An Integrated Agro-Economic and Agro-Ecological Framework for Land Use Planning and Policy Analysis

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To Nusa

For Hamodi, Marmar and Mazoni

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Abstract

The growing concern about land resource management and the associated decline in land qualities, has led to the realisation that land use planning and policy problems cannot be addressed adequately through a single discipline. This awareness has resulted in renewed attention for integrated, interdisciplinary approaches. It is argued that such an integrated, interdisciplinary approach to problems of land use planning and policy analysis is specifically hampered by lack of an adequate methodology. Although the limitation is increasingly recognised in the various disciplines, relatively little attention has been paid to the question of how to integrate agro-ecological and socio-economic aspects of land use. The study reported here, contributes to development and Operationalisation of a land use planning and policy analysis methodology that integrates agro-ecological and agro-economic information in such a way that land use policy options at sub-regional level can be formulated and evaluated with the aim of aiding policy makers.

The study starts with a critical review of the current state of the formal tools of land use planning with particular emphasis on their strengths and weaknesses to integrating bio-physical and socio-economic analysis, stating a need for an alternative integrated methodology, with due recognition of the obstacles and challenges this involves. After a thorough literature search, conceptual and methodological challenges that stand in the way of integration are analysed and described. The basic structure of the framework to a methodology for integrating bio-physical and socio-economic analysis in land use planning and policy analysis is developed and outlined.

The integrated framework derives its conceptual foundation largely from an adaptation of the theory of economic policy of agricultural sector analysis, the systems analytic approach, and the concepts of regional planning, to land use planning and policy analysis. The procedure of building the methodological framework is structured in a set of interrelated blocks (sub-frameworks). Each sub-framework of the methodology actually contains a number of steps, and requires a number of tools and/or methods for its Operationalisation. The sub-frameworks of the methodology are further developed and operationaliesd for a case of Amol sub-region in Iran.

After an identification of limitations of existing farm classification procedures, an alternative methodology is developed and outlined. The main purpose for farm classification methodology is to reduce aggregation errors, while integrating farm level with aggregate level of analysis. The methodology combines various clustering methods and proximity measures to group farms on the basis of operational parameters that reflect conditions necessary for exact aggregation. The methodology builds a step-by-step search procedure through a

set of possible classifications to identify one that fits the purpose reasonably well. The methodology is illustrated for Amol Township. It allows generating and testing alternative classifications each with different resultant farm types.

The study argues that land has a very strong socio-economic components that are not dealt with in the land unit concept and, therefore, a more integrated unit is defined. For this purpose the concept of "farm type land unit (FTLU)" is introduced. A FTLU is considered to be a farm type's share in a particular land unit or, alternatively, a land unit share in a particular farm type. The concept of FTLU is operationalised by establishing a (partial) link between geographic information system (GIS) and classification models. This link allows mapping of farm types and then linking them spatially with land units.

An integrated approach to definition and description of land use systems, and quantification of their input and output coefficients is presented. The approach presented here considers land use systems as integral systems that include both bio-physical and socio-economic components. The concept ILUS is proposed for a specific form of describing a land use system. The term ILUS is defined as a unique combination of a farm type land unit (FTLU), a land use type (LUT), and a production technique. ILUSs are described in terms of operation sequences. Such a description then serves as a basis for the calculation of the required input-output coefficients. Each unique operation sequence within a ILUS can be interpreted as a specific (land use) activity. Each activity is defined and described quantitatively in terms of input and output coefficients which quantify the relation between inputs of production and the outputs, desired as well as undesired.

Information on bio-physical and socio-economic components of land use systems is then confronted in an integrated land use planning and policy analysis (ILUPPA) model. The linear programming model. ILUPPA is a mathematical programming model in terms of solution technique, however, it is best described as a behavioural simulation model. It attempts to describe how farmers will react to certain classes of policy instruments that may influence their land allocation decisions. ILUPPA generates alternative land use policy options through the definition and description of various land use policy scenarios, corresponding to various policy instruments.

Because the purpose of the model is to generate sustainable land use policy options, various land use scenarios corresponding to different policy instruments are defined. On the basis of these scenarios, the model generates a number of feasible land use policy alternatives with their associated ILUSs and corresponding input and output coefficients. A multi-criteria evaluation technique is applied to rank the set of alternative land use policy scenarios, and hence to assist policy makers in selecting the "best" or the most preferred land use alternative or to facilitate a movement towards a consensus. To take into account the multiple and conflicting views, various preferences or priorities are included in the evaluation.

The rankings of the various policy scenarios, from different policy perspectives, are presented. Results show, that, for the specific situation of Amol sub-region and under the assumed policy views: non-price policy instruments are more effective in bringing about the desired changes and in achieving policy objectives; when more priority is given to environmental protection, the present situation, as reflected by the base scenario, is ranked most unfavourable; and the 'land consolidation' scenario is a good compromise among the different policy views.

In conclusion, the proposed methodology proves to considerably reduce the aggregation errors when compared to the existing modelling approaches in land use planning and policy analysis and is therefore expected to make a significantly positive contribution to improved quality of agricultural planning and policy analysis. Some degree of aggregation is, of course, inevitable to facilitate modelling and to restrict the costs of the analysis to 'reasonable' levels. Implementation of the proposed methodology requires a large database and the gains in precision of the analysis must be balanced against the higher costs of developing and implementing the methodology.

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Chapter 1

Towards an Integrated Approach in Land Use Planning and Policy Analysis

1.1 Background

It needs no arguing that more than ever before in the course of human history, the way people use the land has become a source of widespread concern for the future of the world. There is bound to be conflict over land use. The demand for land exceeds the resources available and, even where land appears to be plentiful, many are denied access or receive inadequate benefits from its use (FAO, 1993). Land in developing and developed countries is increasingly subject to population pressure, soil degradation and pollution. The need for improved ways of using land resources is widely recognized (see for instance Van Lier et al., 1994; and Stomph et al., 1994).

In recent years, sustainability has become a key notion defined as the successful management of resources for agriculture to satisfy changing human needs while maintaining or improving the quality of the environment and conserving natural resources (TAC, 1988). Today, one is witnessing a situation of changing demands on land use, and of growing concerns about environmental issues. Under these conditions, designing sustainable land use systems capable of meeting qualitatively and quantitatively expanding needs of the population in developing countries, presents an enormous challenge to all those concerned: policy makers, planners, scientists and last but not least, the population itself (Fresco et al, 1992).

Evidently, solving land use problems requires contributions from various disciplines and involves several levels of aggregation. Tensions between aggregation levels and also between disciplines frequently occur (Rabbinge and Van Ittersum, 1994). Moreover, land use problems deal with multi-purpose use of land, trade-offs between different functions of the land, and conflicting interests among different categories of stakeholders and between individual and collective goals and needs (Van Diepen et al., 1991). More than ever, therefore, the need for an integrated approach in land use planning and policy analysis is evident to assist in optimizing land use by identifying the conditions in which specific agro-economic and agro-ecological goals can be met.

It is argued that an integrated approach to sustainable land use is specifically hampered by the lack of adequate research methodology (RAWOO, 1989). The crux of the argument is that an integrated approach is essential if scientific research is to make an effective contribution to protecting and restoring natural resources. This research aims to contribute to developing a land use planning methodology that integrates agro-economic and agro-ecological information in land use planning with the aim of supporting and aiding policy makers to formulate and evaluate sustainable land use options at regional level.

1.2 The problem of integration

Various tools and techniques with different orientations (agro-ecological and agro-economic) have evolved to assess and analyze production potentials of land and farms, in support of the land use planning and policy analysis. Among these, land evaluation (FAO, 1976), farming systems analysis (Byerlee and Collinson, 1980) or a combination of land evaluation and farming systems analysis (Fresco et al., 1992) are the most elaborate and, in many ways, seem the most promising. A critical review of the current state of these tools with a particular view to their strengths and weaknesses to integrating bio-physical and socio-economic information for analysis and planning of sustainable land use is briefly presented and discussed. This review is necessary for justifying a need for an alternative methodology, and for profiting from the contributions of these tools and overcoming their shortcomings with regard to the integration of socio-economic and bio-physical components of land use analysis.

1.2.1 Land evaluation (LE)

Land evaluation (LE) was developed as a physical land assessment by soil survey specialists; it has broadened during the last twenty years by the inclusion of some socio-economic aspects (Van Diepen et al., 1991). Over the years, a variety of evaluation procedures has been proposed to cope with the complexity of land and its use. Contributions were brought together in a series of meetings, starting in 1973, culminating in the publication of the "Framework for Land Evaluation" by the Food and Agriculture Organization (FAO) of the United Nations in 1976. This Framework sets out basic concepts, methods and procedures for land evaluation that are claimed to be "universally valid, applicable in any part of the world and at any level, from global to single farm". Land evaluation is concerned with the assessment of land performance when used for specified purpose (FAO, 1976). In land evaluation, analysis of land suitability combines a study of land (properties) with a study of land use and determines whether the compounded requirements of land use are adequately met by the compounded properties of the land (Driessen and Konijn, 1992).

The Framework has been followed by a series of subsequent guidelines for: rainfed agriculture (FAO, 1983); forestry (FAO, 1984); irrigated agriculture (FAO, 1985) and extensive grazing (FAO, 1987). These guidelines provide an expansion of the basic concepts and details on the operational aspects of the procedures recommended in the Framework. The FAO Framework for Land Evaluation (FAO, 1976) has become the most quoted reference in land evaluation, and most authors agree on its importance for the development of land evaluation as a discipline. Beek (1980), for example, describes the Framework as a milestone in the evolution of a realistic approach to land evaluation.

Formal methods of land evaluation in the context of land use planning, have been critically reviewed by, for example, Stomph and Fresco (1991); Van Diepen et al. (1991); Fresco et al. (1992); Sharifi (1992); Erenstein and Schipper (1993); Hengsdijk and Kruseman (1993), Huising (1993); Kruseman et al. (1993); Alfaro et al. (1994); Bronsveld et al. (1994); Van Duivenbooden (1995); and Schipper (1996). From these reviews, problems related to integrating socio-economic and bio-physical information, emerge as the major constraints for successful land evaluations. In addition methodological, operational, logistic and administrative constraints play a role.

Of major concern here is why do land evaluations so often fail to fulfill their promise to serve as a tool for integrating bio-physical and socio-economic disciplines in support of land use planning? In the following an attempt is made to find answers to this question with reference to the previous reviews.

- LE is primarily concerned with land, and identification of the best use of each piece of land is its prime goal. People are considered to the extent that they participate in land use, and then not as actors but as management skill or labour. In this way, the concept of land is reduced to a set of bio-physical or ecological characteristics or properties alone. Purely socio-economic characteristics are not included in the concept of land.
- In LE it is stated clearly that selected land use types should be physically and socio-economically relevant to the local area concerned. However, in practice this requirement is not sufficiently met, especially with regard to the socio-economic aspects. Socio-economic information is included in the description of land use types, but that information is not used in an operational way in the suitability assessment procedures.
- LE ignores possible relations between land use types within the context of the farm, in the sense that the allocation of resources to some kind of land use type may withdraw resources from others and that farmers will optimize land use at the farm level and not at plot level, given their own specific constraints and potentials.

- LE procedures are not designed to contribute to decision making in situations where conflicts arise among various groups of stakeholders and/or between individual and collective goals and needs.
- LE procedures do not take sufficiently into account potentials and constraints of the local land users by whom decisions regarding land use are made.
- LE procedures do not provide guidelines for comprehensive environmental impact assessment, and do not discuss rules for operationalising the sustainability concept.

In summary, land evaluation treats socio-economic aspects with a great deal of generality and particularly omits the farm as a decision-making unit and neglects or ignores the intrahousehold allocation of resources. Many suitability assessments, although relevant, are therefore less applicable for land use planning, and certainly for implementing proposed land use changes (Fresco et al., 1992; Erenstein and Schipper, 1993; Schipper, 1996). Notwithstanding these problems and constraints, there are considerable potentials, merits and contributions for land evaluation procedures to serve as one of the tools for land use planning. These potentials and contributions can be summarized in the following (Beek, 1978; Driessen and Konijn, 1992; Van Lanen, 1991; Fresco et al., 1992; Hengsdijk and Kruseman, 1993; Stomph et al., 1994):

- LE looks at the bio-physical potentials for the use of land which is an important starting point for land use planning. These potentials are based on an evaluation of physical and biological resources. This gives land use planning a more thou base to link bio-physical aspects to socio-economic ones.
- LE has been successful in developing quantitative methods for assessing the bio-physical potential of land and linking up with quantitative system analysis. The qualitative assessment of the bio-physical potential of land is gradually replaced by quantitative methods.
- LE has a strong geographical orientation. It emphasizes mapping, and has recently integrated some of the geographic information systems methodology.

