	-$ 78,042				$ 58,900	-$ 113,351	-$ 243,337
Sep.				$ 150,000	$ 58,900	$ 114,691	-$ 128,646
Oct.	-$ 60,032	$ 30,000	$ 118,400		$ 58,900	$ 53,059	-$ 75,587
Nov.		$ 1,500			$ 58,900	-$ 33,809	-$ 109,396
Dec.	$ 488,254	$ 1,950	$ 9,300		$ 58,900	$ 464,195	$ 354,799
Jan.		$ 1,950	$ 9,300		$ 58,900	-$ 24,059	$ 330,740
Feb.		$ 1,950	$ 9,300		$ 58,900	-$ 24,059	$ 306,681
Mar.		$ 1,950	$ 9,300		$ 58,900	-$ 24,059	$ 282,622

Income less expenses	**$ 1,413,130**
Monthly cash expenses (-20%)	**$ 94,209**
Working capital	**$ 243,337**
Maximum loan	**$ 500,000**
Risk target	**$ 1,704,355**

Yearly GMs

	Wheat (fl)	Wheat (hi)	Ewes	Lamb	Cow	Yearling	FGM
'85	$ 83,581	$ 76,431	$ 2,078	$ 8,650	$ 15,485	$ 37,120	$ 1,663,069
'86	$ 83,858	$ 76,907	$ 2,402	$ 8,800	$ 17,577	$ 42,440	$ 1,704,355
'87	$ 64,769	$ 59,055	$ 2,494	$ 9,890	$ 17,717	$ 44,640	$ 1,520,073
'88	$ 58,361	$ 52,835	$ 2,582	$ 10,870	$ 16,182	$ 42,400	$ 1,457,108
'89	$ 60,515	$ 54,967	$ 2,468	$ 11,240	$ 15,423	$ 40,800	$ 1,490,785
'90	$ 48,216	$ 43,485	$ 2,207	$ 9,950	$ 13,315	$ 34,760	$ 1,340,619
'91	$ 51,107	$ 46,225	$ 2,262	$ 9,850	$ 16,353	$ 41,880	$ 1,416,357
'92	$ 47,326	$ 42,762	$ 2,422	$ 11,200	$ 16,973	$ 43,760	$ 1,405,388
'93	$ 46,204	$ 41,860	$ 1,897	$ 10,170	$ 14,012	$ 37,920	$ 1,377,211
'94	$ 45,861	$ 41,512	$ 1,688	$ 9,400	$ 11,935	$ 34,240	$ 1,368,746
Average	$ 58,980	$ 53,604	$ 2,250	$ 10,002	$ 15,497	$ 39,996	$ 1,474,371

3. BASE FARMING SYSTEM MODELS

3.1 BASE FSM-A

MAX AGM[16]
Subject to
-AGM +49081Afwh3 +150700Afch3 +142125Afvi1 +44531Ahwh3 +142045Ahch3 +39981Amwh3 +124735Amch3 +2100Alse1 -12000Alsr1 +12000Alsl1 +2100Alse2 -6000Alsr2 +6000Alsl2 +15500Alcc1 +15500Alcc2 -39000Alch2 +39000Alcy2 +74100Asy01 +74100Asy02 +72540Asy03 +72540Asy04 +73320Asy05 +78000Asy06 +80340Asy07 +81120Asy08 +80340Asy09 +78000Asy10 +74880Asy11 +73320Asy12 -0.075Acil -3000Awmh01 - 3000Awmh02 -3000Awmh03 -3000Awmh04 - 3000Awmh05 -3000Awmh06 -3000Awmh07 - 3000Awmh08 -3000Awmh09 -3000Awmh10 -3000Awmh11 - 3000Awmh12=0
-ARISK +1An85 +1An86 +1An87 +1An88 +1An89 +1An90 +1An91 +1An92 +1An93 +1An94=0
-ASE +7.719Afwh3 +20.314Affa3 -1.584Afch3 +1.747Afvi1 +36.754Ahwh3 +96.721Ahfa3 - 7.544Ahch3 +78.622Amwh3 +206.899Amfa3 -16.138Amch3 +1.204Alse1 +0.806Alsr1 +0.159Alsl1 +1.204Alse2 +0.806Alsr2 +0.159Alsl2 +7.821Alcc1 +9.667Alch1 +1.817Alcy1 +7.821Alcc2 +9.667Alch2 +1.817Alcy2 +12.337Alox +2.276Amppl=0
9) +1Afvi1<=0.2
10) +1Amppl=3
11) +1Afwh3 +1Affa3<=3.13
12) +1Ahwh3 +1Ahfa3<=3.13
13) +1Amwh3 +1Amfa3<=3.13
14) +1Afwh3 -1Affa3<=0
15) +1Ahwh3 -1Ahfa3<=0
16) +1Amwh3 -1Amfa3<=0
17) -1Afwh3 +3Afch3<=0
18) -1Ahwh3 +3Ahch3<=0
19) -1Amwh3 +3Amch3<=0
20) -1400Afwh3 -1330Ahwh3 -1260Amwh3 +1Aswh= -800
21) -577Afch3 -549Ahch3 -520Amch3 +1Asch= -80
22) +31919Afwh3 +22400Afch3 +6000Afvi1 +31919Ahwh3 +22400Ahch3 +31919Amwh3 +22400Amch3 -1Acil -1Acoc=0
23) +0.2Alse1 -1Alsr1<=0
24) -0.81Alse1 +1Alsl1<=0
25) +0.2Alse2 -1Alsr2<=0
26) -0.81Alse2 +1Alsl2<=0
27) +0.15Alcc1 -1Alch1<=0
28) -0.74Alcc1 +1Alcy1<=0
29) +0.15Alcc2 -1Alch2<=0

[16] First letter of the variable represents the FS and the following the variable's name, which are explained in Appendix 4

30) -0.74Alcc2 +1Alcy2<=0

31) -1141Afwh3 -1084Ahwh3 -1027Amwh3 +270Alse1 +173Alsr1 +61Alsl1 +1764Alcc1 +2180Alch1 +410Alcy1 +2769Alox -800Ampp1 +1Alft1 -0.7Alft2<=0

32) +193Alse1 +137Alsr1 +1244Alcc1 +1538Alch1 +289Alcy1 +1976Alox -0.7Alft1 +1Alft2<=0

33) +1Alch1 -1Alcy1 +1Asy01 +1Asy02 +1Asy03 +1Asy04 +1Asy05 +1Asy06 +1Asy07 +1Asy08 +1Asy09 +1Asy10 +1Asy11 +1Asy12<=0

34) +1Alse1 +1Alse2<=2

35) +1Alcc1 +1Alcc2<=2

36) +1.28Afwh3 +5Afvi1 +1.34Ahwh3 +1.41Amwh3 -1Awmh04 +1Awms04=30

37) -1Awmh05 +1Awms05=31

38) -1Awmh06 +1Awms06=30

39) +3.2Afwh3 +4Afvi1 +3.36Ahwh3 +3.52Amwh3 -1Awmh07 +1Awms07=31

40) +5.76Affa3 +6.05Ahfa3 +6.34Amfa3 -1Awmh08 +1Awms08=31

41) +5.12Afch3 +4Afvi1 +5.38Ahch3 +5.63Amch3 -1Awmh09 +1Awms09=30

42) -1Awmh10 +1Awms10=31

43) +10Afvi1 -1Awmh11 +1Awms11=30

44) +0.2Afwh3 +0.21Ahwh3 +0.22Amwh3 -1Awmh12 +1Awms12=31

45) +9.62Afch3 +10.1Ahch3 +10.58Amch3 -1Awmh01 +1Awms01=31

46) +2.56Affa3 +2.69Ahfa3 +2.82Amfa3 -1Awmh02 +1Awms02=28

47) -1Awmh03 +1Awms03=31

48) -360Alse1 -360Alse2 -3100Alcc1 -3100Alcc2 -65Aswh -72540Asy04 +1Acce +1Acoc -1Acwc +1Acb04 +3000Awmh04=0

49) -149625Afvi1 -73320Asy05 +1Acce -1Acb04 +1Acb05 +3000Awmh05=0

50) -78000Asy06 +1Acce -1Acb05 +1Acb06 +3000Awmh06=0

51) -80340Asy07 +1Acce -1Acb06 +1Acb07 +3000Awmh07=0

52) -81120Asy08 +1Acce -1Acb07 +1Acb08 +3000Awmh08=0

53) -80340Asy09 +1Acce -1Acb08 +1Acb09 +3000Awmh09=0

54) +39000Alch2 -39000Alcy2 -78000Asy10 +1Acce -1Acb09 +1Acb10 +3000Awmh10=0

55) +1500Afvi1 +12000Alsr1 -12000Alsl1 +6000Alsr2 -6000Alsl2 -74880Asy11 +1Acce -1Acb10 +1Acb11 +3000Awmh11=0

56) +10000Afwh3 +10000Ahwh3 +10000Amwh3 -360Alse1 -360Alse2 -3100Alcc1 -3100Alcc2 -73320Asy12 +1Acce -1Acb11 +1Acb12 +3000Awmh12=0

57) -360Alse1 -360Alse2 -3100Alcc1 -3100Alcc2 -74100Asy01 +1Acce +1Acb01 -1Acb12 +3000Awmh01=0

58) -360Alse1 -360Alse2 -3100Alcc1 -3100Alcc2 -300Asch -74100Asy02 +1Acce -1Acb01 +1Acb02 +3000Awmh02=0

59) -360Alse1 -360Alse2 -3100Alcc1 -3100Alcc2 -72540Asy03 +1Acce +1.075Acil +1Acwc +1Acci -1Acb02 +3000Awmh03=0

60) -67903Afwh3 -146853Afch3 -74609Afvi1 -138414Ahwh3 -129976Ahch3 -61852Amwh3 -129976Amch3 -1941Alse1 +8407Alsr1 -8407Alsl1 -1941Alse2 +4203Alsr2 -4204Alsl2 -15484Alcc1 +72384Alch1 -72384Alcy1 -15484Alcc2 +36192Alch2 -36192Alcy2 +2340Awmh01 +2340Awmh02 +2340Awmh03 +2340Awmh04 +2340Awmh05 +2340Awmh06 +2340Awmh07 +2340Awmh08 +2340Awmh09 +2340Awmh10 +2340Awmh11 +2340Awmh12 -1An85 +1Ant<=0

61) -74747Afwh3 -158857Afch3 -174797Afvi1 -149743Ahwh3 -140630Ahch3 -62982Amwh3 -140630Amch3 -2240Alse1 +8553Alsr1 -8553Alsl1 -2240Alse2 +4276Alsr2 -4277Alsl2 -17577Alcc1 +82758Alch1 -82758Alcy1 -17577Alcc2 +41379Alch2 -41379Alcy2 +2399Awmh01 +2399Awmh02 +2399Awmh03 +2399Awmh04 +2399Awmh05 +2399Awmh06 +2399Awmh07 +2399Awmh08 +2399Awmh09 +2399Awmh10 +2399Awmh11 +2399Awmh12 -1An86 +1Ant<=0

62) -57178Afwh3 -125923Afch3 -225642Afvi1 -52343Ahwh3 -118661Ahch3 -47506Amwh3 -111400Amch3 -2325Alse1 +9613Alsr1 -9613Alsl1 -2325Alse2 +4806Alsr2 -4807Alsl2 -17716Alcc1 +87048Alch1 -87048Alcy1 -17716Alcc2 +43524Alch2 -43524Alcy2 +2459Awmh01 +2459Awmh02 +2459Awmh03 +2459Awmh04 +2459Awmh05 +2459Awmh06 +2459Awmh07 +2459Awmh08 +2459Awmh09 +2459Awmh10 +2459Awmh11 +2459Awmh12 -1An87 +1Ant<=0

63) -51417Afwh3 -110686Afch3 -86787Afvi1 -46741Ahwh3 -104282Ahch3 -42064Amwh3 -97877Amch3 -2406Alse1 +10565Alsr1 -10565Alsl1 -2406Alse2 +5282Alsr2 -5283Alsl2 -16182Alcc1 +82680Alch1 -82680Alcy1 -16182Alcc2 +41340Alch2 -41340Alcy2 +2521Awmh01 +2521Awmh02 +2521Awmh03 +2521Awmh04 +2521Awmh05 +2521Awmh06 +2521Awmh07 +2521Awmh08+2521Awmh09 +2521Awmh10 +2521Awmh11 +2521Awmh12 -1An88 +1Ant<=0

64) -51200Afwh3 -189945Afch3 -61357Afvi1 -46506Ahwh3 -179083Ahch3 -41810Amwh3 -168221Amch3 -2301Alse1 +10925Alsr1 -10925Alsl1 -2301Alse2 +5462Alsr2 -5463Alsl2 -15422Alcc1 +79560Alch1 -79560Alcy1 -15422Alcc2 +39780Alch2 -39780Alcy2 +2585Awmh01 +2585Awmh02 +2585Awmh03 +2585Awmh04 +2585Awmh05 +2585Awmh06 +2585Awmh07 +2585Awmh08 +2585Awmh09 +2585Awmh10 +2585Awmh11 +2585Awmh12 -1An89 +1Ant<=0

65) -38737Afwh3 -201949Afch3 -77123Afvi1 -34734Ahwh3 -190412Ahch3 -30730Amwh3 -178875Amch3 -2060Alse1 +9671Alsr1 -9671Alsl1 -2060Alse2 +4835Alsr2 -4836Alsl2 -13314Alcc1 +67782Alch1 -67782Alcy1 -13314Alcc2 +33891Alch2 -33891Alcy2 +2650Awmh01 +2650Awmh02 +2650Awmh03 +2650Awmh04 +2650Awmh05 +2650Awmh06 +2650Awmh07 +2650Awmh08 +2650Awmh09 +2650Awmh10 +2650Awmh11 +2650Awmh12 -1An90 +1Ant<=0