1.2.2 Farming systems analysis (FSA)

Almost concurrently, but entirely separately, the concept of farming systems analysis (FSA) evolved, in which agronomists and agro-socio-economists played an important role (Fresco et al., 1992). FSA emerged in response to the concern over the increasing gap between the yields obtained on experimental fields and actual farmer yields. This led to the awareness that higher crop yield potentials alone can not account for development (Hengsdijk and Kruseman, 1993). Attempts to find a better way to take into account all elements that influence the farmer in his decision-making process has led to the development of farming systems analysis and farming systems research. FSA deals with understanding of the structures and functions of farming systems, and the analysis of constraints to agricultural production at farm level (Fresco, 1988). It can be defined as the body of knowledge that is concerned with diagnosis and analysis of farm level variables (Fresco et al., 1992). It is restricted to the farm level and focuses on specific cropping systems and their interactions (Stoorvogel et al., 1995).

Concepts, methods, and procedures used in FSA are described, for example, in Byerlee and Collinson (1980), Conway (1985) and Norman and Collinson (1985). A distinguishing feature of farming systems analysis in comparison to most classical research in agriculture is its attempts to integrate the results of various disciplines, in order to understand the linkages between the agro-ecological and socio-economic aspects of a farm. It distinguishes between systems at various hierarchical levels, ranging from crop system to the higher level of land use systems (Fresco et al., 1992). The contributions of farming systems analysis to land use planning are (Fresco et al., 1992; Hengsdijk and Kruseman, 1993):

- FSA gives insight in farm level constraints and potentials and thus can identify the bottlenecks and the possibilities for intervention.
- FSA opens up a dialogue with farmers who are, after all, both the real land users and the end users of the results from the whole land use planning process.

Problems in FSA have been discussed, for example, in Simonds (1986), Fresco et al. (1992), Hengsdijk and Kruseman (1993), Huising (1993), Van Duivenbooden (1995) and Van Rheenen (1995). These problems are related to methodological, conceptual, institutional, and organizational issues. Particular questions relating to the methodological and conceptual difficulties of integration of socio-economic and bio-physical information in FSA are:

- FSA is mainly farmer oriented. It concentrates on the farmer, and only to a less extent on land. It should be, but it should not be only farmer oriented.
- FSA provides generalized, aggregated regional information on natural resources, and hardly provides bio-physical detail at the farm level.
- FSA lacks the geographical orientations. Geo-referencing of farm level data, apart from transects, is hardly ever considered in FSA.
- FSA has been too qualitative. While the awareness of the need for quantitative data is growing among farming systems analysts, FSA remains surprisingly qualitative when it comes to the ultimate judgment.
- FSA does not address the complex issues of sustainability. In particular, the design of sustainable land use systems has been neglected in FSA.

1.2.3 Land evaluation and farming systems analysis (LEFSA)

Land evaluation (LE) and farming system analysis (FSA), even when remaining separate, can benefit from one another methodologically and conceptually. While both approaches have merits of their own and are to some extent complementary, there is little integration because each belongs to different schools of thought (Alfaro et al., 1994). Fresco et al. (1992) discuss how elements from both LE and FSA can be integrated into a new set of procedures called "Land Evaluation and Farming Systems Analysis (LEFSA) for Land Use Planning" which may meet some of the criticism advanced against both approaches but combines the strengths of each.

Concepts, methods, and procedures of the LEFSA sequence are discussed and presented in Fresco et al. (1992). It is argued that the LEFSA sequence presents some advantages over the separate application of land evaluation and farming system analysis. A brief summary of the main advantages of the LEFSA sequence on each of the component procedures and their expected relevance for land use planning are presented in Fresco et al. (1992).

The LEFSA sequence is relatively new and it is too early to voice well-founded criticism, since the actual implementation should demonstrate its strengths and weaknesses. No such effort is known to be undertaken, but there is no doubt that effective integration of LE and FSA into a LEFSA sequence will present great difficulties. In the context of land use planning, many problems may be expected when applying the LEFSA sequence in practice (Fresco et al., 1992; Hengsdijk and Kruseman, 1993). The operational integration of bio-physical and socio-economic information in the LEFSA sequence, however, is the most important problem and that extend beyond the suggested procedures. Many conceptual and methodological constraints are expected to challenge the process of integrating socio-economic and bio-physical information in the LEFSA sequence. Some of these constraints are:

- The difficulty of geo-referencing the farming system data collected through FSA procedures. This complicates linking of the spatially explicit (bio-physical) information produced by LE and the generally non-spatially referenced (socio-economic) information provided by FSA.
- LEFSA recognizes the importance and necessity of linking and combining analysis at a macro level (e.g., regional level) with those at micro level (e.g., farm level) and mentions it as one of the most important prerequisites for integration of the bio-physical and socio-economic information. But the LEFSA sequence doesn't provide any guidelines or procedures in this respect. The following extract from LEFSA document shows clearly this fact: *"In economics, the relations between analyses at the micro and at the macro level are theoretically among the most difficult*

problems...and as yet unsolved in a satisfactory way, certainly for practical situations. The present document cannot even attempt to provide any guidelines in this area, except via adjustment in a process of trial and error (Fresco et al., 1992)."

- Integration of LE and FSA into LEFSA would indeed contribute to the design of sustainable land use systems. Unfortunately, little progress has been made in the operationalisation of the sustainability concept in the LEFSA sequence.

1.3 The need for an alternative integrated approach

It should be clear from the above reviews that many conceptual and methodological issues constitute severe limitations to the integration of bio-physical and socio-economic analysis in land use planning. Because of the complexity of these issues and the range of dimensions involved in the problems of sustainable land use, the need for an integrated, interdisciplinary approach in land use planning is pressing, and the theoretical importance of the integrated approach is well recognized (RAWOO, 1989; Fresco et al., 1992; Alfaro et al., 1994). However, current methods and procedures of land use planning are inadequate to address, what is perhaps the major problem in land use planning (Stomph et al., 1994), the problem of integrating bio-physical and socio-economic information.

It is argued that an integrated, interdisciplinary approach to problems of land use is specifically hampered by the lack of adequate methodology (RAWOO, 1989). The present lack of a methodology for integration is one of the main reasons why planned interventions fail or are not effective (RAWOO, 1989) and why land use planning efforts have often not lived up to expectations (Stomph et al., 1994). Therefore, an alternative methodology that integrates bio-physical and socio-economic disciplines for analysis and planning of sustainable land use options appears necessary to enhance the quality of the land use planning and policy analysis.

1.4 Scope and objectives of the study

The complex nature of land use problems and issues, calls for a more adequate integrated methodology in land use planning than presently available. The main contribution of this study, however, lies in an attempt to develop a methodology that integrates bio-physical and socio-economic information in land use planning and policy analysis. It proposes an integrated methodology that aims at removing some of the obstacles that stand in the way of integration. The overall objective of this study is the development and operationalisation of a methodology that permits integration of bio-physical and socio-economic analysis in such a way that options for sustainable land use at (sub)-regional level can be formulated and evaluated with the aim of aiding policy makers. The overall objective can be divided in the following sub-objectives:

- Description and analysis of main conceptual and methodological challenges and obstacles that stand in the way of integrating agro-economic and agro-ecological information in land use planning and policy analysis;
- Development of a methodology that integrates agro-economic and agro-ecological information in land use planning and policy analysis with the aim of aiding and supporting policy makers to formulate and evaluate land use policy options at (sub)-regional level;
- Operationalisation of the methodology for a case study of Amol sub-region, Iran.

1.5 For whom?

The development of the methodology is geared towards aiding policy makers at regional level in their decisions to formulate and evaluate sustainable land use options. It is not intended to help farmers make decisions at farm household level. Therefore, the ultimate level of aggregation of the system is the region. What happens at a lower (e.g., farm) or higher (e.g., national) level of aggregation may be necessary to analyze to be able to reach conclusions about the region (Hengsdijk and Kruseman, 1993). To be able to correctly analyze regional possibilities, it is necessary to give micro (e.g., farm) level explanations of both the technical parameters and of the behaviour of the relevant actors (e.g., farmers). Similarly, constraints from national level have to be considered, but are treated as premises not as endogenous variables.

1.6 Outline and structure of the study

This study can be divided into three main parts. The first part (Chapters 1 and 2) gives insights for understanding the problem of integrating socio-economic and agro-ecological information in land use planning and policy analysis. In the second part (Chapter 3) an integrated methodology for land use planning is developed and in the third part (Chapters 4 to 8) the methodology is operationalised on the basis of a real case study.

Chapter 1 gives an introduction to an integrated approach to land use planning and policy analysis, containing a critical review of the current state of the formal tools of land use planning with particular emphasis on their strengths and weaknesses to integrating agro-ecological and socio-economic analysis is briefly presented and discussed. The need for an alternative integrated approach is then stated, with due recognition of the obstacles and challenges this involves. Main conceptual and methodological constraints that stand in the way of integration are analyzed and described in Chapter 2. These constraints form the basis for the development of a framework to a methodology for integrating agro-ecological and socio-economic analysis in land use planning as described in Chapter 3.

Opertionalisation of this methodology is laid out in Chapters 4 to 8. Chapter 4 introduces a procedure for farm classification as a starting step for integration, and Chapter 5 goes on to conceptualize and opertionalise an approach to define an integrated unit for land use planning and policy analysis through mapping of farm types and then linking them spatially with land units. An integrated framework for the definition and description of land use systems, and quantification of their input and output coefficients is presented in Chapter 6. Information on bio-physical and socio-economic components of land use systems is then integrated in a land use planning and policy analysis model (Chapter 7).

Generation and evaluation of land use policy options is presented in Chapter 8. This chapter consists of two main parts. Firstly, the linear programming technique has been used to simulate (generate) the possible effects of alternative policy instruments on predefined policy objectives. Secondly, these alternative policy options have been evaluated using a multi-criteria evaluation technique under various policy priorities. The study ends with a discussion on strengths and weaknesses and conclusions regarding the proposed methodology to integrating agro-ecological and agro-economic analysis in land use planning and policy analysis (Chapter 9).

Chapter 2

Description and Analysis of Challenges to the Integration

2.1 Introduction

To answer the question "why is integration necessary?", Luning (1986) states that: "integration is necessary to aid communication and co-operation among parties to the development process, to link natural resource studies to social and economic development processes, to improve efficiency in the use of resources available for development and to help ensure that all parties in the development process are working to the same ends on projects which have a high social and economic utility".

Despite the recognition of its importance in natural resources management, the problem of integrating bio-physical and socio-economic analysis remains the major challenge, and as has yet not been solved in a satisfactory manner. In this part of the study a thorough literature search has been carried out to answer the question: "why is integration difficult?". This literature search aims at identifying challenges and impediments to the integration, clues on how they can be approached, and at identification of elements and/or components to be included in the integrated methodology.

The chapter starts with the discussion of some basic terminologies and definitions that are necessary for understanding the integration problem. Then, it goes on to show the importance of an interdisciplinary approach in land use planning, with due recognition and attention for the nature of land use problems. Finally, it describes and analyses the challenges that stand in the way of integration.

2.2 Terminologies and definitions

Integration is a key word, yet it is not new. All through the history of science the output from one discipline has been used as input for another (Hengsdijk and Kruseman, 1993). Integration generally refers to the act of combining or adding parts to make a unified whole. In natural resources management, Pickett et al. (1994) define integrated models as "models that deal with interactions among socio-economic, physical and ecological aspects of a system". In integrated economic-ecological modelling, Braat and Van Lierop (1987) distinguish between integrated models in operational sense and in structural sense. In operational sense, integrated models are those that are capable of assessing the relevant impact of the economic activities on the eco-system, as well as the relevant effects of the state of the eco-system on economic activity. In structural sense, integrated models refers to models in which both the economic and the ecological aspects relevant to a particular problem, as well as the relationships between economic activities and ecological processes essential to the problem, are included in an adequate manner.

Integration, in the current study, refers to both its meaning in structural as well as in operational sense. In combination with the word "methodology" or "approach", it refers to conceptually structuring the interactions and relationships between socio-economic and bio-physical elements of land use systems, and to developing procedures, methods, tools, and techniques that are necessary for analyzing and evaluating the impact of the socio-economic activities on the eco-system, as well as the relevant effects of the state of the eco-system on socio-economic activity. Integration, defined this way, implies interdisciplinarity.

A discussion of interdisciplinarity must start with a definition of the term *discipline.* According to Van Dusseldorp and Van Staveren (1980) the term discipline is understood to mean: a branch of science(s). Science, however, can ramify in two ways: according to methods; or according to themes. Such themes are, in fact, professional branches which combine a number of basic sciences. The latter type of ramification is used in Luning (1986) to define the term discipline. Luning (1986) states that: "development of sciences has led to appearance of what we term 'discipline', in which a coherent body of knowledge arises from a thematic study of part of reality". The term discipline is used here to mean the latter type of ramification.

Disciplines are characterized not only by subject matter but also by the principle of scientific reduction which helps to focus analysis (Janssen and Goldsworthy, 1996). A discipline is not a static concept, however. New disciplines emerge as a result of the generalization of science and further specialization, or through knowledge of new phenomena or simply in response to new perceived problems. When two or more disciplines co-operate, the terms 'multi-disciplinary' and 'interdisciplinary' are both used. In fact, different types of disciplinary terms can be distinguished by adding a prefix before the term 'disciplinary', e.g. mono-disciplinary, multi-disciplinary, and inter-disciplinary. These terms are used loosely among the various disciplines. The conceptual differences among mono-, multi- and inter-disciplinarity are discussed by, for example, Van Dusseldorp and Van Staveren (1980); Luning (1986); Fresco et al. (1992); Hengsdijk and Kruseman (1993); and Vedled (1994).

Mono-disciplinarity refers to a situation where a problem is addressed by sticking to a single discipline. In a mono-disciplinary approach, research scientists mainly investigate those aspects that fall within their competence, which entails the risk of a biased or inadequate analysis (Hengsdijk and Kruseman, 1993). It is like two individuals looking at a mountain from different sides and each deciding how to climb the mountain without considering what they cannot see (Luning, 1986). Only if the problem relates to principally one and insignificantly to other dimensions will a mono-disciplinary approach be adequate (Janssen and Goldsworthy, 1996).

Multi-disciplinarity is when scientists versed in different disciplines work together or in parallel on a certain problem or topic without any explicit pattern of relationship (Van Dusseldorp and Van Staveren, 1980; Hengsdijk and Kruseman, 1993; Vedeld, 1994), or when a solution to a problem is aimed at through combinations of the contributions made by each discipline. When multi-disciplinarity does not go beyond a summation of the contributions, from each discipline, that is not really integration (Fresco et al., 1992).

In contrast, interdisciplinarity requires a purposeful pattern of interrelation right from the start (Van Dusseldorp and Van Staveren, 1980), an intimate co-operation among disciplines (Hengsdijk and Kruseman, 1993), and an emergence of an area of knowledge and activities at the interface among these disciplines (Luning, 1986). Interdisciplinarity takes place when efforts are consciously taken to develop a common language or set of concepts in order to undertake a joint study. Such co-operation can lead to integrated conclusions and insights of a far better quality than would be possible under the cumulative approach. This does not involve developing a new science, but rather creating a common ground for special purpose (Vedeld, 1994).

2.3 The importance of an interdisciplinary approach in land use planning and policy analysis

The comparison among mono-, multi-, and inter-disciplinary approaches does not imply a lower to higher type of science practice. It is the nature of questions or problems that largely dictates whether mono-, multi-, or interdisciplinary approaches are required and appropriate (Luning, 1986). Natural resource problems, such as land use problems, result from the use of ecological systems for socio-economic activities. Apparently, looking at a particular land use problem, one may rightly focus on either: (i) the socio-economic dimension or (ii) the ecological dimension.

These two viewpoints illustrate that resource problems generally have at least an economic and an ecological dimension. Economic activities are characterized by, for example, social, political and technological factors. This implies that land use problems also have these characteristics. Ecological systems are of course governed by, for example, the laws of physics and biology. Therefore, land use problems also comprise these aspects. Since land use problems are not disciplinary abstractions but real-life phenomena with many dimensions to them, they cannot be addressed adequately by mono-disciplinary approaches. There is no doubt that for land use planning and policy analysis, an interdisciplinary approach is essential (RAWOO, 1989; Alfaro et al., 1994).

The complexity of the issues involved is only one reason for dictating that progress in interdisciplinary approaches be accelerated. Janssen and Goldsworthy (1996) give three reasons for following an interdisciplinary approach in natural resource management research. One reason is that the complexity and range of dimensions for many natural resource problems are such that they can not be tackled by a single discipline. Another reason is that interdisciplinarity facilitates the development of a user perspective and greater consultation with stakeholders in the problem-solving process. A third reason is that interdisciplinary approaches in natural resource management research may lead to the formation of new disciplines, such as ecological economics which addresses the relationship between ecosystems and economic systems in the broadest sense.

2.4 Conceptual and methodological challenges

Although the theoretical importance of integrating bio-physical and socio-economic analysis in planning sustainable land use is now well recognized (see for example Fresco et al., 1992; Stomph et al., 1994; Alfaro et al., 1994), applications are still hampered by major obstacles which render difficult the integration process. In the realm of agricultural planning, many conceptual and methodological constraints that stand in the way of integration are discussed by, for example, Malingreau and Mangunsukardjo (1978); Luning (1986); Braat and Van Lierop (1987); RAWOO (1989); Van Diepen et al. (1991); Fresco et al. (1992); Hengsdijk and Kruseman (1993); Sharifi and Van Keulen (1994); Stomph et al. (1994); Pichett et al. (1994); Schipper (1996). From these reviews the main constraints have been distilled.

2.4.1 Aggregation[1] problem and difficulty of integrating levels

In integrating bio-physical and socio-economic aspects for analysis of land use problems, one is always confronted with the problem of combining data from different spatial scales (the aggregation problem). Linking levels of analysis, therefore, is an important prerequisite for the integration (Fresco et al., 1992). Land use decisions involve choices on at least two spatial scales (or levels). At one level, the regional level (macro level), a policy maker is trying to decide how best to allocate limited resources in the face of uncertainty about what all the allocational consequences will be. This uncertainty really is uncertainty about how farmers will respond to policy changes. At the other level, the farm level (micro level), farmers have their own decision problem: how best to respond to the new policy environment, given their own resources, objectives and limitations of actions (Hazell and Norton, 1986). In order to solve the macro-level decision problem, the uncertainty about farm responses has to be reduced. Ideally this can be done by aggregating the behaviour of individual farms to be able to estimate their responses.

In land use planning, the aggregation from farm level to regional level of analysis remains a pressing issue with both methodological and empirical aspects. Briefly stated, the empirical aspects of the problem refer to the development of a computationally feasible procedure which minimizes aggregation bias. The methodological ones do not immediately concern the feasibility of the computations, but rather the conditions under which it is possible to achieve aggregation with zero (or minimum) bias (Paris and Rausser, 1973). The problem of finding appropriate procedures for aggregating various individual farms in land use planning is still unsolved in a satisfactory manner and much further research is needed (Fresco et al., 1992).

At this point, it is desirable to give a more rigorous definition of aggregation bias and analyze its causes and directions. Generally, the aggregation problem casts its shadow on research whenever aggregate variables are studied without explicit reference to individual decision making units (Day, 1963). In agricultural planning, scaling up analysis from farm level to regional level, is the source of the aggregation problem (Spreen and Takayama, 1980). In this transition, aggregation bias arises because not all farms are similar. The aggregation error, as defined by, for example, Miller (1966) and Miller and Heady (1973), is the error of estimating aggregate outcome for a group of farms by modeling their behaviour at a certain degree of aggregation, rather than modeling the behaviour of each farm individually. In terms of

[1] Aggregation problem analyzed and described in this sub-section is related to aggregation levels in socio-economic terms. Although tension between aggregation levels in production-ecological terms also exists in time and space, yet this type of aggregation problem can be handled by the credo 'first calculate, then average' (De Wit and Van Keulen, 1987; Rabbinge and Van Ittersum, 1994).

programming jargon, aggregation error is said to exist when the sum of the solutions for each of the individual farms in the set does not equal the estimate obtained by determining the optimum solution to the entire set directly (Wossink, 1994).

This error was first designated in economic literature as aggregation bias (Stovall, 1966), a term that implicitly denotes a systematic direction in error arising from aggregation. There are some evidences in hypothetical examples (Hazell and Norton, 1986; Nafessa, 1996) and in empirical work (Sheehy and McAlexander, 1966) to suggest that bias is always in an upward direction. Therefore, the basic problem becomes how to avoid or minimize aggregation bias when linking farm level information to regional level analysis.

The ideal but impractical procedure would be to program the behaviour of every individual farm in the region and to sum them into the desired aggregate estimate. The result of this procedure is an estimate free of aggregation bias. Hence, it becomes a logical standard against which all other procedures may be judged (Day, 1963). Although this approach would result in a bias-free "exact aggregation", the limited resources available for study and the bewildering number of micro estimates required to represent the behaviour of all farms (each of which in itself requires a considerable amount of empirical estimation) usually makes it impractical (Day, 1963; Miller, 1966; Spreen and Takayama, 1980; Hazell and Norton, 1986).

Alternative abstract approaches often used for aggregation in agricultural planning are "representative farms" or the "aggregate regional" approaches (Hazell and Norton, 1986). The "representative farms" approach often includes scaling up the behaviour of a representative farm to generate information about the aggregate behaviour of the group or set of individual farms it represents. The aggregate regional approach involves aggregating the resources of a homogenous region and considering these aggregated variables as variables of a single large farm. This approach is identical to the representative farms approach if representative farms are defined as arithmetic mean farms for the same region.

Inherent in these conventional procedures is the possibility of aggregation bias or error (Day, 1963; Miller and Heady, 1973; Hazell and Norton, 1986). To illustrate the aggregation problem, consider the following *two farm problem* formulated in a linear programming format, each with two cropping activities X_1 and X_2:

Farm A	X_1	X_2	Resources
Profit	60	85	Maximize
Labour	20	30	20
Land	1	1	2

Farm B	X_1	X_2	Resources
Profit	100	85	Maximize
Labour	50	30	70
Land	1	1	2

The optimal strategy for farm A is to grow 1 unit of X_1, while farm B should grow 2 units X_2. For farm A the profit is 60 while for farm B the profit is 170. Suppose now the aggregate farm is taken to represent farms A and B in an aggregate model. The aggregate farm problem would be as follows:

Aggregate farm	X_1	X_2	Resources
Profit	80	85	Maximize
Labour	35	30	90
Land	1	1	4

The optimal solution to this problem is 3 units of X_2 for a total profit of 255; an amount which exceeds the sum of the profits obtained from the individual farm models, which is 230. This outcome illustrates the fact that aggregation bias is always in an upward direction: it overstates resource mobility by enabling farms to combine resources in proportions not available to them individually, and it carries the implicit assumption that the aggregated farms have equal access to the same technologies of production (Hazell and Norton, 1986).

It seems apparent that the conventional aggregation procedures described above can produce significant aggregation errors. Such an aggregate analysis often exhibits results that are not in agreement with behavioural relationships specified at a micro level (Nijkamp, 1987). If such procedures are used for planning, serious mistakes could result (Egbert and Kim, 1975). Therefore, an alternative procedure for developing an error-free or minimum-error farm aggregate becomes necessary as a basis for integrating and linking farm level to regional level of analysis. This is motivated by the fact that one of the important advantages of the integration is the possibility of linking levels (Fresco et al., 1992).

2.4.2 Difficulty of finding an integrated unit of analysis

While land use problems are rooted in physical and biological sciences, they are driven by human behaviour. It is not feasible to determine how land use problems arose or how they could be solved without understanding the human decision-making process. Typically, land use planning requires understanding interactions among socio-economic and agro-ecological processes (Schimel, 1994). These interactions, which are critical to the land use planning process, suggest the need for an integrated, interdisciplinary approach to understanding this problem.

Currently, it is not clear how to implement such an integrated approach, but it is perceived that an initial necessary step is to integrate the different disciplines with their characteristically different focus on processes and scales (Fresco et al., 1992; Elizabeth, 1994). This does not involve developing a new discipline, but creating a common (i.e., an integrated interdisciplinary) unit for analysis. In land use analysis and planning, many constraints or problems hamper identification of such an integrated unit, i.e. a unit that has both strong socio-economic as well as bio-physical characteristics. The main constraints are: the different nature of disciplines involved; different units of analysis they use; different levels of analysis they focus on; and the difficulty of spatially linking these disciplines.