66) -39038Afwh3 -183173Afch3 -189981Afvi1 -34908Ahwh3 -172692Ahch3 -30776Amwh3 -162211Amch3 -2110Alse1 +9574Alsr1 -9574Alsl1 -2110Alse2 +4787Alsr2 -4787Alsl2 -16352Alcc1 +81666Alch1 -81666Alcy1 -16352Alcc2 +40833Alch2 -40833Alcy2 +2717Awmh01 +2717Awmh02 +2717Awmh03 +2717Awmh04 +2717Awmh05 +2717Awmh06 +2717Awmh07 +2717Awmh08 +2717Awmh09 +2717Awmh10 +2717Awmh11 +2717Awmh12 -1An91 +1Ant<=0

67) -35287Afwh3 -135003Afch3 -285557Afvi1 -31425Ahwh3 -127231Ahch3 -27562Amwh3 -119458Amch3 -2258Alse1 +10886Alsr1 -10886Alsl1 -2258Alse2 +5443Alsr2 -5443Alsl2 -16972Alcc1 +85332Alch1 -85332Alcy1 -16972Alcc2 +42666Alch2 -42666Alcy2 +2785Awmh01 +2785Awmh02 +2785Awmh03 +2785Awmh04 +2785Awmh05 +2785Awmh06 +2785Awmh07 +2785Awmh08 +2785Awmh09 +2785Awmh10 +2785Awmh11 +2785Awmh12 -1An92 +1Ant<=0

68) -34104Afwh3 -111918Afch3 -153829Afvi1 -30429Ahwh3 -105444Ahch3 -26752Amwh3 -98970Amch3 -1774Alse1 +9885Alsr1 -9885Alsl1 -1774Alse2 +4942Alsr2 -4943Alsl2 -14012Alcc1 +73944Alch1 -73944Alcy1 -14012Alcc2 +36972Alch2 -36972Alcy2 +2855Awmh01 +2855Awmh02 +2855Awmh03 +2855Awmh04 +2855Awmh05 +2855Awmh06 +2855Awmh07 +2855Awmh08 +2855Awmh09 +2855Awmh10 +2855Awmh11 +2855Awmh12 -1An93 +1Ant<=0

69) -35122Afwh3 -142852Afch3 -91568Afvi1 -31442Ahwh3 -134638Ahch3 -27761Amwh3 -126424Amch3 -1581Alse1 +9136Alsr1 -9136Alsl1 -1581Alse2 +4568Alsr2 -4568Alsl2 -11935Alcc1 +66768Alch1 -66768Alcy1 -11935Alcc2 +33384Alch2 -33384Alcy2 +2927Awmh01 +2927Awmh02 +2927Awmh03 +2927Awmh04 +2927Awmh05 +2927Awmh06 +2927Awmh07 +2927Awmh08 +2927Awmh09 +2927Awmh10 +2927Awmh11 +2927Awmh12 -1An94 +1Ant<=0

SUB[17] Afvi1 0.2
SLB Alox 1
SLB Acce 29093
SUB Acwc 56174
SLB Ant 718005
SUB Ant 718005

3.2 BASE FSM-B

MAX BGM
Subject to

-BGM +121065Bfwh1 +191500Bfch1 +174500Bfle1 +219200Bfpe1 +111926Bhwh1 +179500Bhch1 +164500Bhle1 +205200Bhpe1 +1743Blse1 -12600Blsr1 +12600Blsl1 +14960Blcc1 -42160Bfoa1 -42160Bhoa1 -43Blfah +80750Bsy01 +80750Bsy02 +79050Bsy03 +79050Bsy04 +79900Bsy05 +85000Bsy06 +87550Bsy07 +88400Bsy08 +87550Bsy09 +85000Bsy10 +81600Bsy11 +79900Bsy12 -0.075Bcil -3000Bwmh01 -3000Bwmh02 -3000Bwmh03 -3000Bwmh04 -3000Bwmh05 -3000Bwmh06 -3000Bwmh07 -3000Bwmh08 -3000Bwmh09 -3000Bwmh10 -3000Bwmh11 -3000Bwmh12=0

-BRISK +1Bn85 +1Bn86 +1Bn87 +1Bn88 +1Bn89 +1Bn90 +1Bn91 +1Bn92 +1Bn93 +1Bn94=0

-BSE +5.639Bfwh1 +14.838Bffa1 -1.157Bfch1 +7.568Bfle1 +7.568Bfpe1 +26.847Bhwh1 +70.651Bhfa1 -5.511Bhch1 +36.032Bhle1 +36.032Bhpe1 +0.889Blse1
+0.589Blsr1 +0.116Blsl1 +5.715Blcc1 +7.064Blch1 +1.328Blcy1 +5.894Blho
+0.608Bfrg1 +2.897Bhrg1 +1.662Bmpp1 +5.639Bfoa1 +26.847Bhoa1=0

77) +1Bfwh1 +1Bffa1 +1Bfle1 +1Bfpe1 +1Bfrg1 +1Bfoa1=20
78) +1Bhwh1 +1Bhfa1 +1Bhle1 +1Bhpe1 +1Bhrg1 +1Bhoa1=15
79) +1Bmpp1=40
80) +1Bfwh1 -1Bffa1 +1Bfpe1<=0
81) -1Bfwh1 +3Bfch1<=0

[17] SUB represent upper bounds and SLB lower bounds.

82) +2Bfwh1 +2Bfpe1 -1Bfrg1<=0
83) -1Bfwh1 +3Bfle1<=0
84) -1Bfwh1 +1Bfoa1<=0
85) +1Bhwh1 -1Bhfa1 +1Bhpe1<=0
86) -1Bhwh1 +3Bhch1<=0
87) +2Bhwh1 +2Bhpe1 -1Bhrg1<=0
88) -1Bhwh1 +3Bhle1<=0
89) -1Bhwh1 +1Bhoa1<=0
90) -2265Bfwh1 -2135Bhwh1 +1Bswh= -800
91) -700Bfch1 -660Bhch1 +1Bsch= -200
92) -355Bfle1 -335Bhle1 +1Bsle=0
93) +0.2Blse1 -1Blsr1<=0
94) -0.81Blse1 +1Blsl1<=0
95) +1Blsr1 -1Blsl1 +1Bsla= -8
96) +0.15Blcc1 -1Blch1<=0
97) -0.74Blcc1 +1Blcy1<=0
98) +1Blch1 -1Blcy1 +1Bsy01 +1Bsy02 +1Bsy03 +1Bsy04 +1Bsy05 +1Bsy06 +1Bsy07 +1Bsy08 +1Bsy09 +1Bsy10 +1Bsy11 +1Bsy12=0
99) -3404Bfwh1 -3234Bhwh1 +273Blse1 +173Blsr1 +61Blsl1 +1764Blcc1 +2180Blch1 +410Blcy1 +1819Blho -1320Bfrg1 -1100Bhrg1 -880Bmpp1 -2400Bfoa1 -2280Bhoa1 -1Blfah +1Blft1 -0.7Blft2<=0
100) +195Blse1 +137Blsr1 +1244Blcc1 +1538Blch1 +289Blcy1 +1283Blho -0.7Blft1 +1Blft2<=0
101) +37485Bfwh1 +13500Bfch1 +60800Bfpe1 +37485Bhwh1 +13500Bhch1 +60800Bhpe1 +42160Bfoa1 +42160Bhoa1 -1Bcil -1Bcoc=0
102) +0.21Bfwh1 +0.22Bhwh1 -1Bwmh04 +1Bwms04=30
103) +1.92Bfwh1 +3Bfle1 +3Bfpe1 +2.02Bhwh1 +3.15Bhle1 +3.15Bhpe1 +3Bfoa1 +3.15Bhoa1 -1Bwmh05 +1Bwms05=31
104) -1Bwmh06 +1Bwms06=30
105) +0.57Bfwh1 +0.5Bfpe1 +0.6Bhwh1 +0.53Bhpe1 +0.5Bfoa1 +0.53Bhoa1 -1Bwmh07 +1Bwms07=31
106) +2.56Bffa1 +2.69Bhfa1 -1Bwmh08 +1Bwms08=31
107) +1.92Bffa1 +2Bfch1 +2.02Bhfa1 +2.1Bhch1 -1Bwmh09 +1Bwms09=30
108) +4Bfpe1 +4.2Bhpe1 -1Bwmh10 +1Bwms10=31
109) +0.01Blse1 -1Bwmh11 +1Bwms11=30
110) +0.2Bfwh1 +0.21Bhwh1 +7Bfoa1 +7.35Bhoa1 -1Bwmh12 +1Bwms12=31
111) +9Bfch1 +10Bfle1 +9.45Bhch1 +10.5Bhle1 -1Bwmh01 +1Bwms01=31
112) -1Bwmh02 +1Bwms02=28
113) -1Bwmh03 +1Bwms03=31
114) +962Bfwh1 -360Blse1 -3100Blcc1 -79050Bsy04 +1Bcce +1Bcoc -1Bcwc +1Bcb04 +3000Bwmh04=0
115) +540Blcc1 -79900Bsy05 +1Bcce -1Bcb04 +1Bcb05 +3000Bwmh05=0
116) -85000Bsy06 +1Bcce -1Bcb05 +1Bcb06 +3000Bwmh06=0
117) -87550Bsy07 +1Bcce -1Bcb06 +1Bcb07 +3000Bwmh07=0
118) -88400Bsy08 +1Bcce -1Bcb07 +1Bcb08 +3000Bwmh08=0
119) -12600Bsla -87550Bsy09 +1Bcce -1Bcb08 +1Bcb09 +3000Bwmh09=0
120) -280000Bfpe1 -280000Bhpe1 +85000Blch1 -85000Blcy1 -85000Bsy10 +1Bcce -1Bcb09 +1Bcb10 +3000Bwmh10=0
121) -300Blse1 -81600Bsy11 +1Bcce -1Bcb10 +1Bcb11 +3000Bwmh11=0

122) -360Blse1 -3100Blcc1 -79900Bsy12 +1Bcce -1Bcb11 +1Bcb12 +3000Bwmh12=0

123) +5000Bfch1 +3000Bfle1 +5000Bhch1 +3000Bhle1 -360Blse1 -3100Blcc1 -70Bswh -80750Bsy01 +1Bcce +1Bcb01 -1Bcb12 +3000Bwmh01=0

124) -3Blse1 -3100Blcc1 +43Blfah -300Bsch -500Bsle -80750Bsy02 +1Bcce -1Bcb01 +1Bcb02 +3000Bwmh02=0

125) -360Blse1 -3100Blcc1 -79050Bsy03 +1Bcce +1.075Bcil +1Bcwc +1Bcci -1Bcb02 +3000Bwmh03=0

126) -164504Bfwh1 -152350Bfch1 -198817Bfle1 -153664Bfpe1 -152350Bhwh1 -172471Bhch1 -187447Bhle1 -142520Bhpe1 -1584Blse1 +10899Blsr1 -10899Blsl1 -14944Blcc1 +78880Blch1 -78880Blcy1 +47787Bfoa1 +47787Bhoa1 +36Blfah +2340Bwmh01 +2340Bwmh02 +2340Bwmh03 +2340Bwmh04 +2340Bwmh05 +2340Bwmh06 +2340Bwmh07 +2340Bwmh08 +2340Bwmh09 +2340Bwmh10 +2340Bwmh11 +2340Bwmh12 -1Bn85 +1Bnt<=0

127) -164761Bfwh1 -152945Bfch1 -273190Bfle1 -212794Bfpe1 -152945Bhwh1 -187591Bhch1 -257630Bhle1 -199088Bhpe1 -1883Blse1 +11088Blsr1 -11088Blsl1 -17037Blcc1 +90185Blch1 -90185Blcy1 +42257Bfoa1 +42257Bhoa1 +57Blfah +2399Bwmh01 +2399Bwmh02 +2399Bwmh03 +2399Bwmh04 +2399Bwmh05 +2399Bwmh06 +2399Bwmh07 +2399Bwmh08 +2399Bwmh09 +2399Bwmh10 +2399Bwmh11 +2399Bwmh12 -1Bn86 +1Bnt<=0

128) -132534Bfwh1 -122820Bfch1 -187990Bfle1 -254294Bfpe1 -122820Bhwh1 -146137Bhch1 -177230Bhle1 -238726Bhpe1 -1968Blse1 +12461Blsr1 -12461Blsl1 -17176Blcc1 +94860Blch1 -94860Blcy1 +40166Bfoa1 +40166Bhoa1 +56Blfah +2459Bwmh01 +2459Bwmh02 +2459Bwmh03 +2459Bwmh04 +2459Bwmh05 +2459Bwmh06 +2459Bwmh07 +2459Bwmh08 +2459Bwmh09 +2459Bwmh10 +2459Bwmh11 +2459Bwmh12 -1Bn87 +1Bnt<=0

129) -121714Bfwh1 -112319Bfch1 -128527Bfle1 -232282Bfpe1 -112319Bhwh1 -125252Bhch1 -121117Bhle1 -217456Bhpe1 -2049Blse1 +13696Blsr1 -13696Blsl1 -15642Blcc1 +90100Blch1 -90100Blcy1 +43944Bfoa1 +43944Bhoa1 +50Blfah +2521Bwmh01 +2521Bwmh02 +2521Bwmh03 +2521Bwmh04 +2521Bwmh05 +2521Bwmh06 +2521Bwmh07 +2521Bwmh08 +2521Bwmh09 +2521Bwmh10 +2521Bwmh11 +2521Bwmh12 -1Bn88 +1Bnt<=0

130) -124126Bfwh1 -114695Bfch1 -175387Bfle1 -218322Bfpe1 -114695Bhwh1 -228626Bhch1 -165337Bhle1 -204252Bhpe1 -1944Blse1 +14162Blsr1 -14162Blsl1 -14882Blcc1 +86700Blch1 -86700Blcy1 +44189Bfoa1 +44189Bhoa1 +49Blfah +2585Bwmh01 +2585Bwmh02 +2585Bwmh03 +2585Bwmh04 +2585Bwmh05 +2585Bwmh06 +2585Bwmh07 +2585Bwmh08 +2585Bwmh09 +2585Bwmh10 +2585Bwmh11 +2585Bwmh12 -1Bn89 +1Bnt<=0