Different nature and focus of disciplines

Luning (1986) identifies "the nature of disciplines" as one of the main constraints to their integration. Scientists from different disciplines think, understand and approach the "same phenomenon or the same problem" in different ways. They address problems in the real world from different angles, and therefore the assumptions they apply, the methods they use, and the models they produce may be quite different (Luning, 1986; Vedled, 1994).

Land use problems generally have at least two dimensions: a socio-economic dimension and an agro-ecological dimension. For example, land use decisions are directly related to socio-economic conditions, but are also determined by the bio-physical conditions of land. Economics and Ecology do not deal with the same issues. Economics is a science about human choices and behaviour. This includes management and use of natural systems and resources. Ecology is basically a science of studying natural systems, natural processes and phenomena, and does not deal with human behaviour or adaptations.

Apparently, looking at a particular land use problem, an ecologist will take the ecological system as the point of departure and will regard the land use problem in relation to how people disrupt ecological systems. The economist has man as a point of departure, and will regard the land use problem in terms of how natural resources and ecosystems may be utilized efficiently. These disciplinary focuses have not always resulted in adequate understanding of the processes that couple subsystems (Elizabeth, 1994). The coupling between the processes studied by the natural (e.g., agro-ecological) and human (e.g., socio-economic) sciences is not well understood (Pickett et al., 1994). This is because of lack of an integrated, interdisciplinary framework to problem solving.

Since land use problems are not disciplinary abstractions but real-life phenomena with many dimensions to them, they cannot be addressed adequately by mono-disciplinary focus. There is no doubt that for land use analysis and planning, interdisciplinary focus is essential (RAWOO, 1989; Alfaro et al., 1994). Thus, interdisciplinary efforts remain the goal of integrated approaches in land use planning, but mono-disciplinarity or multi-disciplinarity is the current state.

Different units of analysis

The differences in the nature and focus of disciplines lead to different units of analysis. Land use from an agro-ecological point of view is described in terms of some sort of unit that can be used to discriminate between alternative land uses. The description is basically linked to land. This is evident in the Framework for Land Evaluation (FAO, 1976), in which the land use type is considered to be the subject of land evaluation whereas land unit is the object of land evaluation.

From a socio-economic point of view land use is a special case of resource use. Land is the fundamental resource in agriculture and therefore deserves special attention, however, the objectives that define what use should be made of the land are not necessarily related directly to the land. Often the guiding principle for land use decision making is linked to the aspirations of farm-households. Developing procedures describing how to combine the land unit and the farm system into one unit is one of the main challenges for integrating bio-physical and socio-economic disciplines in land use planning.

Different hierarchical levels of analysis

The discussion on the difference in units of analysis is closely linked to a discussion about the hierarchical levels at which both disciplines operate or exist. The hierarchical systems proposed in agriculture by, for example, Van Dyne and Abramsky, 1975; Fresco, 1986; Conway, 1987; Fresco et al., 1992, are derived from the application of the hierarchical structure of ecology to agriculture. In analogy to ecology, agriculture is described as a hierarchy of systems. In the biological and ecological realm, the central concept of systems theory is the ecosystem whereas in the socio-economic realm the central system is the human system.

Depending on whether socio-economic or bio-physical aspects are studied, a system of agricultural hierarchy includes levels (e.g., farms) combined into socio-economic units such as villages, or into bio-physical units such as watersheds (Fresco et al., 1992). Stomph et al. (1994) pointed to one major disadvantage of the hierarchical approaches in systems analysis in agriculture suggested previously: at the lower levels mainly biophysical criteria are used (e.g., cell-plant-crop) and at higher levels mainly socio-economic or administrative criteria (e.g., village-region-country).

Current modeling of land use practices has been discipline-specific or at best separate disciplinary models are linked at a higher hierarchical level. Extrapolating from separate agro-ecological and socio-economic models in an "additive" fashion may not adequately represent systems behaviour because interactions may occur at levels that are not represented (Pickett et al., 1994). In terms of hierarchy theory, each discipline has traditionally represented systems dynamics as a separate hierarchy of systems, and linkages among the hierarchies have only been considered at the highest levels. Lower-level interactions among disciplines or hierarchies must be considered in order to represent system dynamics adequately. The problem in integrating bio-physical and socio-economic disciplines is, therefore, to find a level in the hierarchy of systems at which both realms meet.

Difficulty of spatial linking of disciplines

Any attempt to integrate bio-physical and socio-economic disciplines for analysis and planning of land use should be based on spatial linking of both types of disciplines. Most of the information on the bio-physical aspects can easily be geo-referenced or mapped. Information on socio-economic aspects can not be mapped, as they are descriptive or conceptual and not geo-referenced. As a consequence, spatial (geo-referenced) information on bio-physical aspects can not be combined with information on socio-economic aspects (Fresco et al., 1992). The difficulty of geo-referencing socio-economic information results in the difficulty of finding an integrated spatial unit.

In land use planning, the problem of spatially integrating land units and farming systems is one of the most pressing issues and as yet unsolved in a satisfactory manner. The difficulty of mapping farming systems results in difficulty of finding an integrated spatial unit. In the farming system development approach of FAO (1990) delineation or mapping of farming system zones has been mentioned as one of the practical limitations in farming system zoning. Likewise, LEFSA (Fresco et al., 1992) recognized the difficulty of mapping farming system information, but it doesn't provide any procedure on how to do it. LEFSA recommends further research to solve or reduce this problem and indicated some promising methods in this respect.

2.4.3 Insufficient attention to quantitative socio-economic analysis

Many procedures and methodologies have been developed for analysis and planning of land use (see for example, Fresco et al., 1992; Sharifi, 1992; Erenstein and Schipper, 1993; FAO, 1993; Huising, 1993; Fresco et al., 1994; Stoorvogel, 1995; Van Duivenbooden, 1995; Schipper, 1996). Qualitative (FAO, 1976; FAO, 1983), or semi-qualitative (Dumanski and Stewart, 1981; Sys et al., 1991) methods can indicate the suitability of a certain land use type for a certain land unit. There are situations, however, where qualitative or semi-qualitative descriptions of the performance of land use systems are simply 'not good enough' (Driessen and Konijn, 1992), e.g., if the bio-physical information is needed to be integrated with socio-economic information (Stomph et al., 1994). This explains why developments in land use planning methodologies are increasingly directed at measurement and calculation of the performance of land use systems (Jansen and Schipper, 1995), and at mathematical description of processes and interactions (Alfaro et al., 1994; Schipper et al., 1995).

The qualitative or semi-qualitative nature of these methods does not facilitate optimization of land use in relation to agro-ecological and socio-economic conditions in a given situation (Jansen and Schipper, 1995). Better geared to the task are methods that quantify the bio-physical processes (e.g., Driessen and Konijn, 1992; Van Diepen et al., 1991; Van Lanen, 1991), and that allow for the quantitative analysis of the effects of cropping practices on production and environment (e.g., Jansen et al., 1995; Stoorvogel, 1995) and a quantitative integration of assessments of bio-physical production and their socio-economic feasibility and acceptability (Stomph et al., 1994).

Land use planning efforts have often not lived up to expectation. This could be attributed to what is perhaps the major problem in land use planning: quantitative integration of bio-physical and socio-economic information (Stomph et al., 1994). Although at the bio-physical side the mainly qualitative assessment are gradually being replaced by quantitative methods (Driessen and Konijn, 1992; Beek et al., 1987; Van Diepen et al, 1991) and attempts have been made to formulate procedures for a more balanced approach to both the bio-physical and the socio-economic aspects of land (Stomph and Fresco, 1991; Fresco et al., 1992; Stomph et al., 1994; Sharifi, 1992; Hengsdijk and Kruseman, 1993), the problem of (quantitative) integration remains as yet unsolved.

The integration of the bio-physical aspects and the socio-economic aspects of land use practices requires a format for the quantitative description of both. Unfortunately, there is a large discrepancy between the degree of detail in the quantitative description of the bio-physical aspects, and the broad qualitative terms in which the socio-economic aspects are generally described. While tremendous progress have been made in the quantification of the bio-physical aspects, similar descriptions of the socio-economic aspects are still in their infancy (Stomph and Fresco, 1991; Van Rheenen, 1995; Stomph et al., 1994; Schipper, 1996).

An excellent example for the insufficient attention to socio-economic analysis of land use practices is the economic critique of land evaluation by Schipper (1996). An equally important example for the qualitative nature of socio-economic analysis of land use practices is the argument by Van Rheenen (1995) that farming systems analysis methods are too qualitative when used to assess policy making. A missing link for their integration is, therefore, a quantitative description of the socio-economic component of land use practices. One of the challenges for the integration is, therefore, how to quantify the socio-economic component as a part of an integrated land use system analysis.

2.4.4 Multi-objective nature of land use problems

Land use planning in its simplest form is the allocation of land (land units) to various categories of use (land use types) according to predetermined criteria (Van Diepen et al., 1991). An important step in land use planning is, therefore, the selection of the preferred land use type for a certain land unit. Because land units may be suitable for more than one land use type, choices must often be made. Normally, the selection of the "best" land use types for the land units of a region, district, or village must take into account a number of goals (Huizing and Bronsveld, 1994). Goals may be government development goals or goals of the land users themselves; or may be socio-economic goals or environmental goals (El Shishiny, 1988).

Goals differ from area to area and those of groups or individuals with different interests may conflict. For example, the main objective of farmers on sloping lands may be to produce food for subsistence (even in cases where this leads to severe erosion), while the government priority may be the conservation of land and water to avoid adverse downstream effects and the future loss of agricultural land. Such objectives may be non-commensurable and often conflicting. There is often a need for compromise. These considerations make it clear that each person or organization will have its own preferred "best" land use. Different politicians, planners, village heads and individual farmers may all have good reasons for preferring certain land uses, but these land uses are not necessarily the same. (Huizing and Bronsveld, 1994).

Land use planning , therefore, deals with multipurpose use of land, trade-offs among different functions of the land, and conflicting interests among the different categories of stakeholders and between collective and individual goals and needs (Van Diepen et al., 1991). When only one goal has to be pursued (optimized) the approach is straightforward. However, when a number of possibly conflicting goals have to be pursued, the choice for a certain development path becomes dependent on the relative weight attached to each of the goals, which is not necessarily the same for various interest groups (Fresco et al., 1992). One of the challenging issues for the integration is, therefore, how to integrate (incorporate) this diversity of stakeholders and their goals into the land use planning process (Fresco, 1994).

Chapter 3

An Integrated Agro-Economic and Agro-Ecological Framework to a Methodology for Land Use Planning and Policy Analysis

3.1 Introduction

The growing concern about natural resource management has led to the realization that many problems in that domain e.g., land use problems cannot be addressed adequately through a single discipline (Janssen and Goldsworthy, 1996). This awareness has resulted in renewed attention to integrated, interdisciplinary approaches. It is argued that an integrated, interdisciplinary approach to problems of sustainable land use is specifically hampered by the lack of adequate methodology (RAWOO, 1989). The present lack of a methodology for integration is one of the main reasons why planned interventions fail or are not effective (RAWOO, 1989) and why land use planning efforts have often not lived up to expectations (Stomph et al., 1994).

This chapter aims to contribute to developing a land use planning methodology that integrates agro-economic and agro-ecological information in such a way that sustainable land use options at sub-regional level can be formulated and evaluated with the aim of aiding policy makers. The chapter defines the terminology of land use planning and introduces some basic concepts related to this terminology, including the concepts of planning and a region. Then it outlines the conceptual foundation of the integrated framework, sets out its main characteristics and properties, and then shows how these characteristics are given operational meaning in the discussion of an integrated framework to a methodology for land use planning. Finally, the structure of the basic methodological framework and its main building blocks or sub-frameworks are presented.

3.2 What is land use planning?

The term *"land use planning"* is used in so many different ways that there is often no consensus about what people actually mean when they talk about land use planning. Moreover, many of its uses are so broad that its basic elements are difficult to identify and can not easily be distinguished. It is mainly the confusion over the use of the concept *"planning"* which has led to the various meanings of the term land use planning. The purpose of this section is to identify the boundaries of the term "land use planning" as applied in the current framework and, at the same time, to clarify the way in which certain basic concepts related to land use planning are used.

Following Fresco et al. (1992), the term "land use planning" refers here to a form of regional agricultural planning which is concerned directly with managing the use of the natural resource land[2]. It seems, therefore, that many concepts are necessary for understanding the term "land use planning". Basic concepts are *"planning"* in general, *"land use planning"* in particular, and the concept of a *" region"*. The following sections look at each of these concepts in turn.

3.2.1 The concept of "planning"

The meaning of the term "land use planning" should be based on and comply with the definition of the concept *"planning"*. There are innumerable definitions of planning and the term "planning" is used in many different ways. The terminologies used in planning literature can have various meanings depending on the range of activities included in the planning process. Conceptualization of the relationships among these terminologies is useful as a starting point for discussing the theoretical boundaries of planning. However, it has some serious limitations when one looks in more detail at the nature of these activities. It then becomes apparent that it is seldom possible to draw clear boundaries between them.

Despite the surfeit of existing definitions and terms, it might therefore be wise to outline some of these definitions and to distinguish planning from other related activities, such as *planned development*, *policy making*, and *implementation*. One of the most comprehensive definitions of planning is that of Conyers and Hill (1990). Planning is defined as a continuous process which involves decisions, or choices, about alternative ways of using available resources, with the aim of achieving particular goals at some time in the future.

Conyers and Hills (1990) distinguish between three related activities: "planning", "policy making", and "implementation". In very simple terms, it can be said that policy making involves making decisions about the general directions in which change or development should occur, while planning is the process of deciding what courses of action can best bring about these changes

[2] Land use planning as such also involves, of course, other uses than agricultural ones, such as industrial, commercial, urban, and recreational. In the context of this study, the term land use planning is restricted to agricultural uses. Furthermore, planning the use of land involves at the same time managing the use of other resources or factors of production such as labour and capital. Therefore, regional agricultural planning would be an even more correct term than land use planning. However, in view of the wide acceptance of the term land use planning, it is used here.

or developments and how they should be undertaken, and implementation is the actual execution of these courses of actions.

Van Dusseldorp (1980) makes a distinction between the terms "planned development" and "planning". Planned development is the type of development that one tries to influence via planning. Planned development is a continuous process that consists of the following phases: (a) formulation of goals; (b) stocking, research, and surveys; (c) drawing up the plan; (d) acceptance of the plan; (e) implementation of the plan; and (f) evaluation. These activities follow this sequence but may occur with a considerable overlap in time.

In the literature on agricultural planning, see for example Fresco et al. (1992); and Schipper (1996), the process of "planned development" is considered to consist of three main stages: (1) plan preparation (corresponds to phases a to d); (2) plan implementation (corresponds to phase e); and (3) plan evaluation (corresponds to phase f). Within the process of planned development those components (including phases a, c and f) with specific planning character together make up the planning process in the narrow sense. The planning process thus, as seen by Van Dusseldorp, stops short of the acceptance and implementation of the plan.

In describing the procedure of (economic) policy making, Tinbergen (1956) differentiates between policy planning and policy design, and divides the policy making process into five stages: (a) describing the actual state of affairs; (b) comparing it to the most desirable situation to identify deviations; (c) estimating the effects of possible alternative policies; (d) deciding about policies; and (e) execution. Stages a to c are called policy planning, while stages a to e are called policy design.

3.2.2 Perspectives on the definition of "land use planning"

The concept of planning which has been described so far, covers a wide range of planning types. If the scope of the activities which planning is designed to influence is the use of the natural resource land, it is called land use planning[3]. Dent (1988; 1993) defines land use planning as a means of helping decision-makers to decide how to use land: by systematically evaluating land and alternative patterns of land use, choosing that use which meets specified goals, and the drawing up of policies and programmes for the use of land.

One of the most frequently quoted definitions is that of Fresco et al. (1992), who define land use planning as a form of (regional) agricultural planning,

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[3] Land use planning is one of several terms used to describe a variety of planning activities which are concerned with managing the use of land. Other terms used in the literature to describe this type of planning are for example physical planning, urban and regional planning, town and country planning, etc. depending on the type of land use.

directed to the best use of land in view of accepted objectives, and of environmental and societal opportunities and constraints. They go on to explain that: land use planning should result in the identification of projects and or programmes, with which the proposed changes in land use should be accomplished. Detailed formulation and execution of these projects and programmes, however, are not part of land use planning. Furthermore, they add that: it is important in land use planning to suggest changes in policies that do effect the use of land, if it is considered that such policy changes will be useful in bringing about a desired change in land use. However, the actual formulation of, and decisions with regard to policies require a higher level of planning.

According to the FAO Guidelines for Land Use Planning (FAO, 1993), land use planning is the systematic assessment of land (and water) potential, alternatives for land use and economic and social conditions in order to select and adopt the best land use options. It outlines the land use planning process into the following steps: (1) establish goals and terms of reference; (2) organize the work; (3) analyze the problems; (4) identify opportunities for change; (5) evaluate land suitability; (6) appraise the alternatives; (7) choose the best option; (8) prepare the land use plan; (9) implement the plan; and (10) monitor and revise the plan.

Although the various perspectives on defining land use planning presented above differ in their degree of complexity and detail, certain common elements and features can be identified. All these terminologies agree to view and interpret the activity of land use planning as a continuous, cyclic process of decision making. The rational approach to decision making is central in all these terminologies, and indeed, is of fundamental importance in the context of the land use planning process. This view of rationality is closely associated with economics and its concern with efficiency in the allocation of resources.

In FAO (1993), the land use planning process has been defined in a broad sense that contains the complete range of activities that can be included in a planning process: plan preparation, implementation and evaluation. It is in this sense that the steps in land use planning as distinguished in the "FAO Guidelines for Land Use Planning" are considered refinements of the stages of planned development of Van Dusseldorp (Fresco et al., 1992). Hence, it is implicitly equated with the "planned development" terminology of Van Dusseldorp (1980). This point has been emphasized by Schipper (1996), who advocates replacement of the term "land use planning" with the term "land use analysis", which is then restricted to analyzing possible land uses. It does not include plan implementation, and it excludes taking decisions with regard to land use, and the elaboration of the final plan.

In Fresco et al. (1992) the land use planning process stops short of implementation and evaluation of the plan. In the terminology of Dent (1988;

1993), the concept of land use planning concurs more or less with Tinbergen's stages *a* to *d* of policy making. The issue of policy making is treated more explicitly in Dent (1988; 1993) than in Fresco et al. (1992). For Dent, land use planning serves as support for policy making, while in Fresco et al. (1992) emphasis is more directed towards plan preparation which is expected to result in identification of projects and/or programmes as instruments to implement the plans, and in suggestions for policy changes.

It is true that in most situations land users themselves decide on the use of their land, not the land use planners nor policy makers. Hence the term "land use planning", here, should be considered as a concept based on the notion that the process of development can be influenced, or in other words, it is possible to indicate possible paths from the present situation towards some desired situation in the future. Therefore, land use planning implies the possibility of influencing decisions regarding land use. Land use planning does not however, imply the possibility of determining actual land use. The influence exerted by planners or policy makers is indirect. Therefore, the term "land use planning and policy analysis" is used for the type of analysis carried out in the framework of the methodology developed in this study.

The term "land use planning", as used in this study, draws on the common features of many of the terminologies described above, and it also rests on principles and reasoning of the decision making process. Similarly to the terms: "policy planning" of Tinbergen (1956), "planning process" in a narrow sense of Van Dusseldorp (1980), "land use planning" of Dent (1988; 1993), and "land use analysis" of Schipper (1996), the boundary of "land use planning" excludes acceptance and implementation of the plan.

Moreover, unlike land use analysis as defined by Schipper (1996), land use planning does involve a procedure to help policy makers in the process of deciding which course(s) of action to select, from those on offer. Land use planning provides capability to help policy makers to decide on the acceptability of trade-offs which are involved in choosing between sets of policy options and the extent to which a particular option will achieve desired goals and objectives that have been determined through the political process. This stage of choice in land use planning is essentially technical in nature, but planning moves back explicitly into the political arena when politicians have to make their choice. Hence the actual formulation of, and decisions with regard to policies, which refer to a higher level of planning, are not part of the "land use planning" process as used in this study.

3.2.3 The concept of a "region"

Since land use planning is considered here as a form of regional planning, it is useful to explicitize the concept of a *region*. There is no agreed definition of the term "region" when it is used unqualified by an adjective: but it seems generally to be used by, for example, Grigg (1970) to mean a part of the earth's surface which is distinguished in some way from surrounding areas. This distinctiveness may be based on a single criterion or may be based on a number of criteria. There are a great many synonyms for the word region. Thus terms such as province, division, zone, belt, locality, and district have all been used by geographers in much the same sense as "region", save that these words have often been used to imply a particular rank in a hierarchy of regions.

In the literature on planning many types of regions have been distinguished. Grigg (1970) differentiated between three distinct approaches to the regional concept: the pay concept, the natural region, and the single feature regions. According to Van Dusseldorp (1980) the principles of delineating regions can be brought together under four categories: the principle of homogeneity, the principle of functionality, hydrological coherence, and ad hoc regions. Similarly, but slightly different Schipper (1996) distinguished four types of regions: functional regions, administrative regions, homogenous regions, and planning regions. No attempt will be made here to re-open this issue. For elaboration and detailed description on these types of regions see the previously referred authors respectively.

Each type of these regions has its own advantages and disadvantages when used for regional planning. As a compromise, an administrative unit is often chosen as a region for planning and this region is then subdivided in homogenous zones (Schipper, 1996). The main reasons for preferring administrative regions are that: they confirm to the criteria of complete-split-up and no-overlap; many of the data important for planning are available on the basis of these geographical units; and various government departments are often organized by administrative divisions which are of great importance for the coordination and implementation of a plan.

When used in this thesis, the term "region" means a part of a country (including its population) and under the authority of its government, and that is, as described in Van Dusseldorp (1980), "a convenient device to keep planning problems and functions within manageable proportions". Regional level refers, here, to administrative units that fall between national and local levels. A sub-region is considered to be a geographical part of a region, which in turn is part of a country. The main difference between a region and a sub-region is, as illustrated by Schipper (1996), the relative economic size in comparison to the size of a country. A sub-region is sufficiently small compared to the country, that neither the quantity of output produced nor the inputs demanded influences their prices. In contrast, a region is considered an important part of the economy of a country.

3.2.4 The relevance of an integrated regional approach in land use planning

Following Fresco et al. (1992), land use planning is considered here as a form of (regional) agricultural planning. Regional agricultural planning, and, consequently, land use planning, are specific forms of intermediate level planning of regions (or sectors) within the national context. Intermediate level planning may be defined as planning of regions (or sectors) with a view to bridging the gap between general macro-planning (or policy) and specific project planning. Accordingly, regional agricultural land use planning can be considered as an intermediate planning level which on one hand is sufficiently specific for guiding action and on the other global enough to be placed in a national context.

The regional approach in agricultural land use planning seems to be the most appropriate in the perspectives of (Hengsdijk and Kruseman, 1993): (1) agriculture as the biggest user of land; (2) agriculture as the largest regional employer in most developing countries; (3) the need for food security and; (4) the need for management of natural resources in a region. There is also a more practical reason for a regional approach from an integrated, interdisciplinary point of view. At this level, sustainable land use can be studied by contributing disciplines in land use studies: from an agro-ecological perspective as well as from an socio-economic point of view. At lower aggregation levels agro-ecological aspects will dominate, whereas at higher levels socio-economic aspects dominate.

Elizabeth (1994) gives three arguments justifying the need for integrated regional modeling. Perhaps the most general and compelling argument is that interactions among human, ecological, and physical processes are critical to the structure, dynamics and vitality of regions. A second reason is that the couplings of natural (ecological) and human (socio-economic) sciences are understudied because of a lack of integrated, interdisciplinary approaches to problem solving. The process is dominated currently by concerns over single issues, which in many cases are merely components of complex, linked problems. An other major reason for the integration of human and ecological processes is a shift in emphasis from "advancement of science" to more of an applied focus. Better management of resources, providing a means to play out management alternatives and incorporation of policy issues has been raised as justification for integrated regional models development.

3.3 The conceptual/analytical approach

The integrated framework to a methodology for land use planning, presented here, derives its conceptual foundation largely from an adaptation of the theory of economic policy of agricultural sector analysis to land use planning. The agricultural sector analysis offers great potential as a tool for planning and policy analysis (Thorbecke and Hall, 1990; Hazell and Norton, 1986) and it has proven its applicability in land use analysis (Hengsdijk and Kruseman, 1993; Schipper et al., 1995; and Schipper, 1996). Moreover, the theory of economic policy of sector analysis provides the common denominator and language to contributions from various disciplines involved in agriculture (Thorbecke and Hall, 1990) for the following reasons:

- economics is the discipline which optimizes the allocation of scarce resources among competing uses;
- it can provide a means of measurement of different objectives. By expressing various objectives in value terms it is possible to compare the benefits achieved to their costs;
- economics provides methods and techniques that permit a quantitative integration of socio-economic and bio-physical analysis at the sectoral level and provides a framework within which quantitative alternative options can be formulated and evaluated;
- more specifically, economic theory can build a bridge between farm level information and aggregate level information, and allows integration and linking of these levels through an appropriate aggregation procedure.