131) -102598Bfwh1 -94556Bfch1 -208580Bfle1 -249671Bfpe1 -94556Bhwh1 -245933Bhch1 -196660Bhle1 -234103Bhpe1 -1703Blse1 +12537Blsr1 -12537Blsl1 -12774Blcc1 +73865Blch1 -73865Blcy1 +41614Bfoa1 +41614Bhoa1 +35Blfah +2650Bwmh01 +2650Bwmh02 +2650Bwmh03 +2650Bwmh04 +2650Bwmh05 +2650Bwmh06 +2650Bwmh07 +2650Bwmh08 +2650Bwmh09 +2650Bwmh10 +2650Bwmh11 +2650Bwmh12 -1Bn90 +1Bnt<=0

132) -105881Bfwh1 -97583Bfch1 -187812Bfle1 -283658Bfpe1 -97583Bhwh1 -222020Bhch1 -177062Bhle1 -266158Bhpe1 -1753Blse1 +12411Blsr1 -12411Blsl1 -15812Blcc1 +88995Blch1 -88995Blcy1 +44854Bfoa1 +44854Bhoa1 +34Blfah +2717Bwmh01 +2717Bwmh02 +2717Bwmh03 +2717Bwmh04 +2717Bwmh05 +2717Bwmh06 +2717Bwmh07 +2717Bwmh08 +2717Bwmh09 +2717Bwmh10 +2717Bwmh11 +2717Bwmh12 -1Bn91 +1Bnt<=0

133) -99344Bfwh1 -91585Bfch1 -121605Bfle1 -210724Bfpe1 -91585Bhwh1 -161626Bhch1 -114585Bhle1 -197172Bhpe1 -1901Blse1 +14112Blsr1 -14112Blsl1 -16432Blcc1 +92990Blch1 -92990Blcy1 +43209Bfoa1 +43209Bhoa1 +36Blfah +2785Bwmh01 +2785Bwmh02 +2785Bwmh03 +2785Bwmh04 +2785Bwmh05 +2785Bwmh06 +2785Bwmh07 +2785Bwmh08 +2785Bwmh09 +2785Bwmh10 +2785Bwmh11 +2785Bwmh12 -1Bn92 +1Bnt<=0

134) -97472Bfwh1 -90088Bfch1 -128527Bfle1 -203551Bfpe1 -90088Bhwh1 -133006Bhch1 -121117Bhle1 -190699Bhpe1 -1417Blse1 +12814Blsr1 -12814Blsl1 -13472Blcc1 +80580Blch1 -80580Blcy1 +37191Bfoa1 +37191Bhoa1 +37Blfah +2855Bwmh01 +2855Bwmh02 +2855Bwmh03 +2855Bwmh04 +2855Bwmh05 +2855Bwmh06 +2855Bwmh07 +2855Bwmh08 +2855Bwmh09 +2855Bwmh10 +2855Bwmh11 +2855Bwmh12 -1Bn93 +1Bnt<=0

135) -97723Bfwh1 -90330Bfch1 -134562Bfle1 -172749Bfpe1 -90330Bhwh1 -172534Bhch1 -126812Bhle1 -161549Bhpe1 -1224Blse1 +11844Blsr1 -11844Blsl1 -11395Blcc1 +72760Blch1 -72760Blcy1 +36443Bfoa1 +36443Bhoa1 +34Blfah +2927Bwmh01 +2927Bwmh02 +2927Bwmh03 +2927Bwmh04 +2927Bwmh05 +2927Bwmh06 +2927Bwmh07 +2927Bwmh08 +2927Bwmh09 +2927Bwmh10 +2927Bwmh11 +2927Bwmh12 -1Bn94 +1Bnt<=0

SLB Blfah 3000
SLB Blho 2
SLB Bcce 154544
SUB Bcwc 272165
SUB Bcil 500000
SLB Bnt 2804340
SUB Bnt 2804340

3.3 BASE FSM-C

MAX CGM
Subject to

-CGM +162690Cfwh1 +150210Chwh1 +2100Clse1 -12000Clsr1 +12000Clsl1 -40Clfah -0.075Ccil -3000Cwmh01 -3000Cwmh02 -3000Cwmh03 -3000Cwmh04 -3000Cwmh05 -3000Cwmh06 -3000Cwmh07 -3000Cwmh08 -3000Cwmh09 -3000Cwmh10 -3000Cwmh11 -3000Cwmh12=0

-CRISK +1Cn85 +1Cn86 +1Cn87 +1Cn88 +1Cn89 +1Cn90 +1Cn91 +1Cn92 +1Cn93 +1Cn94=0

-CSE +5.679Cfwh1 +14.945Cffa1 +27.04Chwh1 +71.157Chfa1 +0.889Clse1 +0.589Clsr1 +0.116Clsl1 +5.894Clho +0.613Cfrg1 +2.917Chrg1<=0143) +1Cfwh1 +1Cffa1 +1Cfrg1=12

144) +1Chwh1 +1Chfa1 +1Chrg1=28
145) +1Cfwh1 -1Cffa1<=0
146) +2Cfwh1 -1Cfrg1<=0
147) +1Chwh1 -1Chfa1<=0
148) +2Chwh1 -1Chrg1<=0
149) -3120Cfwh1 -2964Chwh1 +1Cswh= -120
150) +0.2Clse1 -1Clsr1<=0
151) -0.81Clse1 +1Clsl1<=0

152) +1Clsr1 -1Clsl1 +1Csla= -5

153) -1084.928Cfwh1 -1031Chwh1 +273Clse1 +173Clsr1 +61Clsl1 +1819Clho -1200Cfrg1 -1000Chrg1 +1Clft1 -0.7Clft2<=0

154) +195Clse1 +137Clsr1 +1283Clho -0.7Clft1 +1Clft2 -1Clfah<=0

155) +71310Cfwh1 +71310Chwh1 -1Ccil -1Ccoc=0

156) +0.32Cfwh1 +0.34Chwh1 -1Cwmh04 +1Cwms04=30

157) +0.64Cfwh1 +0.67Chwh1 -1Cwmh05 +1Cwms05=31

158) +0.64Cfwh1 +0.67Chwh1 -1Cwmh06 +1Cwms06=30

159) +2.56Cffa1 +2.69Chfa1 -1Cwmh07 +1Cwms07=31

160) -1Cwmh08 +1Cwms08=31

161) +1.28Cffa1 +1.34Chfa1 -1Cwmh09 +1Cwms09=30

162) -1Cwmh10 +1Cwms10=31

163) +0.05Clse1 -1Cwmh11 +1Cwms11=30

164) +0.2Cfwh1 +0.21Chwh1 -1Cwmh12 +1Cwms12=31

165) +0Clsl1 +1Cwmh01 +1Cwms01=31

166) -1Cwmh02 -1Cwmh11 +1Cwms02=28

167) -1Cwmh03 +1Cwms03=31

168) -360Clse1 +1Ccce +1Ccoc -1Ccwc +1Ccb04 +3000Cwmh04=0

169) +1Ccce -1Ccb04 +1Ccb05 +3000Cwmh05=0

170) +1Ccce -1Ccb05 +1Ccb06 +3000Cwmh06=0

171) +1Ccce -1Ccb06 +1Ccb07 +3000Cwmh07=0

172) -12000Csla +1Ccce -1Ccb07 +1Ccb08 +3000Cwmh08=0

173) +1Ccce -1Ccb08 +1Ccb09 +3000Cwmh09=0

174) +1Ccce -1Ccb09 +1Ccb10 +3000Cwmh10=0

175) -300Clse1 +1Ccce -1Ccb10 +1Ccb11 +3000Cwmh11=0

176) -360Clse1 -75Cswh +1Ccce -1Ccb11 +1Ccb12 +3000Cwmh12=0

177) -360Clse1 +1Ccce +1Ccb01 -1Ccb12 +3000Cwmh01=0

178) -360Clse1 +1Ccce -1Ccb01 +1Ccb02 +3000Cwmh02=0

179) -360Clse1 +40Clfah +1Ccce +1.075Ccil +1Ccwc +1Ccci -1Ccb02 +3000Cwmh03=0

180) -217396Cfwh1 -200798Chwh1 -1941Clse1 +10380Clsr1 -10380Clsl1 +34Clfah +2340Cwmh01 +2340Cwmh02 +2340Cwmh03 +2340Cwmh04 +2340Cwmh05 +2340Cwmh06 +2340Cwmh07 +2340Cwmh08 +2340Cwmh09 +2340Cwmh10 +2340Cwmh11 +2340Cwmh12 -1Cn85 +1Cnt<=0

181) -217498Cfwh1 -201361Chwh1 -2240Clse1 +10560Clsr1 -10560Clsl1 +53Clfah +2399Cwmh01 +2399Cwmh02 +2399Cwmh03 +2399Cwmh04 +2399Cwmh05 +2399Cwmh06 +2399Cwmh07 +2399Cwmh08 +2399Cwmh09 +2399Cwmh10 +2399Cwmh11 +2399Cwmh12 -1Cn86 +1Cnt<=0

182) -175582Cfwh1 -162316Chwh1 -2325Clse1 +11868Clsr1 -11868Clsl1 +53Clfah +2459Cwmh01 +2459Cwmh02 +2459Cwmh03 +2459Cwmh04 +2459Cwmh05 +2459Cwmh06 +2459Cwmh07 +2459Cwmh08 +2459Cwmh09 +2459Cwmh10 +2459Cwmh11 +2459Cwmh12 -1Cn87 +1Cnt<=0

183) -162720Cfwh1 -149890Chwh1 -2406Clse1 +13044Clsr1 -13044Clsl1 +47Clfah +2521Cwmh01 +2521Cwmh02 +2521Cwmh03 +2521Cwmh04 +2521Cwmh05 +2521Cwmh06 +2521Cwmh07 +2521Cwmh08 +2521Cwmh09 +2521Cwmh10 +2521Cwmh11 +2521Cwmh12 -1Cn88 +1Cnt<=0

184) -165931Cfwh1 -153051Chwh1 -2301Clse1 +13488Clsr1 -13488Clsl1 +45Clfah +2585Cwmh01 +2585Cwmh02 +2585Cwmh03 +2585Cwmh04 +2585Cwmh05

+2585Cwmh06 +2585Cwmh07 +2585Cwmh08 +2585Cwmh09 +2585Cwmh10 +2585Cwmh11 +2585Cwmh12 -1Cn89 +1Cnt<=0

185) -139401Cfwh1 -128419Chwh1 -2060Clse1 +11940Clsr1 -11940Clsl1 +33Clfah +2650Cwmh01 +2650Cwmh02 +2650Cwmh03 +2650Cwmh04 +2650Cwmh05 +2650Cwmh06 +2650Cwmh07 +2650Cwmh08 +2650Cwmh09 +2650Cwmh10 +2650Cwmh11 +2650Cwmh12 -1Cn90 +1Cnt<=0

186) -144791Cfwh1 -133459Chwh1 -2110Clse1 +11820Clsr1 -11820Clsl1 +32Clfah +2717Cwmh01 +2717Cwmh02 +2717Cwmh03 +2717Cwmh04 +2717Cwmh05 +2717Cwmh06 +2717Cwmh07 +2717Cwmh08 +2717Cwmh09 +2717Cwmh10 +2717Cwmh11 +2717Cwmh12 -1Cn91 +1Cnt<=0

187) -136834Cfwh1 -126238Chwh1 -2258Clse1 +13440Clsr1 -13440Clsl1 +33Clfah +2785Cwmh01 +2785Cwmh02 +2785Cwmh03 +2785Cwmh04 +2785Cwmh05 +2785Cwmh06 +2785Cwmh07 +2785Cwmh08 +2785Cwmh09 +2785Cwmh10 +2785Cwmh11 +2785Cwmh12 -1Cn92 +1Cnt<=0

188) -133358Cfwh1 -123274Chwh1 -1774Clse1 +12204Clsr1 -12204Clsl1 +34Clfah +2855Cwmh01 +2855Cwmh02 +2855Cwmh03 +2855Cwmh04 +2855Cwmh05 +2855Cwmh06 +2855Cwmh07 +2855Cwmh08 +2855Cwmh09 +2855Cwmh10 +2855Cwmh11 +2855Cwmh12 -1Cn93 +1Cnt<=0

189) -133380Cfwh1 -123284Chwh1 -1581Clse1 +11280Clsr1 -11280Clsl1 +32Clfah +2927Cwmh01 +2927Cwmh02 +2927Cwmh03 +2927Cwmh04 +2927Cwmh05 +2927Cwmh06 +2927Cwmh07 +2927Cwmh08 +2927Cwmh09 +2927Cwmh10 +2927Cwmh11 +2927Cwmh12 -1Cn94 +1Cnt<=0

SLB Clho 2
SUB Clho 2
SLB Clfah 900
SLB Ccce 131433
SUB Ccwc 808056
SUB Ccil 900000
SLB Cnt 2587988
SUB Cnt 2587988

3.4 Base FSM-D

MAX DGM
Subject to

-DGM +47284Dfwh2 +42724Dhwh2 +2100Dlse1 -12000Dlsr1 +12000Dlsl1 -40Dlfah - 0.075Dcil -3000Dwmh01 -3000Dwmh02 -3000Dwmh03 -3000Dwmh04 - 3000Dwmh05 -3000Dwmh06 -3000Dwmh07 -3000Dwmh08 -3000Dwmh09 - 3000Dwmh10 -3000Dwmh11 -3000Dwmh12=0

-DRISK +1Dn85 +1Dn86 +1Dn87 +1Dn88 +1Dn89 +1Dn90 +1Dn91 +1Dn92 +1Dn93 +1Dn94=0

-DSE +2.733Dfwh2 +7.192Dffa2 +13.012Dhwh2 +34.242Dhfa2 +0.418Dlse1 +0.279Dlsr1 +0.055Dlsl1 +2.792Dlho +0.295Dfrg1 +1.404Dhrg1=0

197) +1Dfwh2 +1Dffa2 +1Dfrg1=12

198) +1Dhwh2 +1Dhfa2 +1Dhrg1=12

199) +1Dfwh2 -1Dffa2<=0

200) +2Dfwh2 -1Dfrg1<=0

201) +1Dhwh2 -1Dhfa2<=0
202) +2Dhwh2 -1Dhrg1<=0
203) -1024Dfwh2 -973Dhwh2 +1Dswh=0
204) +0.2Dlse1 -1Dlsr1<=0
205) -0.81Dlse1 +1Dlsl1<=0
206) +1Dlsr1 -1Dlsl1 +1Dsla= -12
207) -991Dfwh2 -942Dhwh2 +271Dlse1 +173Dlsr1 +61Dlsl1 +1819Dlho -1200Dfrg1 -1000Dhrg1 +1Dlft1 -0.7Dlft2<=0
208) +193Dlse1 +137Dlsr1 +1283Dlho -0.7Dlft1 +1Dlft2 -1Dlfah<=0
209) +29516Dfwh2 +29516Dhwh2 -1Dcil -1Dcoc=0
210) -1Dwmh04=0
211) -1Dwmh05=0
212) -1Dwmh06=0
213) -1Dwmh07=0
214) -1Dwmh08=0
215) -1Dwmh09=0
216) -1Dwmh10=0
217) -1Dwmh11=0
218) -1Dwmh12=0
219) -1Dwmh01=0
220) -1Dwmh02=0
221) -1Dwmh03=0
222) -360Dlse1 +1Dcce +1Dcoc -1Dcwc +1Dcb04 +3000Dwmh04=0
223) +1Dcce -1Dcb04 +1Dcb05 +3000Dwmh05=0
224) +1Dcce -1Dcb05 +1Dcb06 +3000Dwmh06=0
225) +1Dcce -1Dcb06 +1Dcb07 +3000Dwmh07=0
226) +1Dcce -1Dcb07 +1Dcb08 +3000Dwmh08=0
227) +1Dcce -1Dcb08 +1Dcb09 +3000Dwmh09=0
228) +1Dcce -1Dcb09 +1Dcb10 +3000Dwmh10=0
229) -300Dlse1 -12000Dsla +1Dcce -1Dcb10 +1Dcb11 +3000Dwmh11=0
230) -360Dlse1 -75Dswh +1Dcce -1Dcb11 +1Dcb12 +3000Dwmh12=0
231) -360Dlse1 +1Dcce +1Dcb01 -1Dcb12 +3000Dwmh01=0
232) -360Dlse1 +1Dcce -1Dcb01 +1Dcb02 +3000Dwmh02=0
233) -360Dlse1 +40Dlfah +1Dcce +1.075Dcil +1Dcwc +1Dcci -1Dcb02 +3000Dwmh03=0
234) -64802Dfwh2 -58738Dhwh2 -1941Dlse1 +10380Dlsr1 -10380Dlsl1 +34Dlfah +2340Dwmh01 +2340Dwmh02 +2340Dwmh03 +2340Dwmh04 +2340Dwmh05 +2340Dwmh06 +2340Dwmh07 +2340Dwmh08 +2340Dwmh09 +2340Dwmh10 +2340Dwmh11 +2340Dwmh12 -1Dn85 +1Dnt<=0
235) -66497Dfwh2 -60601Dhwh2 -2240Dlse1 +10560Dlsr1 -10560Dlsl1 +53Dlfah +2399Dwmh01 +2399Dwmh02 +2399Dwmh03 +2399Dwmh04 +2399Dwmh05 +2399Dwmh06 +2399Dwmh07 +2399Dwmh08 +2399Dwmh09 +2399Dwmh10 +2399Dwmh11 +2399Dwmh12 -1Dn86 +1Dnt<=0
236) -51832Dfwh2 -46985Dhwh2 -2325Dlse1 +11868Dlsr1 -11868Dlsl1 +53Dlfah +2459Dwmh01 +2459Dwmh02 +2459Dwmh03 +2459Dwmh04 +2459Dwmh05 +2459Dwmh06 +2459Dwmh07 +2459Dwmh08 +2459Dwmh09 +2459Dwmh10 +2459Dwmh11 +2459Dwmh12 -1Dn87 +1Dnt<=0
237) -45325Dfwh2 -40638Dhwh2 -2406Dlse1 +13044Dlsr1 -13044Dlsl1 +47Dlfah +2521Dwmh01 +2521Dwmh02 +2521Dwmh03 +2521Dwmh04 +2521Dwmh05

+2521Dwmh06 +2521Dwmh07 +2521Dwmh08 +2521Dwmh09 +2521Dwmh10 +2521Dwmh11 +2521Dwmh12 -1Dn88 +1Dnt<=0

238) -47245Dfwh2 -42539Dhwh2 -2301Dlse1 +13488Dlsr1 -13488Dlsl1 +45Dlfah +2585Dwmh01 +2585Dwmh02 +2585Dwmh03 +2585Dwmh04 +2585Dwmh05 +2585Dwmh06 +2585Dwmh07 +2585Dwmh08 +2585Dwmh09 +2585Dwmh10 +2585Dwmh11 +2585Dwmh12 -1Dn89 +1Dnt<=0

239) -38825Dfwh2 -34812Dhwh2 -2060Dlse1 +11940Dlsr1 -11940Dlsl1 +33Dlfah +2650Dwmh01 +2650Dwmh02 +2650Dwmh03 +2650Dwmh04 +2650Dwmh05 +2650Dwmh06 +2650Dwmh07 +2650Dwmh08 +2650Dwmh09 +2650Dwmh10 +2650Dwmh11 +2650Dwmh12 -1Dn90 +1Dnt<=0

240) -40673Dfwh2 -36532Dhwh2 -2110Dlse1 +11820Dlsr1 -11820Dlsl1 +32Dlfah +2717Dwmh01 +2717Dwmh02 +2717Dwmh03 +2717Dwmh04 +2717Dwmh05 +2717Dwmh06 +2717Dwmh07 +2717Dwmh08 +2717Dwmh09 +2717Dwmh10 +2717Dwmh11 +2717Dwmh12 -1Dn91 +1Dnt<=0

241) -39207Dfwh2 -35336Dhwh2 -2258Dlse1 +13440Dlsr1 -13440Dlsl1 +33Dlfah +2785Dwmh01 +2785Dwmh02 +2785Dwmh03 +2785Dwmh04 +2785Dwmh05 +2785Dwmh06 +2785Dwmh07 +2785Dwmh08 +2785Dwmh09 +2785Dwmh10 +2785Dwmh11 +2785Dwmh12 -1Dn92 +1Dnt<=0

242) -39175Dfwh2 -35490Dhwh2 -1774Dlse1 +12204Dlsr1 -12204Dlsl1 +34Dlfah +2855Dwmh01 +2855Dwmh02 +2855Dwmh03 +2855Dwmh04 +2855Dwmh05 +2855Dwmh06 +2855Dwmh07 +2855Dwmh08 +2855Dwmh09 +2855Dwmh10 +2855Dwmh11 +2855Dwmh12 -1Dn93 +1Dnt<=0

243) -39241Dfwh2 -35551Dhwh2 -1581Dlse1 +11280Dlsr1 -11280Dlsl1 +32Dlfah +2927Dwmh01 +2927Dwmh02 +2927Dwmh03 +2927Dwmh04 +2927Dwmh05 +2927Dwmh06 +2927Dwmh07 +2927Dwmh08 +2927Dwmh09 +2927Dwmh10 +2927Dwmh11 +2927Dwmh12 -1Dn94 +1Dnt<=0

SLB Dlho 1
SLB Dlfah 1500
SLB Dcce 0
SUB Dcwc 0
SUB Dcil 300000
SLB Dnt 605214
SUB Dnt 605214

3.5 BASE FSM-E

MAX EGM
Subject to
-EGM +144956Efwh1 +134511Ehwh1 +2100Else1 -12000Elsr1 +12000Elsl1 +2100Else2 -6000Elsr2 +6000Elsl2 +14960Elcc1 +14960Elcc2 +13750Elho -40Elfah +1400Essb +76000Esy01 +76000Esy02 +74400Esy03 +74400Esy04 +75200Esy05 +80000Esy06 +82400Esy07 +83200Esy08 +82400Esy09 +80000Esy10 +76800Esy11 +75200Esy12 +4000Esco08 +4000Esco09 -0.075Ecil +0.0033Ecb01 +0.0033Ecb02 +0.0033Ecb04 +0.0033Ecb05 +0.0033Ecb06 +0.0033Ecb07 +0.0033Ecb08 +0.0033Ecb09 +0.0033Ecb10 +0.0033Ecb11 +0.0033Ecb12 -3000Ewmh01 -3000Ewmh02 -3000Ewmh03 -3000Ewmh04 -

3000Ewmh05 -3000Ewmh06 -3000Ewmh07 -3000Ewmh08 -3000Ewmh09 -3000Ewmh10 -3000Ewmh11 -3000Ewmh12=0

-ERISK +1En85 +1En86 +1En87 +1En88 +1En89 +1En90 +1En91 +1En92 +1En93 +1En94=0

-ESE +4.686Efwh1 +12.331Effa1 +22.311Ehwh1 +58.712Ehfa1 +0.741Else1 +0.496Elsr1 +0.098Elsl1 +0.741Else2 +0.496Elsr2 +0.098Elsl2 +4.813Elcc1 +5.949Elch1 +1.118Elcy1 +4.813Elcc2 +5.949Elch2 +1.118Elcy2 +4.963Elho +0.506Efrg1 +2.407Ehrg1 +0.0023Esco08 +0.0023Esco09=0

251) +1Efwh1 +1Effa1 +1Efrg1=38

252) +1Ehwh1 +1Ehfa1 +1Ehrg1=38

253) +1Efwh1 -1Effa1<=0

254) +2Efwh1 -1Efrg1<=0

255) +1Ehwh1 -1Ehfa1<=0

256) +2Ehwh1 -1Ehrg1<=0

257) -2918Efwh1 -2773Ehwh1 +1Eswh= -2000

258) -4005Efwh1 -3805Ehwh1 +1Elfst +25Essb=0

259) +0.2Else1 -1Elsr1<=0

260) -0.81Else1 +1Elsl1<=0

261) +0.2Else2 -1Elsr2<=0

262) -0.81Else2 +1Elsl2<=0

263) +1Elsr1 -1Elsl1 +0.5Elsr2 -0.5Elsl2 +1Esla<=0

264) +1Else1 +1Else2<=20

265) +0.15Elcc1 -1Elch1<=0

266) -0.74Elcc1 +1Elcy1<=0

267) +0.15Elcc2 -1Elch2<=0

268) -0.74Elcc2 +1Elcy2<=0

269) +1Elch1 -1Elcy1 +0.5Elch2 -0.5Elcy2 +1Esy01 +1Esy02 +1Esy03 +1Esy04 +1Esy05 +1Esy06 +1Esy07 +1Esy08 +1Esy09 +1Esy10 +1Esy11 +1Esy12=0

270) +1Elcc1 +1Elcc2<=20

271) +270Else1 +173Elsr1 +61Elsl1 +1764Elcc1 +2180Elch1 +410Elcy1 +1819Elho -1320Efrg1 -1100Ehrg1 -1Elfah -1Elfst +1Elft1 -0.7Elft2<=0

272) +193Else1 +137Elsr1 +1244Elcc1 +1538Elch1 +289Elcy1 +1283Elho -0.7Elft1 +1Elft2<=8000

273) +53468Efwh1 +53468Ehwh1 -1Ecil -1Ecoc=0

274) +1Esco08 +1Esco09<=100

275) -1Ewmh04 +1Ewms04=59

276) +1.28Efwh1 +1.34Ehwh1 -1Ewmh05 +1Ewms05=61

277) -1Ewmh06 +1Ewms06=59

278) +0.32Efwh1 +0.34Ehwh1 -1Ewmh07 +1Ewms07=61

279) +0.3Esco08 -1Ewmh08 +1Ewms08=60

280) +3.84Effa1 +4.03Ehfa1 +0.3Esco09 -1Ewmh09 +1Ewms09=59

281) +2.56Effa1 +2.69Ehfa1 -1Ewmh10 +1Ewms10=60

282) -1Ewmh11 +1Ewms11=58

283) +0.2Efwh1 +0.21Ehwh1 -1Ewmh12 +1Ewms12=60

284) -1Ewmh01 +1Ewms01=60

285) -1Ewmh02 +1Ewms02=54

286) -1Ewmh03 +1Ewms03=61

287) -360Else1 -360Else2 -3100Elcc1 -3100Elcc2 -2750Elho -74400Esy04 +1Ecce +1Ecoc -1Ecwc +1Ecb04 +3000Ewmh04=0