Since the theory of economic policy to sector analysis will provide the foundation for land use planning in this study, it is, essential to describe briefly its underlying principles and characteristics. The methodology underlying the theory of quantitative economic policy (Tinbergen, 1956; Thorbecke and Hall, 1990) consists of three major elements. First, the preference function is supposed to reflect the major policy objectives that the policy-maker is striving for as well as the relative importance of these objectives. Policy views usually are expressed in terms of multiple objectives which makes their optimization more difficult since there may be trade-offs or conflicts between various objectives.

The second major element underlying the theory of quantitative economic policy is the classification of variables useful for policy purposes into exogenous variables and endogenous variables. Two types of exogenous variables determined outside the model: policy instruments under the control of the policy makers, and variables that can not be controlled by the policy makers. Two classes of endogenous variables are quantified within the model: variables reflecting the policy goals, and variables reflecting side effects of policies. The third element of the theory of quantitative economic policy consists in building and specification of a model which is supposed to reflect or approximate the underlying structure of the policy problem under consideration. Typically the model would comprise different types of relations such as behavioural, technical, and definitional relations.

Thorbecke and Hall (1990) identify certain characteristics or properties that agricultural sector analysis and planning must have to be useful to the policy maker. First it must be relatively quantitative and based on empirical evidence. A second major requirement is to incorporate policy means, i.e., variables under the control of the policy maker, in at least some of the relations which appear in the model or framework. Another characteristic of sector analysis is that it ought to be interdisciplinary and combine contributions from the bio-physical sciences and from the socio-economic sciences. Finally, agricultural sector analysis and planning should rely on and utilize the scientific method.

These characteristics of a useful sector analytical capacity are given operational meaning below in the discussion of an integrated framework to a methodology for land use planning. The major features of the proposed conceptual/analytical approach are as follows: it follows a systems analytical framework for the definition and description of land use systems; it utilizes a linear programming technique for the quantitative integration of bio-physical and socio-economic components of land use systems in such a way that alternative sustainable land use policy options can be generated; it uses a multi-level approach for modeling the interaction between various aggregation levels; and it uses a multi-criteria technique to support appraising alternative sustainable land use policy options in a multiple objective environment. The need for these frameworks, techniques and approaches in land planning is presented and discussed below:

3.3.1 A systems approach for land use planning

The need and relevance of a "systems approach" to land use planning

Agriculture is a complex activity, even if it can be considered in simple terms as "the human activity that transforms solar energy at the earth's surface into useful chemical energy by means of plants and animals" (De Wit and Van Heemst, 1976) or as "an activity, carried out primarily to produce food and fiber by the deliberate and controlled use of plants and animals" (Spedding,1979). The study of agricultural systems requires the contribution of many disciplines and sciences. As Spedding (1975) pointed out, agricultural systems lie at the intersection of economics, social sciences and biology. Van Dyne and Abramsky (1975) took a rather broad view of agricultural systems which include biological, physical, economic, social and political components. Leffelaar (1992) distinguished between applied sciences like agronomy, soil science and crop micro-meteorology and basic sciences like biology, chemistry, physics and mathematics. Whatever the exact definition, all references clearly indicate that, at least to some extent, the study of agricultural systems needs an integrated, interdisciplinary approach and moreover unifying concepts.

Experience suggests that the "systems approach" could provide such a unifying concept (Spedding, 1975) and could serve as integrator of contributions from various disciplines to agriculture (Dent, 1975). The recognition of the need to consider whole systems of agriculture is, after all, not new. A few decades ago it was recognized that a new approach contrasting to the previously predominant, reductionist, fragmented approach, was needed to answer the wide range of questions in agricultural sciences (Spedding, 1975; Dent, 1975; Charlton and Street, 1975; Van Dyne and Abramsky, 1975; Arnold and De Wit, 1976; Beek, 1978).

In agricultural planning, many resource allocation problems can be usefully analyzed from a systems point of view. This is because the complex interactions and processes involved in agricultural systems have to be viewed in a holistic manner if they are to be properly understood and controlled. This also holds for land use planning decisions where determination of the optimal land use involves knowledge not only of the biological and physical responses but also of socio-economic considerations. Potentially, the systems approach, in which the bio-physical and socio-economic aspects of a problem are examined in an integrated way, is very relevant to production and resource decisions in agriculture (Doyle, 1990).

Following the experience of Spedding (1975) and Dent (1975), and the analysis of Bawden et al. (1984) and Stuth et al. (1991), an important step in achieving interdisciplinarity in agricultural analysis is the use of the *"systems analytical approach"*. The need for such an approach originates from the complexity of land use problems which involve various aggregation levels; interaction among different disciplines; and trade-offs among multiple goals. A "systems approach" provides the necessary framework for analyzing such complex problems (Spedding, 1975; Odum, 1983; Fresco, 1986; Conway, 1990; Fresco et al., 1992; Hengsdijk and Kruseman, 1993; Stomph et al., 1994).

Since the systems analytical approach is suggested in this study, some of its underlying concepts and principles are briefly explained. The nub of the "systems approach" is, a statement credited to Aristotle, that 'the whole is more than the sum of its parts' (Van Dyne and Abramsky, 1975). In a sense, general systems theory provides the scientific explanation of wholes and wholeness. This implies that an isolated study of the components that make up the system is inadequate to understand the complete system. This is because the separate parts are linked in an interacting manner and it is the interaction among the various components that gives the system its integrity (Spedding, 1979).

Systems analysis is the formulation and manipulation of a set of mathematical relationships that represent the ways in which the components of the selected system are likely to interact (Phillipson, 1975). The aim of systems analysis is to construct a common theoretical framework within which scientists from different disciplines can find a common language. The term 'system' has many meanings. Some reduce the definition to its parts and their interrelations: "system is a limited part of reality with interrelated elements" (De Wit and Goudriaan, 1974), others expand it to include processes: "system is a group of parts that are interacting according to some kind of process (Odum, 1983), or broadly defined "system involves an arrangement of components (sub-systems), which transform inputs into outputs (Fresco, 1986). Thus, it is the properties of systems that matters. Knowing only the parts, therefore, does not adequately predict the behaviour of the system as a whole. More important is that in all systems five elements can be distinguished: *components, interactions between components, boundaries, inputs and outputs* (Fresco et al, 1992). The structure of the system is defined by the quantitative and qualitative characteristics of the components and the interactions between them. The way in which inputs are processed into output determines the function of the system.

Land use system as an "integral system"

Agricultural systems lie at the intersection of many disciplines e.g. biology, physics, economics, social sciences. Spedding's (1975) approach to this complexity is to define systems strictly in terms of their purpose and then to define boundaries, components and processes accordingly (Spedding, 1979). This has turned out to be a highly practical and powerful approach. However, a case can equally be made, particularly in the light of increased knowledge of environmental systems, for defining agricultural systems not only in terms of human (socio-economic) purpose but also by their ecological components. In part this rests on a recognition that natural ecosystems are the basis of all agricultural systems, even if the link in some systems is very tenuous.

The resulting agricultural system is thus as much a socio-economic system as it is an ecological system: "agroecosystem" (Conway, 1987), and has both bio-physical and socio-economic components (Stomph et al., 1994). In the present study, land use system is conceptualized and regarded as an "integral socio-economic-bio-physical system". Conceptualization of the land use system in this way helps to foster an integrated, interdisciplinary approach to land use planning:

- First, the conceptualization of land use systems as an integral system makes it possible to characterize it in terms of a set of properties. Many authors suggest different properties, see for example Conway (1987). What is important here is that these system properties can be defined in both bio-physical and socio-economic terms. Clearly, goals of land use planning may be grouped under these properties (see for example FAO, 1993).

- Second, the definition of land use systems in terms of both their bio-physical and socio-economic components helps to foster a genuine integrated, interdisciplinary approach to agricultural system analysis (Conway, 1990; Hengsdijk and Kruseman, 1993; Stomph et al., 1994).
- The third consequence of defining land use system in this way is that it naturally leads to the further concept of a hierarchy of systems. The importance of such a hierarchic view for any attempt to integrate agro-economic and agro-ecological aspects in land use planning is emphasized by many authors (see for example Conway, 1990; Fresco et al., 1992; Hengsdijk and Kruseman, 1993; Stomph et al., 1994). Different levels require different kinds of investigation, involving different disciplines and using different methods and tools for assessment.
- Perhaps the most important of the consequences, however, is the recognition of trade-offs in agricultural planning among system properties (Conway, 1987). Clearly, in land use planning there are conflicts and trade-offs among goals. The trade-offs occur within systems and also between systems in the hierarchy (Kruseman et al., 1993). Moreover they are particularly associated with the intersection of biophysical and socio-economic processes. The use of pesticides for crop protection, for instance, represents a case of higher productivity at the expense of sustainability.

Land use system as "a hierarchy of systems"

The land use system is not a closed system but a sub-system of a larger system at a higher level of aggregation. Conceptually, any attempt to integrate bio-physical and socio-economic realms in land use planning should start with the recognition that both realms exist at various hierarchical levels and with some differences of emphasis. The first step is, therefore, to define (a)hierarchical level(s) that is/are acceptable for both realms. The best way to do this, is to describe a land use system as a hierarchy of systems. A systems hierarchy is a hierarchical arrangement in which one level of a system can be nested within another (Van Dyne and Abramsky, 1975). The hierarchical systems proposed in agriculture are derived from the application of the hierarchical structure of ecology to agriculture.

In analogy to ecology, agriculture is described as a hierarchy of systems. In the biological and ecological realm, the central concept of systems theory is the ecosystem. The ecosystem is a biological community, comprising various populations, that interact with the physical environment (De Ridder and Van Ittersum, 1995). Each population consists of organisms that in turn consist of organs. Thus, ecosystems are based on a hierarchical relationship: each sub-system is at the same time a system in itself with its own sub-systems as well as a component of a larger system, also called the supra-system.

The total range of systems hierarchies proposed in agriculture starts from sub-cellular particles and cells at the lowest level to continents and the globe at the highest level. In the hierarchical order used by Van Dyne and Abramsky (1975), one can distinguish sub-cellular particle, tissue, organism, population, community, ecosystem, economic firm, region, nation, continent, and globe. In this hierarchical order, biological components enter at the lowest level and carry on throughout all levels. Physical components enter at the ecosystem level, which has biotic and abiotic components. Economic components enter when one couples ecosystems for human purposes. Even at the economic firm level, but certainly at the regional level, social and political components enter.

Fresco (1986) distinguishes between systems at various hierarchical levels, ranging from the plant system through the crop system, the cropping system, the farm system (which includes the farm household), to the higher level land use system (village or watershed and regional or national). In agroecosystem terms the hierarchy is one which begins with an agroecosystem that consists of an individual plant or animal, its immediate microenvironment and the people who tend and harvest it. The next level is the field or paddock. The hierarchy then continues upwards in this way, each agroecosystem forming a component of the agroecosystem at the next level.

The higher up the hierarchy, the greater is the apparent dominance of socio-economic processes, but ecological processes remain important and, at least in sustainability terms, crucial to achieving human goals (Conway, 1987). When the hierarchical structure of ecology is applied to agriculture, it appears immediately that the higher levels in the agricultural hierarchy are less easily defined than the lower levels. At lower levels, the analogy with ecology poses no problem. Depending on whether socio-economic or bio-physical aspects are studied, a system at the higher level of the agricultural hierarchy includes levels (e.g., farms) combined into socio-economic units such as villages, or into bio-physical units such as watersheds (Fresco et al., 1992).

Stomph et al. (1994) pointed to one major disadvantage of the hierarchical approach in systems analysis in agriculture suggested previously (e.g., Van Dyne and Abramsky, 1975; Fresco, 1986; Conway, 1987): at the lower levels mainly biophysical criteria are used (e.g., cell-plant-crop) and at higher levels mainly socio-economic or administrative criteria (e.g., village-region-country). The point in this hierarchy at which the criteria change from mainly bio-physical to mainly socio-economic or administrative is the only level at which relations between the bio-physical and socio-economic aspects of land use systems are explicitly treated (generally the farm system). In reality, however, socio-economic and bio-physical factors interact at various systems levels (Fresco et al., 1992).