288) -75200Esy05 +1Ecce -1.0033Ecb04 +1Ecb05 +3000Ewmh05=0
289) -80000Esy06 +1Ecce -1.0033Ecb05 +1Ecb06 +3000Ewmh06=0
290) +540Elcc1 +540Elcc2 -82400Esy07 +1Ecce -1.0033Ecb06 +1Ecb07 +3000Ewmh07=0
291) -83200Esy08 +1Ecce -1.0033Ecb07 +1Ecb08 +3000Ewmh08=0
292) -12000Esla -82400Esy09 -4000Esco08 -4000Esco09 +1Ecce -1.0033Ecb08 +1Ecb09 +3000Ewmh09=0
293) -80000Esy10 +1Ecce -1.0033Ecb09 +1Ecb10 +3000Ewmh10= -13020
294) -76800Esy11 +1Ecce -1.0033Ecb10 +1Ecb11 +3000Ewmh11= -17600
295) -360Else1 -360Else2 -3100Elcc1 -2750Elho -68Eswh -75200Esy12 +1Ecce - 1.0033Ecb11 +1Ecb12 +3000Ewmh12=0
296) -360Else1 -360Else2 -3100Elcc1 -2750Elho +400Essb -76000Esy01 +1Ecce +1Ecb01 -1.0033Ecb12 +3000Ewmh01=0
297) -360Else1 -360Else2 -3100Elcc1 -2750Elho -1000Essb -76000Esy02 +1Ecce - 1.0033Ecb01 +1Ecb02 +3000Ewmh02=0
298) -360Else1 -360Else2 -3100Elcc1 -2750Elho +40Elfah -74400Esy03 +1Ecce +1.075Ecil +1Ecwc +1Ecci -1.0033Ecb02 +3000Ewmh03=0
299) -193090Efwh1 -179198Ehwh1 -1941Else1 +5190Elsr1 -5190Elsl1 -1941Else2 +2595Elsr2 -2595Elsl2 -14944Elcc1 +74240Elch1 -74240Elcy1 -14944Elcc2 +37120Elch2 -37120Elcy2 -8014Elho +35Elfah -1670Essb -4772Esco08 - 4772Esco09 +2340Ewmh01 +2340Ewmh02 +2340Ewmh03 +2340Ewmh04 +2340Ewmh05 +2340Ewmh06 +2340Ewmh07 +2340Ewmh08 +2340Ewmh09 +2340Ewmh10 +2340Ewmh11 +2340Ewmh12 -1En85 +1Ent<=0
300) -194035Efwh1 -180530Ehwh1 -2240Else1 +5280Elsr1 -5280Elsl1 -2240Else2 +2640Elsr2 -2640Elsl2 -17037Elcc1 +84880Elch1 -84880Elcy1 -17037Elcc2 +42440Elch2 -42440Elcy2 -10207Elho +54Elfah -1727Essb -4936Esco08 - 4936Esco09 +2399Ewmh01 +2399Ewmh02 +2399Ewmh03 +2399Ewmh04 +2399Ewmh05 +2399Ewmh06 +2399Ewmh07 +2399Ewmh08 +2399Ewmh09 +2399Ewmh10 +2399Ewmh11 +2399Ewmh12 -1En86 +1Ent<=0
301) -156533Efwh1 -145430Ehwh1 -2325Else1 +5934Elsr1 -5934Elsl1 -2325Else2 +2967Elsr2 -2967Elsl2 -17176Elcc1 +89280Elch1 -89280Elcy1 -17176Elcc2 +44640Elch2 -44640Elcy2 -11241Elho +53Elfah -1523Essb -4352Esco08 - 4352Esco09 +2459Ewmh01 +2459Ewmh02 +2459Ewmh03 +2459Ewmh04 +2459Ewmh05 +2459Ewmh06 +2459Ewmh07 +2459Ewmh08 +2459Ewmh09 +2459Ewmh10 +2459Ewmh11 +2459Ewmh12 -1En87 +1Ent<=0
302) -143770Efwh1 -133033Ehwh1 -2406Else1 +6522Elsr1 -6522Elsl1 -2406Else2 +3261Elsr2 -3261Elsl2 -15642Elcc1 +84800Elch1 -84800Elcy1 -15642Elcc2 +42400Elch2 -42400Elcy2 -10309Elho +48Elfah -1415Essb -4044Esco08 - 4044Esco09 +2521Ewmh01 +2521Ewmh02 +2521Ewmh03 +2521Ewmh04 +2521Ewmh05 +2521Ewmh06 +2521Ewmh07 +2521Ewmh08 +2521Ewmh09 +2521Ewmh10 +2521Ewmh11 +2521Ewmh12 -1En88 +1Ent<=0
303) -147939Efwh1 -137160Ehwh1 -2301Else1 +6744Elsr1 -6744Elsl1 -2301Else2 +3372Elsr2 -3372Elsl2 -14882Elcc1 +81600Elch1 -81600Elcy1 -14882Elcc2 +40800Elch2 -40800Elcy2 -9667Elho +46Elfah -1421Essb -4060Esco08 - 4060Esco09 +2585Ewmh01 +2585Ewmh02 +2585Ewmh03 +2585Ewmh04 +2585Ewmh05 +2585Ewmh06 +2585Ewmh07 +2585Ewmh08 +2585Ewmh09 +2585Ewmh10 +2585Ewmh11 +2585Ewmh12 -1En89 +1Ent<=0
304) -123747Efwh1 -114555Ehwh1 -2060Else1 +5970Elsr1 -5970Elsl1 -2060Else2 +2985Elsr2 -2985Elsl2 -12774Elcc1 +69520Elch1 -69520Elcy1 -12774Elcc2

+34760Elch2 -34760Elcy2 -8001Elho +34Elfah -1204Essb -3440Esco08 -3440Esco09 +2650Ewmh01 +2650Ewmh02 +2650Ewmh03 +2650Ewmh04 +2650Ewmh05 +2650Ewmh06 +2650Ewmh07 +2650Ewmh08 +2650Ewmh09 +2650Ewmh10 +2650Ewmh11 +2650Ewmh12 -1En90 +1Ent<=0

305) -129367Efwh1 -119883Ehwh1 -2110Else1 +5910Elsr1 -5910Elsl1 -2110Else2 +2955Elsr2 -2955Elsl2 -15812Elcc1 +83760Elch1 -83760Elcy1 -15812Elcc2 +41880Elch2 -41880Elcy2 -9855Elho +33Elfah -1337Essb -3820Esco08 -3820Esco09 +2717Ewmh01 +2717Ewmh02 +2717Ewmh03 +2717Ewmh04 +2717Ewmh05 +2717Ewmh06 +2717Ewmh07 +2717Ewmh08 +2717Ewmh09 +2717Ewmh10 +2717Ewmh11 +2717Ewmh12 -1En91 +1Ent<=0

306) -121985Efwh1 -113117Ehwh1 -2258Else1 +6720Elsr1 -6720Elsl1 -2258Else2 +3360Elsr2 -3360Elsl2 -16432Elcc1 +87520Elch1 -87520Elcy1 -16432Elcc2 +43760Elch2 -43760Elcy2 -12554Elho +34Elfah -1323Essb -3780Esco08 -3780Esco09 +2785Ewmh01 +2785Ewmh02 +2785Ewmh03 +2785Ewmh04 +2785Ewmh05 +2785Ewmh06 +2785Ewmh07 +2785Ewmh08 +2785Ewmh09 +2785Ewmh10 +2785Ewmh11 +2785Ewmh12 -1En92 +1Ent<=0

307) -119872Efwh1 -111433Ehwh1 -1774Else1 +6102Elsr1 -6102Elsl1 -1774Else2 +3051Elsr2 -3051Elsl2 -13472Elcc1 +75840Elch1 -75840Elcy1 -13472Elcc2 +37920Elch2 -37920Elcy2 -10643Elho +35Elfah -1219Essb -3484Esco08 -3484Esco09 +2855Ewmh01 +2855Ewmh02 +2855Ewmh03 +2855Ewmh04 +2855Ewmh05 +2855Ewmh06 +2855Ewmh07 +2855Ewmh08 +2855Ewmh09 +2855Ewmh10 +2855Ewmh11 +2855Ewmh12 -1En93 +1Ent<=0

308) -119249Efwh1 -110799Ehwh1 -1581Else1 +5640Elsr1 -5640Elsl1 -1581Else2 +2820Elsr2 -2820Elsl2 -11395Elcc1 +68480Elch1 -68480Elcy1 -11395Elcc2 +34240Elch2 -34240Elcy2 -8717Elho +33Elfah -1159Essb -3312Esco08 -3312Esco09 +2927Ewmh01 +2927Ewmh02 +2927Ewmh03 +2927Ewmh04 +2927Ewmh05 +2927Ewmh06 +2927Ewmh07 +2927Ewmh08 +2927Ewmh09 +2927Ewmh10 +2927Ewmh11 +2927Ewmh12 -1En94 +1Ent<=0

SUB Essb 80
SLB Elfah 3000
SLB Elho 8
SLB Ecce 261319
SUB Ecwc 593529
SUB Ecil 1002525
SLB Ent 4708913
SUB Ent 4708913

3.6 Base FSM-F

MAX FGM
Subject to
-FGM +193281Ffwh1 +174892Ffch1 -60580Ffoc1 +342600Ffvi1 +95833Ffwh2 +87446Ffch2 +180453Fhwh1 +169892Fhch1 -60580Fhoc1 +90059Fhwh2 +84946Fhch2 +73920Fmeu01 +73920Fmeu02 +73920Fmeu03f +2100Flse1 -14000Flsr1 +14000Flsl1 +15500Flcc1 +47500Flcy3 -40Flfah +90250Fsy01 +90250Fsy02 +88350Fsy03 +88350Fsy04 +89300Fsy05 +95000Fsy06 +97850Fsy07 +98800Fsy08 +97850Fsy09 +95000Fsy10 +91200Fsy11

+89300Fsy12 +3150Fsco08 +3150Fsco09 -0.075Fcil -3000Fwmh01 -3000Fwmh02 -3000Fwmh03 -3000Fwmh04 -3000Fwmh05 -3000Fwmh06 -3000Fwmh07 -3000Fwmh08 -3000Fwmh09 -3000Fwmh10 -3000Fwmh11 -3000Fwmh12=0

-FRISK +1Fn85 +1Fn86 +1Fn87 +1Fn88 +1Fn89 +1Fn90 +1Fn91 +1Fn92 +1Fn93 +1Fn94=0

-FSE +3.267Ffwh1 +8.598Fffa1 -0.671Ffch1 +2.94Ffoc1 +0.739Ffvi1 +3.267Ffwh2 +8.598Fffa2 -0.671Ffch2 +15.556Fhwh1 +40.937Fhfa1 -3.193Fhch1 +14Fhoc1 +15.556Fhwh2 +40.937Fhfa2 -3.193Fhch2 +7.969Fmeu01 +3.59Fmeu02 +0.963Fmeu03f +0.486Flse1 +0.341Flsr1 +0.067Flsl1 +3.309Flcc1 +4.09Flch1 +0.769Flcy1 +3.309Flcc3 +0.769Flcy3 +3.412Flho +0.353Ffrg1 +1.678Fhrg1 +1.674Fmpp1 +0.353Ffrg3 +0.0023Fsco08 +0.0023Fsco09=0

316) +1Ffwh1 +1Fffa1 +1Ffoc1 +1Ffvi1 +1Ffwh2 +1Fffa2 +1Ffrg1=20

317) +1Fhwh1 +1Fhfa1 +1Fhoc1 +1Fhwh2 +1Fhfa2 +1Fhrg1=10

318) +1Fmeu01 +1Fmeu02 +1Fmeu03f +1Fmpp1=12

319) +1Ffwh1 -1Fffa1<=0

320) +2Ffwh1 +2Ffoc1 +2Ffwh2 -1Ffrg1<=0

321) -1Ffwh1 +3Ffch1<=0

322) +1Ffwh2 -1Fffa2<=0

323) -1Ffwh2 +3Ffch2<=0

324) +1Fhwh1 -1Fhfa1<=0

325) +2Fhwh1 +2Fhoc1 +2Fhwh2 -1Fhrg1<=0

326) -1Fhwh1 +3Fhch1<=0

327) +1Fhwh2 -1Fhfa2<=0

328) -1Fhwh2 +3Fhch2<=0

329) -3347Ffwh1 -1673Ffwh2 -3180Fhwh1 -1590Fhwh2 +1Fswh= -2000

330) -1Fmeu01 +1Fmeu02=0

331) -18Fmeu02 +1Fmeu03f=0

332) +0.2Flse1 -1Flsr1<=0

333) -0.81Flse1 +1Flsl1<=0

334) +1Flsr1 -1Flsl1 +1Fsla= -10

335) +0.15Flcc1 -1Flch1<=0

336) -0.74Flcc1 +1Flcy1<=0

337) +1Flch1 -1Flcy1 +1Fsy01 +1Fsy02 +1Fsy03 +1Fsy04 +1Fsy05 +1Fsy06 +1Fsy07 +1Fsy08 +1Fsy09 +1Fsy10 +1Fsy11 +1Fsy12=0

338) +2.4Flcc3 -1Ffrg3=0

339) -0.74Flcc3 +1Flcy3<=0

340) -4848Ffwh1 -4848Ffwh2 -4606Fhwh1 -4606Fhwh2 +258Flse1 +173Flsr1 +61Flsl1 +1764Flcc1 +2180Flch1 +410Flcy1 +1764Flcc3 +410Flcy3 +1819Flho -1440Ffrg1 -1200Fhrg1 -960Fmpp1 -1440Ffrg3 +1Flft1 -0.7Flft2<=0

341) -6000Ffoc1 -5700Fhoc1 +184Flse1 +137Flsr1 +1244Flcc1 +1538Flch1 +289Flcy1 +1244Flcc3 +289Flcy3 +1283Flho -1Flfah -0.7Flft1 +1Flft2<=0

342) +37662Ffwh1 +31416Ffch1 +60580Ffoc1 +19638Ffwh2 +15708Ffch2 +37662Fhwh1 +31416Fhch1 +60580Fhoc1 +19638Fhwh2 +15708Fhch2 -1Fcil -1Fcoc=0

343) +1Fsco08 +1Fsco09<=200

344) +2Ffoc1 +6Ffvi1 +2.1Fhoc1 +2Fmeu02 +2Fmeu03f -1Fwmh04 +1Fwms04=15

345) +1.92Ffwh1 +2Ffoc1 +2.02Fhwh1 +2.1Fhoc1 +2Fmeu02 +2Fmeu03f -1Fwmh05 +1Fwms05=15.5

346) +2Fmeu02 +2Fmeu03f -1Fwmh06 +1Fwms06=15

347) +0.32Ffwh1 +0.34Fhwh1 +2Fmeu02 +2Fmeu03f -1Fwmh07 +1Fwms07=15.5

348) +0.15Ffoc1 +12Ffvi1 +0.16Fhoc1 +2Fmeu01 +2Fmeu02 +2Fmeu03f +0.2Fsco08 -1Fwmh08 +1Fwms08=15.5

349) +1.92Fffa1 +3.56Ffch1 +8Ffvi1 +2.02Fhfa1 +3.74Fhch1 +6Fmeu01 +2Fmeu02 +2Fmeu03f +0.2Fsco09 -1Fwmh09 +1Fwms09=15

350) +1.28Fffa1 +14Ffvi1 +1.34Fhfa1 +2Fmeu01 +2Fmeu02 +2Fmeu03f -1Fwmh10 +1Fwms10=15.5

351) +2Fmeu01 +2Fmeu02 +2Fmeu03f -1Fwmh11 +1Fwms11=15

352) +0.2Ffwh1 +8Ffoc1 +0.21Fhwh1 +8.4Fhoc1 +2Fmeu01 +2Fmeu02 +2Fmeu03f -1Fwmh12 +1Fwms12=15.5

353) +2Fmeu01 +2Fmeu02 +2Fmeu03f -1Fwmh01 +1Fwms01=15.5

354) +2Fmeu01 +2Fmeu02 +2Fmeu03f -1Fwmh02 +1Fwms02=14

355) +2Fmeu01 +2Fmeu02 +2Fmeu03f -1Fwmh03 +1Fwms03=15.5

356) -360Flse1 -88350Fsy04 +1Fcce +1Fcoc -1Fcwc +1Fcb04 +3000Fwmh04=0

357) -89300Fsy05 +1Fcce -1Fcb04 +1Fcb05 +3000Fwmh05=0

358) -95000Fsy06 +1Fcce -1Fcb05 +1Fcb06 +3000Fwmh06=0

359) -97850Fsy07 +1Fcce -1Fcb06 +1Fcb07 +3000Fwmh07=0

360) -172500Ffvi1 -98800Fsy08 +1Fcce -1Fcb07 +1Fcb08 +3000Fwmh08=0

361) -172500Ffvi1 -7500Fsla -97850Fsy09 -3150Fsco08 -3150Fsco09 +1Fcce -1Fcb08 +1Fcb09 +3000Fwmh09=0

362) -47500Flcy3 -6500Fsla -95000Fsy10 +1Fcce -1Fcb09 +1Fcb10 +3000Fwmh10=0

363) -91200Fsy11 +1Fcce -1Fcb10 +1Fcb11 +3000Fwmh11=0

364) -660Flse1 -69Fswh -89300Fsy12 +1Fcce -1Fcb11 +1Fcb12 +3000Fwmh12=0

365) +57692Ffch1 +28846Ffch2 +57692Fhch1 +28846Fhch2 -360Flse1 -90250Fsy01 +1Fcce +1Fcb01 -1Fcb12 +3000Fwmh01=0

366) -264000Ffch1 -132000Ffch2 -250800Fhch1 -125400Fhch2 -360Flse1 -90250Fsy02 +1Fcce -1Fcb01 +1Fcb02 +3000Fwmh02=0

367) -360Flse1 +40Flfah -88350Fsy03 +1Fcce +1.075Fcil +1Fcwc +1Fcci -1Fcb02 +3000Fwmh03=0

368) -261388Ffwh1 -169234Ffch1 +63912Ffoc1 -192525Ffvi1 -129865Ffwh2 -84617Ffch2 -244328Fhwh1 -151488Fhch1 +63912Fhoc1 -121335Fhwh2 -75744Fhch2 -77985Fmeu01 -77985Fmeu02 -77985Fmeu03f -1941Flse1 +12975Flsr1 -12975Flsl1 -15484Flcc1 +88160Flch1 -88160Flcy1 -44080Flcy3 +34Flfah -3323Fsco08 -3323Fsco09 +2340Fwmh01 +2340Fwmh02 +2340Fwmh03 +2340Fwmh04 +2340Fwmh05 +2340Fwmh06 +2340Fwmh07 +2340Fwmh08 +2340Fwmh09 +2340Fwmh10 +2340Fwmh11 +2340Fwmh12 -1Fn85 +1Fnt<=0

369) -258724Ffwh1 -192842Ffch1 +69365Ffoc1 -418500Ffvi1 -128538Ffwh2 -96421Ffch2 -242139Fhwh1 -173676Fhch1 +69365Fhoc1 -120246Fhwh2 -86838Fhch2 -84638Fmeu01 -84638Fmeu02 -84638Fmeu03f -2240Flse1 +13200Flsr1 -13200Flsl1 -17577Flcc1 +100795Flch1 -100795Flcy1 -50397Flcy3 +53Flfah -3606Fsco08 -3606Fsco09 +2399Fwmh01 +2399Fwmh02 +2399Fwmh03 +2399Fwmh04 +2399Fwmh05 +2399Fwmh06 +2399Fwmh07 +2399Fwmh08 +2399Fwmh09 +2399Fwmh10 +2399Fwmh11 +2399Fwmh12 -1Fn86 +1Fnt<=0

370) -208658Ffwh1 -137948Ffch1 +64882Ffoc1 -533730Ffvi1 -103515Ffwh2 -68974Ffch2 -195022Fhwh1 -122678Fhch1 +64882Fhoc1 -96698Fhwh2 -61339Fhch2 -79168Fmeu01 -79168Fmeu02 -79168Fmeu03f -2325Flse1

+14835Flsr1 -14835Flsl1 -17716Flcc1 +106020Flch1 -106020Flcy1 -53010Flcy3 +53Flfah -3373Fsco08 -3373Fsco09 +2459Fwmh01 +2459Fwmh02 +2459Fwmh03 +2459Fwmh04 +2459Fwmh05 +2459Fwmh06 +2459Fwmh07 +2459Fwmh08 +2459Fwmh09 +2459Fwmh10 +2459Fwmh11 +2459Fwmh12 -1Fn87 +1Fnt<=0

371) -197506Ffwh1 -107728Ffch1 +59248Ffoc1 -215985Ffvi1 -97930Ffwh2 -53864Ffch2 -184320Fhwh1 -94260Fhch1 +59248Fhoc1 -91336Fhwh2 -47130Fhch2 -72293Fmeu01 -72293Fmeu02 -72293Fmeu03f -2406Flse1 +16305Flsr1 -16305Flsl1 -16182Flcc1 +100700Flch1 -100700Flcy1 -50350Flcy3 +47Flfah -3080Fsco08 -3080Fsco09 +2521Fwmh01 +2521Fwmh02 +2521Fwmh03 +2521Fwmh04 +2521Fwmh05 +2521Fwmh06 +2521Fwmh07 +2521Fwmh08 +2521Fwmh09 +2521Fwmh10 +2521Fwmh11 +2521Fwmh12 -1Fn88 +1Fnt<=0

372) -198396Ffwh1 -242148Ffch1 +63549Ffoc1 -157335Ffvi1 -98385Ffwh2 -121074Ffch2 -185158Fhwh1 -219308Fhch1 +63549Fhoc1 -91766Fhwh2 -109654Fhch2 -77542Fmeu01 -77542Fmeu02 -77542Fmeu03f -2301Flse1 +16860Flsr1 -16860Flsl1 -15422Flcc1 +96900Flch1 -96900Flcy1 -48450Flcy3 +45Flfah -3304Fsco08 -3304Fsco09 +2585Fwmh01 +2585Fwmh02 +2585Fwmh03 +2585Fwmh04 +2585Fwmh05 +2585Fwmh06 +2585Fwmh07 +2585Fwmh08 +2585Fwmh09 +2585Fwmh10 +2585Fwmh11 +2585Fwmh12 -1Fn89 +1Fnt<=0

373) -166003Ffwh1 -261704Ffch1 +57127Ffoc1 -192525Ffvi1 -82198Ffwh2 -130852Ffch2 -154716Fhwh1 -237442Fhch1 +57127Fhoc1 -76554Fhwh2 -118721Fhch2 -69706Fmeu01 -69706Fmeu02 -69706Fmeu03f -2060Flse1 +14925Flsr1 -14925Flsl1 -13314Flcc1 +82555Flch1 -82555Flcy1 -41277Flcy3 +33Flfah -2970Fsco08 -2970Fsco09 +2650Fwmh01 +2650Fwmh02 +2650Fwmh03 +2650Fwmh04 +2650Fwmh05 +2650Fwmh06 +2650Fwmh07 +2650Fwmh08 +2650Fwmh09 +2650Fwmh10 +2650Fwmh11 +2650Fwmh12 -1Fn90 +1Fnt<=0

374) -170418Ffwh1 -224784Ffch1 +61610Ffoc1 -453345Ffvi1 -84409Ffwh2 -112392Ffch2 -158771Fhwh1 -202742Fhch1 +61610Fhoc1 -78585Fhwh2 -101371Fhch2 -75176Fmeu01 -75176Fmeu02 -75176Fmeu03f -2110Flse1 +14775Flsr1 -14775Flsl1 -16352Flcc1 +99465Flch1 -99465Flcy1 -49732Flcy3 +32Flfah -3203Fsco08 -3203Fsco09 +2717Fwmh01 +2717Fwmh02 +2717Fwmh03 +2717Fwmh04 +2717Fwmh05 +2717Fwmh06 +2717Fwmh07 +2717Fwmh08 +2717Fwmh09 +2717Fwmh10 +2717Fwmh11 +2717Fwmh12 -1Fn91 +1Fnt<=0

375) -159615Ffwh1 -143440Ffch1 +62095Ffoc1 -672420Ffvi1 -79014Ffwh2 -71720Ffch2 -148724Fhwh1 -127096Fhch1 +62095Fhoc1 -73568Fhwh2 -63548Fhch2 -75768Fmeu01 -75768Fmeu02 -75768Fmeu03f -2258Flse1 +16800Flsr1 -16800Flsl1 -16972Flcc1 +103930Flch1 -103930Flcy1 -51965Flcy3 +33Flfah -3228Fsco08 -3228Fsco09 +2785Fwmh01 +2785Fwmh02 +2785Fwmh03 +2785Fwmh04 +2785Fwmh05 +2785Fwmh06 +2785Fwmh07 +2785Fwmh08 +2785Fwmh09 +2785Fwmh10 +2785Fwmh11 +2785Fwmh12 -1Fn92 +1Fnt<=0

376) -155709Ffwh1 -107074Ffch1 +53008Ffoc1 -366750Ffvi1 -77071Ffwh2 -53537Ffch2 -145345Fhwh1 -93462Fhch1 +53008Fhoc1 -71889Fhwh2 -46731Fhch2 -64680Fmeu01 -64680Fmeu02 -64680Fmeu03f -1774Flse1 +15255Flsr1 -15255Flsl1 -14012Flcc1 +90060Flch1 -90060Flcy1 -45030Flcy3

+34Flfah -2756Fsco08 -2756Fsco09 +2855Fwmh01 +2855Fwmh02 +2855Fwmh03 +2855Fwmh04 +2855Fwmh05 +2855Fwmh06 +2855Fwmh07 +2855Fwmh08 +2855Fwmh09 +2855Fwmh10 +2855Fwmh11 +2855Fwmh12 -1Fn93 +1Fnt<=0

377) -156375Ffwh1 -162244Ffch1 +51069Ffoc1 -222885Ffvi1 -77400Ffwh2 -81122Ffch2 -145998Fhwh1 -144972Fhch1 +51069Fhoc1 -72212Fhwh2 -72486Fhch2 -62314Fmeu01 -62314Fmeu02 -62314Fmeu03f -1581Flse1 +14100Flsr1 -14100Flsl1 -11935Flcc1 +81320Flch1 -81320Flcy1 -40660Flcy3 +32Flfah -2655Fsco08 -2655Fsco09 +2927Fwmh01 +2927Fwmh02 +2927Fwmh03 +2927Fwmh04 +2927Fwmh05 +2927Fwmh06 +2927Fwmh07 +2927Fwmh08 +2927Fwmh09 +2927Fwmh10 +2927Fwmh11 +2927Fwmh12 -1Fn94 +1Fnt<=0

SUB Ffrg3 12
SUB Ffvi1 0.5
SLB Flho 3
SLB Flfah 2500
SLB Fcce 183182
SUB Fcwc 899147
SUB Fcil 500000
SLB Fnt 3819395
SUB Fnt 3819395
SUB Fwmh04 5
SUB Fwmh05 5
SUB Fwmh06 5
SUB Fwmh07 5
SUB Fwmh08 5
SUB Fwmh09 5
SUB Fwmh10 5
SUB Fwmh11 5
SUB Fwmh12 5
SUB Fwmh01 5
SUB Fwmh02 5
SUB Fwmh03 5

3.7 Base FSM-G

MAX GGM
Subject to
-GGM +125247Gfwh1 +381012Gfto8 +316012Gfto9 +2000Gflm1 +113697Ghwh1 +73920Gmeu01 +73920Gmeu02 +73920Gmeu03f +1800Glse1 -12000Glsr1 +12000Glsl1 -37863Gfoa1 -42497Gfop1 -37863Ghoa1 -42497Ghop1 -40Glfah +2625Gsco02 +2625Gsco03 +2625Gsco04 +2625Gsco05 +2625Gsco06 +2625Gsco07 +2625Gsco08 +2625Gsco09 -0.075Gcil -3000Gwmh01 -3000Gwmh02 -3000Gwmh03 -3000Gwmh04 -3000Gwmh05 -3000Gwmh06 -3000Gwmh07 -3000Gwmh08 -3000Gwmh09 -3000Gwmh10 -3000Gwmh11 -3000Gwmh12=0

-GRISK +1Gn85 +1Gn86 +1Gn87 +1Gn88 +1Gn89 +1Gn90 +1Gn91 +1Gn92 +1Gn93 +1Gn94=0

-GSE +3.004Gfwh1 +7.906Gffa1 +0Gfto8 +0Gfto9 +0.696Gflm1 +14.305Ghwh1 +37.645Ghfa1 +3.426Gmeu01 +1.543Gmeu02 +0.414Gmeu03f +0.464Glse1 +0.31Glsr1 +0.061Glsl1 +3.102Glho +3.004Gfoa1 +3.004Gfop1 +0.182Gfph1 +0.324Gfrg1 +14.305Ghoa1 +14.305Ghop1 +0.866Ghph1 +1.543Ghrg1 +0.0016Gsco02 +0.0016Gsco03 +0.0016Gsco04 +0.0016Gsco05 +0.0016Gsco06 +0.0016Gsco07 +0.0016Gsco08 +0.0016Gsco09=0