Stomph et al. (1994) use slightly different characterization in their hierarchy of systems. Their basic premise is the possibility of comparing and integrating the hierarchy of systems of the socio-economic realm and the bio-physical realm. They compare the hierarchy of bio-physical systems: crop, cropping system, physiographic units at different scales, with the hierarchy of socio-economic systems: household members, farm-household, administrative and economic units at different scales. Hence they suggest an hierarchy of systems characterized by bio-physical and socio-economic elements. This hierarchical approach consists of two parallel hierarchies of bio-physical systems and socio-economic systems relevant to agriculture. Systems are combinations of both hierarchies and can be defined at different levels. In other words, the analysis is based on a scale-independent concept. This approach implies that socio-economic systems do not precede bio-physical systems in the hierarchy.

No matter how the hierarchy of systems is defined, there will always be discussion on which level in the hierarchy is acceptable to both bio-physical and socio-economic realms. Within the hierarchy of systems, the farming system level has been mentioned as the meeting point between the socio-economic realms and the bio-physical realms (Hengsdijk and Kruseman, 1993; Alfaro et al., 1994; Stomph et al., 1994; Stoorvogel et al., 1995). In this study, the interface between the socio-economic sub-system and the bio-physical sub-system of land use concentrates around the farming system activities, and their inputs and outputs. The farm is considered the pivot point in the agricultural sector, the level where the production takes place, where bio-physical and socio-economic aspects determine agricultural production (Schipper et al., 1995; Schipper, 1996).

3.3.2 A linear programming modeling approach to land use planning

Models- a way of thinking about systems

Since the early stage the development of systems theory has been connected with the use of models. In this study the analysis and planning of land use systems is, therefore, assisted by the development of a model. The reasons for this are threefold (Wright, 1971). First, it is often impractical or impossible to study the real systems. Second, experimentation may not be feasible due to factors of cost and time. Third, the very act of measurement may disturb the real system to such an extent that the observations relate to something that is artificial. These problems can be overcome by the use of models or simplified representations of the real world. Because the models only represent the key features of reality they are considerably easier to manipulate.

The development of a model based on systems theory is an excellent tool of integrating and combining disciplines (Spedding, 1975; Dent, 1975; Janssen and Goldsworthy, 1996). The model insures that, in a later stage, research activities do not branch off into disciplinary challenges that are irrelevant to the problem situation. The identified problems may be investigated by single disciplines, but the model quarantees that the research is relevant to the problem and can be evaluated with regard to the overall problem.

Consequently, as early as the 1950s with the advent of powerful mainframe computers which allowed more complex interactions to be studied, the rudiments of a systems approach to agricultural problems of resource allocation involving models became evident (Doyle, 1990). It is interesting to note that the model type most frequently used is of a mathematical programming format. This to be expected since this type of model is well suited to resource allocation issues. Linear programming is the simplest and probably the most frequently applied model to explore alternatives within a stated resource allocation problem (Dent, 1990).

Linear programming as a tool for land use planning

Land use planning is directed at the 'best' use of land, in view of accepted objectives, and of environmental and societal opportunities and constraints. Looking for this 'best' or the 'optimal' land use, is akin to the principle of linear programming, or other optimization techniques, in which an objective function is maximized by selecting from alternative activities (opportunities), subject to constraints. Linear programming can thus be of help in the search for the 'best' land use (Schipper et al., 1995). Linear programming is not a new technique; many books on the subject have been published in the 1960s and 1970s. The availability of the linear programming software from MS-DOS-based PCs, together with the need for new tools for land use planning, received interest in the application of linear programming techniques in the 1980s (De Wit et al., 1988).

Recently, linear programming technique is often used in land use planning studies. Examples of applications at various planning levels include the following: land use planning at farm level (Schans, 1991); land use planning at project level (Ayyad and Van Keulen, 1987); land use planning at village level (Huizing and Bronsveld, 1994); land use planning at sub-regional level (Schipper et al., 1995); land use planning at regional level (De Wit et al., 1988; Veeneklaas et al., 1991); and land use planning at the European Community level (WRR, 1992).

3.4 Basic methodological framework

3.4.1 Structure of sub-methodologies

A methodology that integrates agro-economic and agro-ecological analysis in such a way that land use policy options at sub-regional level can be examined, will necessary be very complex, even if all possible simplifications are introduced. Hence, a certain degree of complexity is unavoidable. An all encompassing framework, although more difficult to achieve is preferable to a partial one because solutions to partial problems may not coincide with the solution to the whole problem (Hengsdijk and Kruseman, 1993). The procedure of building the methodological framework is structured in a set of interrelated blocks: components, or sub-frameworks. Since the systems analytic approach is suggested in this study, each sub-framework is built accordingly. The basic structure of each sub-framework contains three distinct parts as presented in Figure 3.1.

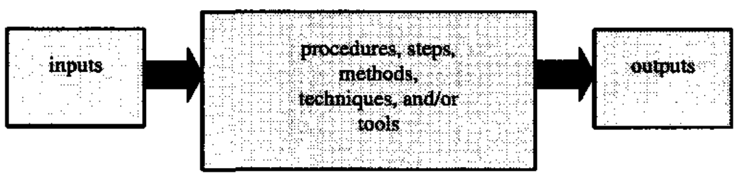


Figure 3.1 A structure of sub-frameworks.

Inputs are the data requirements for the task or the analysis of a specific sub-framework. Outputs describe the results of the analysis performed in that specific sub-framework. All the elements necessary for transforming the input data into results are included in the processes. Processes of each sub-framework can be tools, methods, techniques, procedures, and/or steps necessary for its operationalisation or implementation. A sub-framework can contain disciplinary or interdisciplinary inputs or outputs. It can also belong to a specific level of aggregation or uses a specific unit of analysis. Outputs of one sub-framework can be inputs for an other.

3.4.2 Structure of the main methodology

The development of the methodology does not start from scratch, but has benefited from a number of frameworks developed for land use planning and policy analysis such as the LEFSA sequence (Fresco et al., 1992); the DLV framework (Hengsdijk and Kruseman, 1993); the framework proposed by Stomph and Fresco (1991); the work of Stomph et al. (1994); the USTED methodology of the Atlantic Zone of Costa Rica (Stoorvogel et al., 1995; Schipper et al., 1995) and the work of Schipper (1996). The procedure of building the methodological framework is structured in a set of interrelated blocks (sub-frameworks). Each sub-framework of the methodology actually contains a number of steps, and requires a number of tools and/or methods for its operationalisation. The structure of the basic framework and its main building blocks or sub-frameworks is described in Figure 3.2.

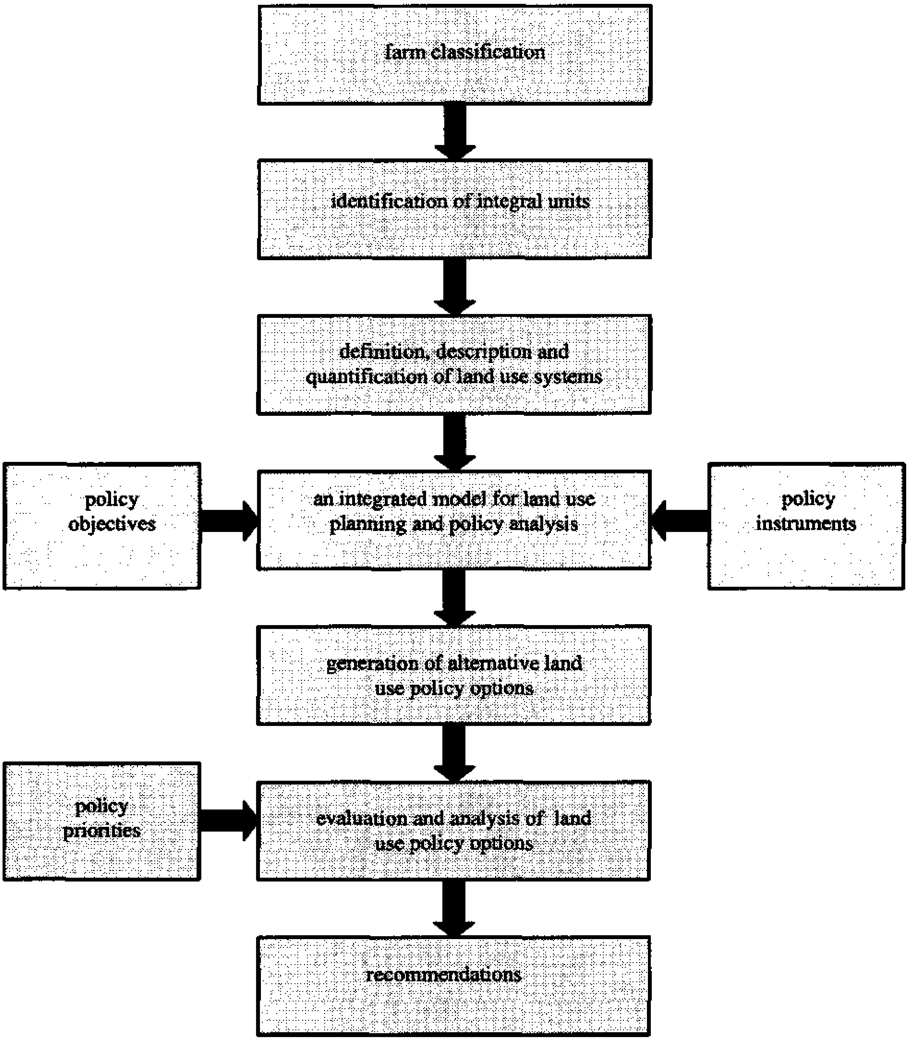


Figure 3.2 An integrated agro-economic and agro-ecological framework to a methodology for land use planning and policy analysis

Farm classification

The framework starts out from the farm, the decision making unit with respect to land use, and from there develops a farm classification methodology to identify farm types (FTs). The main aim for farm classification, in this study, is to eliminate aggregation bias while integrating farm level information with the regional level of analysis. The procedure starts by first exploring the requirements for bias-free aggregation (conceptual analysis), and then, subsequently, investigating the criteria used for farm classification in some empirical studies (empirical analysis). Both conceptual and empirical analysis are then combined to recommend operational variables for classification.

Aggregation bias can only be avoided if farms are classified in groups which are defined according to the theoretical requirements of Day (1963). Therefore, these requirements (institutional proportionality, technological homogeneity, and pecunious proportionality) are used as guidelines for the selection of farm classification criteria Moreover, to facilitate integrating the resultant farm types with land units, the mapping of farm types is of prime importance. This is made possible by incorporation of location attributes in the classification criteria. Therefore, an equally important requirement, called "location proximity", is added to the proposed variables to facilitate the integration procedure. Within these requirements, variables that are expected to result in farm types with similar land use decisions are used for the classification. On the basis of these requirements, farms are classified, by means of cluster analysis.

Identification of an integral unit (IU)

It is perceived that an initial step for integrating socio-economic and bio-physical disciplines in land use planning and policy analysis is to create an integral interdisciplinary unit of analysis. This sub-framework consists of defining conceptually an integral unit at a level of analysis that is acceptable to both bio-physical and socio-economic disciplines, and then developing methods and procedures for operationalising it. To define the level that is acceptable to both disciplines, the land use system is described as a hierarchy of systems. Within the hierarchy of systems, the farming system level is selected as a meeting point between socio-economic and bio-physical disciplines.

The concept developed here is based on the fact that at the farm level, one particular land unit may be shared by two or more farm types. Hence, the use of land units in land use planning may result in bio-physically but not necessarily socio-economically homogenous units. Whereas the use of farm types may result in socio-economically but not necessarily bio-physically homogenous units. Therefore a more integral unit is desirable. The concept of "farm type land unit" (FTLU) or simply an integral unit (IU) is developed to link a farm type and a land unit into one integral unit.

The concept of FTLU implicitly assumes that both FTs and LUs can be mapped. While LUs can easily be geo-referenced and presented on a map, information on FTs is generally difficult to map. Without geo-referencing of FTs it is quite difficult or may be impossible to link socio-economic and bio-physical disciplines. Therefore, the concept of FTLU has been operationalised by developing a procedure for mapping farm types by establishing a link between a geographical information system (GIS) and classification models. The GIS supplies input data for the classification model and accepted modeling results for further processing, analysis and presentation. Having mapped farm types, and having delineated land units, then spatial linking of farm types and land units has been established in the GIS environment through map overlay procedure. The resultant units are called farm type land units (FTLUs).