385) +1Gfwh1 +1Gffa1 +0.05Gfto8 +0.05Gfto9 +0.001Gflm1 +1Gfoa1 +1Gfop1 +1Gfph1 +1Gfrg1=18

386) +1Ghwh1 +1Ghfa1 +1Gmeu01 +1Gmeu02 +1Gmeu03f +1Ghoa1 +1Ghop1 +1Ghph1 +1Ghrg1=12

387) +1Gfwh1 -1Gffa1 +1Gfoa1<=0

388) +3Gfwh1 +3Gfoa1 -1Gfrg1<=0

389) -4Gfop1 +1Gfph1<=0

390) +1Ghwh1 -1Ghfa1 +1Ghoa1<=0

391) +3Ghwh1 +3Ghoa1 -1Ghrg1<=0

392) -4Ghop1 +1Ghph1<=0

393) +2647Gfwh1 +2514Ghwh1 -1Gswh=1600

394) -1Gmeu01 +1Gmeu02=0

395) -18Gmeu02 +1Gmeu03f=0

396) +0.2Glse1 -1Glsr1<=0

397) -0.81Glse1 +1Glsl1<=0

398) +1Glsr1 -1Glsl1 +1Gsla<= -2

399) -4011Gfwh1 -3811Ghwh1 +271Glse1 +173Glsr1 +61Glsl1 +1819Glho -1500Gfoa1 -3000Gfop1 -2250Gfph1 -1200Gfrg1 -1425Ghoa1 -2850Ghop1 -2138Ghph1 -1000Ghrg1 +1Glft1 -0.7Glft2<=0

400) +193Glse1 +137Glsr1 +1283Glho -1Glfah -0.7Glft1 +1Glft2<=0

401) +500Gfto8 +500Gfto9 +10Gflm1<=600

402) +53278Gfwh1 +53278Ghwh1 +23760Gfoa1 +42497Gfop1 +23760Ghoa1 +42497Ghop1 -1Gcil -1Gcoc=0

403) +1Gsco02 +1Gsco03 +1Gsco04 +1Gsco05 +1Gsco06 +1Gsco07 +1Gsco08 +1Gsco09<=400

404) +2Gmeu02 +2Gmeu03f +0.3Gsco04 -1Gwmh04 +1Gwms04=38

405) +2Gmeu02 +2Gmeu03f +1.92Gfoa1 +3.85Gfop1 +2.02Ghoa1 +4.04Ghop1 +0.3Gsco05 -1Gwmh05 +1Gwms05=39

406) +2Gmeu02 +2Gmeu03f +0.3Gsco06 -1Gwmh06 +1Gwms06=38

407) +0.32Gfwh1 +6.5Gfto8 +0.34Ghwh1 +2Gmeu02 +2Gmeu03f +0.3Gsco07 -1Gwmh07 +1Gwms07=39

408) +1.92Gffa1 +6.5Gfto9 +2.02Ghfa1 +2Gmeu01 +2Gmeu02 +2Gmeu03f +0.32Gfoa1 +0.32Gfop1 +0.34Ghoa1 +0.34Ghop1 +0.3Gsco08 -1Gwmh08 +1Gwms08=39

409) +1.92Gffa1 +0.75Gfto8 +0.75Gfto9 +0.01Gflm1 +2.02Ghfa1 +6Gmeu01 +2Gmeu02 +2Gmeu03f +0.3Gsco09 -1Gwmh09 +1Gwms09=38

410) +1Gfto8 +1Gfto9 +0.01Gflm1 +2Gmeu01 +2Gmeu02 +2Gmeu03f -1Gwmh10 +1Gwms10=39

411) +8Gfto8 +3Gfto9 +2Gmeu01 +2Gmeu02 +2Gmeu03f +5.12Gfop1 +5.12Gfph1 +5.38Ghop1 +5.38Ghph1 -1Gwmh11 +1Gwms11=38412) +0.2Gfwh1 +7Gfto8

+10.5Gfto9 +0.21Ghwh1 +2Gmeu01 +2Gmeu02 +2Gmeu03f -1Gwmh12 +1Gwms12=39

413) +5.5Gfto8 +7Gfto9 +2Gmeu01 +2Gmeu02 +2Gmeu03f +0.02Gfoa1 +0.02Ghoa1 -1Gwmh01 +1Gwms01=39

414) +5Gfto8 +5Gfto9 +2Gmeu01 +2Gmeu02 +2Gmeu03f +0.3Gsco02 -1Gwmh02 +1Gwms02=36

415) +2Gmeu01 +2Gmeu02 +2Gmeu03f +0.3Gsco03 -1Gwmh03 +1Gwms03=39

416) -250Glse1 +1Gcce +1Gcoc -1Gcwc +1Gcb04 +3000Gwmh04=0

417) +200Glse1 +23760Gfoa1 +23760Ghoa1 +1Gcce -1Gcb04 +1Gcb05 +3000Gwmh05=0

418) +1Gcce -1Gcb05 +1Gcb06 +3000Gwmh06=0

419) +113988Gfto8 -666Gflm1 +1Gcce -1Gcb06 +1Gcb07 +3000Gwmh07=0

420) +113988Gfto9 -666Gflm1 +1Gcce -1Gcb07 +1Gcb08 +3000Gwmh08=0

421) -666Gflm1 -2625Gsco02 -2625Gsco03 -2625Gsco04 -2625Gsco05 -2625Gsco06 -2625Gsco07 -2625Gsco08 -2625Gsco09 +1Gcce -1Gcb08 +1Gcb09 +3000Gwmh09=0

422) -12000Glsl1 -12000Gsla +1Gcce -1Gcb09 +1Gcb10 +3000Gwmh10=0423) -300000Gfto8 -50000Gfto9 -550Glse1 +1Gcce -1Gcb10 +1Gcb11 +3000Gwmh11=0

424) -160000Gfto8 -300000Gfto9 -250Glse1 +14103Gfoa1 +14103Ghoa1 -75Gswh +1Gcce -1Gcb11 +1Gcb12 +3000Gwmh12=0

425) -75000Gfto8 -120000Gfto9 -250Glse1 +1Gcce +1Gcb01 -1Gcb12 +3000Gwmh01=0

426) -20000Gfto8 -20000Gfto9 -250Glse1 +1Gcce -1Gcb01 +1Gcb02 +3000Gwmh02=0

427) +60000Gfto8 +60000Gfto9 -250Glse1 +40Glfah +1Gcce +1.075Gcil +1Gcwc +1Gcci -1Gcb02 +3000Gwmh03=0

428) -175069Gfwh1 -328652Gfto8 -297052Gfto9 -1206Gflm1 -159728Ghwh1 -81312Gmeu01 -81312Gmeu02 -81312Gmeu03f -1468Glse1 +10668Glsr1 -10668Glsl1 +43068Gfoa1 +46747Gfop1 +41650Ghoa1 +46747Ghop1 +34Glfah -2887Gsco02 -2887Gsco03 -2887Gsco04 -2887Gsco05 -2887Gsco06 -2887Gsco07 -2887Gsco08 -2887Gsco09 +2340Gwmh01 +2340Gwmh02 +2340Gwmh03 +2340Gwmh04 +2340Gwmh05 +2340Gwmh06 +2340Gwmh07 +2340Gwmh08 +2340Gwmh09 +2340Gwmh10 +2340Gwmh11 +2340Gwmh12 -1Gn85 +1Gnt<=0

429) -178399Gfwh1 -327352Gfto8 -296162Gfto9 -1200Gflm1 -163485Ghwh1 -85303Gmeu01 -85303Gmeu02 -85303Gmeu03f -1717Glse1 +11712Glsr1 -11712Glsl1 +39904Gfoa1 +49042Gfop1 +43694Ghoa1 +49042Ghop1 +53Glfah -3029Gsco02 -3029Gsco03 -3029Gsco04 -3029Gsco05 -3029Gsco06 -3029Gsco07 -3029Gsco08 -3029Gsco09 +2399Gwmh01 +2399Gwmh02 +2399Gwmh03 +2399Gwmh04 +2399Gwmh05 +2399Gwmh06 +2399Gwmh07 +2399Gwmh08 +2399Gwmh09 +2399Gwmh10 +2399Gwmh11 +2399Gwmh12 -1Gn86 +1Gnt<=0

430) -138628Gfwh1 -453332Gfto8 -420392Gfto9 -1916Gflm1 -126366Ghwh1 -87816Gmeu01 -87816Gmeu02 -87816Gmeu03f -1787Glse1 +12840Glsr1 -12840Glsl1 +38962Gfoa1 +50487Gfop1 +44982Ghoa1 +50487Ghop1 +53Glfah -3118Gsco02 -3118Gsco03 -3118Gsco04 -3118Gsco05 -3118Gsco06 -3118Gsco07 -3118Gsco08 -3118Gsco09 +2459Gwmh01 +2459Gwmh02 +2459Gwmh03 +2459Gwmh04 +2459Gwmh05 +2459Gwmh06 +2459Gwmh07

+2459Gwmh08 +2459Gwmh09 +2459Gwmh10 +2459Gwmh11 +2459Gwmh12 -1Gn87 +1Gnt<=0

431) -124299Gfwh1 -386412Gfto8 -325002Gfto9 -3316Gflm1 -112441Ghwh1 -76950Gmeu01 -76950Gmeu02 -76950Gmeu03f -1855Glse1 +13236Glsr1 -13236Glsl1 +40248Gfoa1 +44240Gfop1 +39416Ghoa1 +44240Ghop1 +47Glfah -2732Gsco02 -2732Gsco03 -2732Gsco04 -2732Gsco05 -2732Gsco06 -2732Gsco07 -2732Gsco08 -2732Gsco09 +2521Gwmh01 +2521Gwmh02 +2521Gwmh03 +2521Gwmh04 +2521Gwmh05 +2521Gwmh06 +2521Gwmh07 +2521Gwmh08 +2521Gwmh09 +2521Gwmh10 +2521Gwmh11 +2521Gwmh12 -1Gn88 +1Gnt<=0

432) -127318Gfwh1 -347607Gfto8 -332352Gfto9 -2836Gflm1 -115414Ghwh1 -75546Gmeu01 -75546Gmeu02 -75546Gmeu03f -1768Glse1 +13392Glsr1 -13392Glsl1 +39703Gfoa1 +43432Gfop1 +38696Ghoa1 +43432Ghop1 +45Glfah -2682Gsco02 -2682Gsco03 -2682Gsco04 -2682Gsco05 -2682Gsco06 -2682Gsco07 -2682Gsco08 -2682Gsco09 +2585Gwmh01 +2585Gwmh02 +2585Gwmh03 +2585Gwmh04 +2585Gwmh05 +2585Gwmh06 +2585Gwmh07 +2585Gwmh08 +2585Gwmh09 +2585Gwmh10 +2585Gwmh11 +2585Gwmh12 -1Gn89 +1Gnt<=0

433) -102634Gfwh1 -281712Gfto8 -236842Gfto9 -1842Gflm1 -92483Ghwh1 -59579Gmeu01 -59579Gmeu02 -59579Gmeu03f -1567Glse1 +11892Glsr1 -11892Glsl1 +36783Gfoa1 +34253Gfop1 +30518Ghoa1 +34253Ghop1 +33Glfah -2115Gsco02 -2115Gsco03 -2115Gsco04 -2115Gsco05 -2115Gsco06 -2115Gsco07 -2115Gsco08 -2115Gsco09 +2650Gwmh01 +2650Gwmh02 +2650Gwmh03 +2650Gwmh04 +2650Gwmh05 +2650Gwmh06 +2650Gwmh07 +2650Gwmh08 +2650Gwmh09 +2650Gwmh10 +2650Gwmh11 +2650Gwmh12 -1Gn90 +1Gnt<=0

434) -107252Gfwh1 -509272Gfto8 -399212Gfto9 -2218Gflm1 -96778Ghwh1 -77394Gmeu01 -77394Gmeu02 -77394Gmeu03f -1609Glse1 +11784Glsr1 -11784Glsl1 +37503Gfoa1 +44495Gfop1 +39643Ghoa1 +44495Ghop1 +32Glfah -2748Gsco02 -2748Gsco03 -2748Gsco04 -2748Gsco05 -2748Gsco06 -2748Gsco07 -2748Gsco08 -2748Gsco09 +2717Gwmh01 +2717Gwmh02 +2717Gwmh03 +2717Gwmh04 +2717Gwmh05 +2717Gwmh06 +2717Gwmh07 +2717Gwmh08 +2717Gwmh09 +2717Gwmh10 +2717Gwmh11 +2717Gwmh12 -1Gn91 +1Gnt<=0

435) -100895Gfwh1 -480757Gfto8 -326922Gfto9 -1578Gflm1 -91102Ghwh1 -72293Gmeu01 -72293Gmeu02 -72293Gmeu03f -1732Glse1 +12996Glsr1 -12996Glsl1 +36731Gfoa1 +41563Gfop1 +37031Ghoa1 +41563Ghop1 +33Glfah -2567Gsco02 -2567Gsco03 -2567Gsco04 -2567Gsco05 -2567Gsco06 -2567Gsco07 -2567Gsco08 -2567Gsco09 +2785Gwmh01 +2785Gwmh02 +2785Gwmh03 +2785Gwmh04 +2785Gwmh05 +2785Gwmh06 +2785Gwmh07 +2785Gwmh08 +2785Gwmh09 +2785Gwmh10 +2785Gwmh11 +2785Gwmh12 -1Gn92 +1Gnt<=0

436) -98744Gfwh1 -369387Gfto8 -277912Gfto9 -2328Gflm1 -89424Ghwh1 -63053Gmeu01 -63053Gmeu02 -63053Gmeu03f -1328Glse1 +10980Glsr1 -10980Glsl1 +32690Gfoa1 +36250Gfop1 +32298Ghoa1 +36250Ghop1 +34Glfah -2239Gsco02 -2239Gsco03 -2239Gsco04 -2239Gsco05 -2239Gsco06 -2239Gsco07 -2239Gsco08 -2239Gsco09 +2855Gwmh01 +2855Gwmh02 +2855Gwmh03 +2855Gwmh04 +2855Gwmh05 +2855Gwmh06 +2855Gwmh07

+2855Gwmh08 +2855Gwmh09 +2855Gwmh10 +2855Gwmh11 +2855Gwmh12 -1Gn93 +1Gnt<=0

437) -99196Gfwh1 -325102Gfto8 -247802Gfto9 -1560Gflm1 -89865Ghwh1 -59949Gmeu01 -59949Gmeu02 -59949Gmeu03f -1168Glse1 +10500Glsr1 -10500Glsl1 +33075Gfoa1 +34466Gfop1 +30707Ghoa1 +34466Ghop1 +32Glfah -2128Gsco02 -2128Gsco03 -2128Gsco04 -2128Gsco05 -2128Gsco06 -2128Gsco07 -2128Gsco08 -2128Gsco09 +2927Gwmh01 +2927Gwmh02 +2927Gwmh03 +2927Gwmh04 +2927Gwmh05 +2927Gwmh06 +2927Gwmh07 +2927Gwmh08 +2927Gwmh09 +2927Gwmh10 +2927Gwmh11 +2927Gwmh12 -1Gn94 +1Gnt<=0

SLB Glfah 750
SLB Glho 5
SLB Gcce 113344
SUB Gcwc 702524
SUB Gcil 500000
SLB Gnt 2498993
SUB Gnt 2498993

3.8 Base FSM-H

MAX HGM
Subject to

-HGM +73698Hfwh3 -14720Hffa3 +68322Hhwh3 -15456Hhfa3 +2250Hlse2 -10000Hlsr2 +10000Hlsl2 +15500Hlcc2 -40000Hlch2 +40000Hlcy2 +1500Hsco05 +1500Hsco06 +1500Hsco07 +1500Hsco08 +27184.61538Hsol=0

-HRISK +1Hn85 +1Hn86 +1Hn87 +1Hn88 +1Hn89 +1Hn90 +1Hn91 +1Hn92 +1Hn93 +1Hn94=0

-HSE +3.795Hfwh3 +9.987Hffa3 +18.069Hhwh3 +47.55Hhfa3 +0.603Hlse2 +0.403Hlsr2 +0.079Hlsl2 +3.913Hlcc2 +4.833Hlch2 +0.909Hlcy2 +0.0015Hsco05 +0.0015Hsco06 +0.0015Hsco07 +0.0015Hsco08=0

443) +1Hfwh3 +1Hffa3<=9.5
444) +1Hhwh3 +1Hhfa3<=9.5
445) +1Hfwh3 -1Hffa3<=0
446) +1Hhwh3 -1Hhfa3<=0
447) +1363Hfwh3 +1286.2Hhwh3 -1Hswh<=2000
448) +0.2Hlse2 -1Hlsr2<=0
449) -0.81Hlse2 +1Hlsl2<=0
450) +1Hlsr2 -1Hlsl2 +1Hsla<=1
451) +0.15Hlcc2 -1Hlch2<=0
452) -0.74Hlcc2 +1Hlcy2<=0
453) +1Hsco05 +1Hsco06 +1Hsco07 +1Hsco08<=100
454) +1Hsol -1Huth04<=30
455) +0.64Hfwh3 +0.672Hhwh3 +0.14Hsco05 +1Hsol -1Huth05<=31
456) +0.14Hsco06 +1Hsol -1Huth06<=30
457) +0.14Hsco07 +1Hsol -1Huth07<=31
458) +0.14Hsco08 +1Hsol -1Huth08<=31
459) +1Hsol -1Huth09<=30

460) +1Hsol -1Huth10<=31
461) +1Hsol -1Huth11<=30
462) +0.02Hfwh3 +0.021Hhwh3 +1Hsol -1Huth12<=31
463) +1Hsol -1Huth01<=31
464) +1Hsol -1Huth02<=28
465) +1Hsol -1Huth03<=31
466) +1Huth01 +1Huth02 +1Huth03 +1Huth04 +1Huth05 +1Huth06 +1Huth07 +1Huth08 +1Huth09 +1Huth10 +1Huth11 +1Huth12<=27
467) -390Hlse2 -3100Hlcc2 -2265.384615Hsol +1Hcce -1Hcwc +1Hcb05=0
468) -2265.384615Hsol +1Hcce -1Hcb05 +1Hcb06=0
469) -2265.384615Hsol +1Hcce -1Hcb06 +1Hcb07=0
470) -2265.384615Hsol +1Hcce -1Hcb07 +1Hcb08=0
471) +8320Hffa3 +8736Hhfa3 -2265.384615Hsol +1Hcce -1Hcb08 +1Hcb09=0
472) +6400Hffa3 +6720Hhfa3 -10000Hsla -1500Hsco05 -1500Hsco06 -1500Hsco07 -1500Hsco08 -2265.384615Hsol +1Hcce -1Hcb09 +1Hcb10=0
473) +40000Hlch2 -40000Hlcy2 -2265.384615Hsol +1Hcce -1Hcb10 +1Hcb11=0
474) -300Hlse2 -2265.384615Hsol +1Hcce -1Hcb11 +1Hcb12=0
475) +21712Hfwh3 +21712Hhwh3 -390Hlse2 -3100Hlcc2 -70Hswh -2265.384615Hsol +1Hcce +1Hcb01 -1Hcb12=0
476) -390Hlse2 -3100Hlcc2 -2265.384615Hsol +1Hcce -1Hcb01 +1Hcb02=0
477) -390Hlse2 -3100Hlcc2 -2265.384615Hsol +1Hcce -1Hcb02 +1Hcb04=0
478) -390Hlse2 -3100Hlcc2 -2265.384615Hsol +1Hcce +1Hcwc +1Hcci -1Hcb04=0
479) -83580Hfwh3 -76430Hhwh3 -2078Hlse2 +8650Hlsr2 -8650Hlsl2 -15484Hlcc2 +37120Hlch2 -37120Hlcy2 -1947Hsco05 -1947Hsco06 -1947Hsco07 -1947Hsco08 -21240Hsol -1Hn85 +1Hnt<=0
480) -83858Hfwh3 -76907Hhwh3 -2402Hlse2 +8800Hlsr2 -8800Hlsl2 -17577Hlcc2 +42440Hlch2 -42440Hlcy2 -1995Hsco05 -1995Hsco06 -1995Hsco07 -1995Hsco08 -21771Hsol -1Hn86 +1Hnt<=0
481) -64769Hfwh3 -59054Hhwh3 -2493Hlse2 +9890Hlsr2 -9890Hlsl2 -17716Hlcc2 +44640Hlch2 -44640Hlcy2 -1647Hsco05 -1647Hsco06 -1647Hsco07 -1647Hsco08 -22315Hsol -1Hn87 +1Hnt<=0
482) -58361Hfwh3 -52834Hhwh3 -2581Hlse2 +10870Hlsr2 -10870Hlsl2 -16182Hlcc2 +42400Hlch2 -42400Hlcy2 -1512Hsco05 -1512Hsco06 -1512Hsco07 -1512Hsco08 -22872Hsol -1Hn88 +1Hnt<=0
483) -60514Hfwh3 -54966Hhwh3 -2468Hlse2 +11240Hlsr2 -11240Hlsl2 -15422Hlcc2 +40800Hlch2 -40800Hlcy2 -1545Hsco05 -1545Hsco06 -1545Hsco07 -1545Hsco08 -23443Hsol -1Hn89 +1Hnt<=0
484) -48215Hfwh3 -43484Hhwh3 -2207Hlse2 +9950Hlsr2 -9950Hlsl2 -13314Hlcc2 +34760Hlch2 -34760Hlcy2 -1255Hsco05 -1255Hsco06 -1255Hsco07 -1255Hsco08 -24029Hsol -1Hn90 +1Hnt<=0
485) -51106Hfwh3 -46225Hhwh3 -2261Hlse2 +9850Hlsr2 -9850Hlsl2 -16352Hlcc2 +41880Hlch2 -41880Hlcy2 -1360Hsco05 -1360Hsco06 -1360Hsco07 -1360Hsco08 -24629Hsol -1Hn91 +1Hnt<=0
486) -47325Hfwh3 -42761Hhwh3 -2421Hlse2 +11200Hlsr2 -11200Hlsl2 -16972Hlcc2 +43760Hlch2 -43760Hlcy2 -1312Hsco05 -1312Hsco06 -1312Hsco07 -1312Hsco08 -25244Hsol -1Hn92 +1Hnt<=0
487) -46204Hfwh3 -41860Hhwh3 -1897Hlse2 +10170Hlsr2 -10170Hlsl2 -14012Hlcc2 +37920Hlch2 -37920Hlcy2 -1234Hsco05 -1234Hsco06 -1234Hsco07 -1234Hsco08 -25875Hsol -1Hn93 +1Hnt<=0

488) -45861Hfwh3 -41511Hhwh3 -1688Hlse2 +9400Hlsr2 -9400Hlsl2 -11935Hlcc2 +34240Hlch2 -34240Hlcy2 -1191Hsco05 -1191Hsco06 -1191Hsco07 -1191Hsco08 -26521Hsol -1Hn94 +1Hnt<=0

SUB Hsol 26
SUB Hlse2 5
SUB Hlcc2 3
SLB Hcce 94209
SUB Hcwc 243336
SLB Hnt 1704354
SUB Hnt 1704354

4. IDENTIFICATION OF THE VARIABLES USED IN MODEL CONSTRUCTION

4.1 FLAT LAND ACTIVITIES

fwh1	wheat	own	ha
fwh2	wheat	given out	ha
fwh3	wheat	share cropped	ha
ffa1	fallow	own	ha
ffa2	fallow	given out	ha
ffa3	fallow	share cropped	ha
frg1	rough grazing	own	ha
frg3	rough grazing	share cropped	ha
fch1	chickpea	own	ha
fch2	chickpea	given out	ha
fch3	chickpea	share cropped	ha
fpe1	pea	own	ha
fle1	lentil	own	ha
fto8	Early tomato	Aug.	ha
fto9	Late tomato	Sep.	ha
fvi1	vineyard	own	ha
flm1	lemon	own	ha
foa1	oats	own	ha
foc1	oat & clover	own	ha
fop1	oat & phalaris	own	ha
fph1	phalaris	own	ha

4.2 HILLY LAND ACTIVITIES

hwh1	wheat	own	ha
hwh2	wheat	given out	ha
hwh3	wheat	share cropped	ha
hfa1	fallow	own	ha
hfa2	fallow	given out	ha

hfa3	fallow	share cropped	ha
hrg1	rough grazing	own	ha
hch1	chickpea	own	ha
hch2	chickpea	given out	ha
hch3	chickpea	share cropped	ha
hpe1	pea	own	ha
hle1	lentil	own	ha
hoa1	oats	own	ha
hoc1	oat & clover	own	ha
hop1	oat & phalaris	own	ha
hph1	phalaris	own	ha

4.3 Mountainous Land Activities

mwh1	wheat	own	ha
mwh2	wheat	given out	ha
mwh3	wheat	share cropped	ha
mfa1	fallow	own	ha
mfa3	fallow	share cropped	ha
mch1	chickpea	own	ha
mch2	chickpea	given out	ha
mch3	chickpea	share cropped	ha
mrg1	rough grazing	own	ha
mrg3	rough grazing	share cropped	ha
mpp1	permanent pasture	own	ha

4.4 Land Transfer Activities

flt	flat land	given out	ha
hlt	hilly land	given out	ha

4.5 Livestock Activities

lse1	ewe	own	hd
lsr1	ewe lamb	own	hd
lsl1	lamb	own	hd
lse2	ewe	given out	hd
lsr2	ewe lamb	given out	hd
lsl2	lamb	given out	hd
lcc1	cow	own	hd
lch1	heifer	own	hd

4.9 Labour activities

hl01 to hl12	Monthly hired labour	Jan. to Dec.	days
uh01 to uh12	Used and transferred bank holidays	Jan. to Dec.	days

4.10 Capital and cash flow activities

cb01 to cb12	monthly cash transfer	Jan. to Dec.	$
cce	cash expenses	monthly	$
cil	INDAP loan	fertiliser	$
col	Other loan		$
coc	own cash	fertilise	$
cwc	working capital	initially available	$
cci	capital increase	yearly change	$

4.11 Risk activities

n85 to n 94	yearly negative deviations from target	$
nt	risk target	$

lcy1	yearling	own	hd
lcc2	cow	given out	hd
lch2	heifer	given out	hd
lcy2	yearling	given out	hd
lcc3	cow	taken	hd
lcy3	yearling	taken	hd
lox	ox	own	hd
lho	horse	own	hd

4.6 Forage activities

lfah	alfalfa hay	bought	kg
lfst	straw output	own	kg
lft1	forage	transfer I-II	kg
lft2	forage	transfer II-I	kg

4.7 Eucalyptus activities

heu01	hill eucalyptus	year1	ha
heu02	hill eucalyptus	year2	ha
heu03f	hill eucalyptus	3-20	ha
meu01	mount eucalyptus	year1	ha
meu02	mount eucalyptus	year2	ha
meu03f	mount eucalyptus	3-20	ha

4.8 Product sale activities

swh	wheat	sold	kg
sch	chickpea	sold	kg
sle	lentil	sold	kg
sla	lamb	sold	hd
sy01 to sy12	yearling	Jan. to Dec.	hd
sol	own labour	sold	days
ssb	straw bales	sold	kg
sco02 to sco09	charcoal	Feb. to Sep.	bags