Definition, description and quantification of land use systems

The approach presented here considers land use systems as integral systems that include both bio-physical and socio-economic components. The concept ILUS is proposed for a specific form of describing a land use system that defined as a combination of a farm type land unit (FTLU), a land use type (LUT), and a production technique. ILUSs are described in terms of operations sequence. Combining information contained in operation sequences with information on ILUSs allows the description of land use systems in an integrated way. Such a description then serves as a basis for the calculation of the required input-output coefficients. Each unique operation sequence within an ILUS can be interpreted as a specific (land use) activity. Each activity is defined and described quantitatively in terms of input and output coefficients which quantify the relation between inputs of production and the outputs, desired as well as undesired. The unit for the calculation of the input and output coefficients of an ILUS activity is one hectare [ha]. All inputs and outputs are expressed as physical quantities or monetary values or time or power per hectare.

Both, current and alternative land use systems are taken into account in the analysis. The basis for determination of the input and output coefficients of the current land use systems is the information derived from the sampled farms. A combination of GIS and statistical techniques has been used for the quantification of these coefficients. Alternative land use systems are defined in such a way that they are technically feasible and aiming at maintaining the resource base and protecting the environment. For quantification of alternative land use activities, a so-called target-oriented approach is applied, in which the combination of inputs required to realize a specific level of outputs is estimated, based on insight in the underlying bio-physical processes.

An integrated model for land use planning and policy analysis (ILUPPA)
An integrated land use planning and policy analysis (ILUPPA) model is built and used as a tool for integrating socio-economic and bio-physical components of land use systems in such a way that land use policy options at the sub-regional level can be generated. The purpose of the ILUPPA is to analyze the possible effects of policy measures on farm household land use decisions and their consequences for realization of regional agricultural development policy objectives. For a better understanding of the effectiveness of different policy measures on agricultural development, a micro-oriented, integrated approach is applied. The effects of policy instruments on farm household and regional objectives is established through examination of the adjustments in land use.

ILUPPA is a mathematical programming model in terms of solution technique, however, it is best described as a behavioural simulation model. It attempts to describe how farmers will react to certain classes of policy instruments that may influence their land allocation decisions and consequently the realization of regional agricultural development policy objectives. Important aspects of the ILUPPA model are the differentiation of and linkages between different levels of aggregation. The model is based on ILUSs as core units at the activity level. The first level of aggregation is ILUS at the FTLU, that is defined at an aggregation level lower than both FT and LU. Therefore, FTLUs can be aggregated to a LU level, based on respective FTs, or to a FT level, based on respective LUs. And finally, FTs or LUs can be aggregated to the sector at sub-regional level.

Generation and evaluation of land use policy secenarios
Because the purpose of the ILUPPA is to generate land use policy options, various land use policy scenarios corresponding to various policy instruments are defined. On the basis of these scenarios, the ILUPPA generates a number of feasible land use policy alternatives with their associated ILUSs and corresponding input and output coefficients. A multi-criteria evaluation technique (MCET) is applied to rank the set of generated land use policy options, and hence to assist policy makers in selecting the "best" or the most preferred land use alternative or to facilitate a movement towards a consensus. To take into account the multiple and conflicting views, different preferences or priorities are included in the evaluation.

Chapter 4

Farm Classification: Concepts, Methodology and Application

4.1 Introduction

Integration of disciplines requires linking levels of analysis. In agricultural planning and policy making, scaling up analysis from farm-level to sector-level may be the source of aggregation bias. This aggregation bias originates from the fact that not all farms are similar. Following Green (1964), aggregation bias may be regarded as belonging to statistical decision theory: part of the information detail is sacrificed for the purpose of making the problem more manageable. Farm classification methodologies are argued to be central in such situations, since they involve exact identification of farm groups and result in a reasonably reduced aggregation bias (Jenkins, 1989; Nafessa, 1996).

This chapter focuses on developing and operationalising a methodology for farm classification. To justify the need for an alternative methodology, the chapter begins with a description of the limitations of existing farm classification procedures. Section two distinguishes different concepts of classification that are often mixed in the literature. An alternative farm classification methodology is developed and outlined in section three. Operationalisation of the methodology for the case of Amol Township is carried out and described in section four.

4.2 Limitations of existing farm classification procedure

The problem of aggregation, i.e. the relationship between micro level and aggregate level, as such, is an old problem (see for example Thiel, 1954; Day, 1963), but the attention it received in agricultural planning, until recently, is very modest. This can be ascribed to the fact that only a mixture of theoretical and empirical aspects has a chance of being successful in this field (Nafessa, 1996). If analysis of the aggregation problem is solely based on theoretical principles, the results will not be very useful in practice. When, on the other hand, the analysis is based on purely empirical foundations, applicability of the results will be seriously hampered by the neglect of the underlying theoretical considerations.

Despite the importance of the aggregation problem in agricultural planning and policy analysis, objective rigor has not been used in the development of farm classification methodologies and the procedures used are often arbitrary. Farm classification is a matter of considerable difficulty and complexity as witnessed in the literature on the subject. In fact, nearly all examples of farm classifications (see for example Miller and Heady, 1973; Ogwel and Clayton, 1973; Monypenny and Walker, 1976; Fox and Driver, 1980; Jenkins, 1989; Hardiman et al., 1990; Marz, 1990; Alfaro et al., 1994; Kruseman et al., 1994; Wossink, 1994; Schipper et al., 1995) for agricultural planning and policy analysis suffer from at least one of the following drawbacks: classifications are treated as ends in themselves, rather than as means to an end; lack of sound, explicit and objective criteria for classification; lack of a consistent framework or procedure for determining the appropriate number of farm types; difficulty in mapping and identifying the geographical boundaries of farm types; and use of untested and non-validated farm types making their appropriateness for a particular application uncertain.

These drawbacks may constitute severe limitations to the use of these procedures as a basis for agricultural planning and policy analysis and may lead to erroneous results. Therefore, a need exists for an alternative procedure that removes these limitations and leads to enhanced quality of agricultural planning. For this purpose, the present study develops a new farm classification methodology to circumvent the aggregation problem, while establishing links between the farm level and the sector level of analysis.

4.3 Basic concepts

At this stage it is useful to introduce some basic concepts in classification. Intuitively, and in its simplest form, classification denotes the process of assembling various objects which behave similarly to distinguish them from other objects, showing different behaviour. Since such a formulation is general, any classification procedure must be preceded by a more formal definitions and investigations of the basic concepts (Bock, 1994). Therefore, it is desirable to present here a definition of some terms in classification. The following terms are the minimum set of basic concepts.

It is of great importance to distinguish among different terms in classification that appear often mixed in the literature. Hence, *classification* is the grouping of similar *objects* (see for example Sneath and Sokal, 1973; Hartigan, 1975; Jain and Dubes, 1988; Bailey, 1994). Objets themselves have been called *individuals, cases, entities, items, subjects, and OTUs*[4] *(operational taxonomic units)* in

[4] OTU is a biological term refer to the basic unit used in numerical analysis. Often the OUT is an individual organism, but it could be a group or some other unit (Sneath and Sokal, 1973).

various applications. The criteria for grouping are called dimensions, measurements, features, attributes, characteristics, scores, variables, factors, parameters, etc. Most commonly, the data are summarized in a rectangular table with objects, say, as rows and dimensions as columns. Classification can either be *uni-dimensional*, i.e. based on a single dimension, or *multidimensional*, i.e. based on a number of dimensions (Marz, 1990).

In the literature two terms are often used alternatively to indicate classification: *typology and taxonomy*. A *typology* is seen to be multi-dimensional, conceptual and qualitative classification. The term *taxonomy* can refer to both the process and the end result. As a process, taxonomy can be defined as the theoretical study of classification, including its bases, principles, procedures and rules. As an end result, a taxonomy is similar to a typology. The basic difference, then, is that a typology is conceptual while a taxonomy is empirical. The term taxonomy originates in biology, while typology is used in the social sciences (Bailey, 1994).

Cluster analysis, as defined by Jain and Dubes (1988), is the study of algorithms and methods for grouping, or classifying objects. Similarly, cluster analysis as defined by Hartigan (1975) and Lorr (1983) refers to a wide variety of statistical methods to group entities into homogenous groups on the basis of similarities. A numerical taxonomy is a quantitative, usually computerized method for constructing taxonomies. A cluster analysis is also a quantitative method of classification, originates in psychology, where the related term of pattern analysis is also used (see Bailey, 1994). The terms numerical taxonomy and cluster analysis are thus virtually synonymous. Methods of numerical taxonomy and cluster analysis are quantitative methods. This is in contrast to typological methods, that have been identified as qualitative.

The end products of a classification are called *classes, types, groups, or clusters*, depending on the type of classification followed. Classes can be *monothetic* or *polythetic*. Monothetic classes are classes containing cases that are identical on all dimensions or variables being measured, whereas polythetic classes are classes that contain cases that are similar (but not identical) on all or some dimensions (Bailey, 1994). Typologies generally contain only monothetic classes.

4.4 Farm classification methodology: skeleton and steps

When stripped of detail, the skeleton of any subject is the part that cannot be removed without destroying the subject itself. To the skeleton details can be added and understood in relation to each other. The skeleton of the farm classification methodology comprises six basic steps (Figure 4.1). This figure relates the basic steps of the methodology.

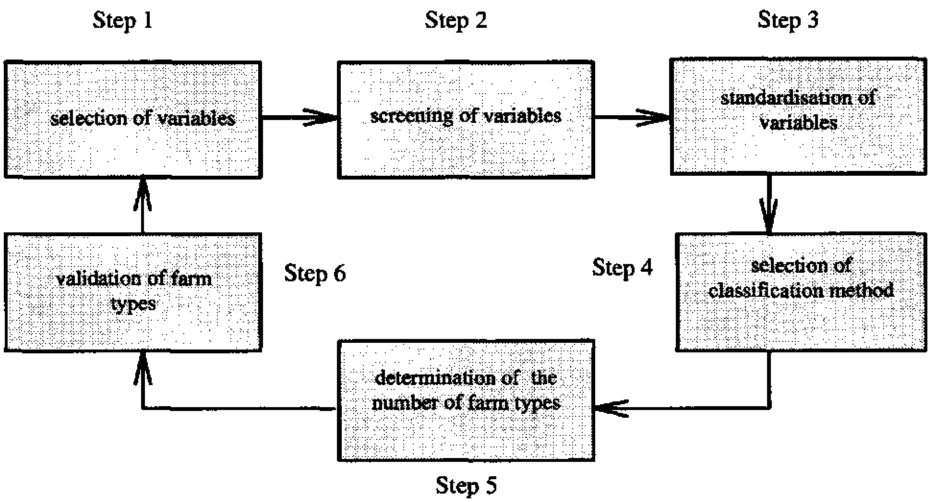


Figure 4.1 Skeleton of the farm classification methodology

Each of the steps in the methodology contains a number of sub-steps, and requires various methods and/or techniques for its operationalisation. The farm classification process is considered an endless loop in which during each passing new insights are obtained and new ideas generated. The feedback chain is the basis for learning how to do better and improve the classification. The end result consists of farm types that match the purpose reasonably well.

4.4.1 Selection of variables

One condition for successful classification is identification of the key fundamental characteristics on which classification is to be based. Therefore, proper selection of variables is clearly a critical point in the application of cluster analysis. For the initial choice of variables only limited statistical and mathematical guidelines are available (Everitt, 1993). Experience of Lorr (1983) shows that when relevant variables are neglected in the analysis poor or misleading findings may result. According to Everitt (1993), the initial choice of the variables presumably reflects the investigator's judgement of relevance for the purpose of classification. Consequently, the first question to ask with respect to the selected variables is whether they are relevant to the type of classification aimed at.

The main purpose for farm classification, in this study, is to eliminate or reduce aggregation bias, while integrating the farm level with aggregate level of analysis. The central question, therefore, is: *what conditions are sufficient and necessary among a set of farms to achieve exact aggregation?* Decisions on which factors to use for farm classification is an important step with both theoretical and empirical aspects. Therefore, the selection of variables is guided, as much as possible, by: first exploring the requirements for bias-free aggregation (*conceptual analysis*); subsequently investigating the criteria used in farm classification in some empirical studies (*empirical analysis*); and finally combining conceptual and empirical analyses to select operational parameters for farm classification (*operational level*). Irrespective of the start of the procedure, with theory or empirical analysis, when the two are combined the result is what Bailey (1994) calls the "*operational level*" of reality.

4.4.1.1 Exploration of theoretical conditions for exact aggregation

Proportional heterogeneity (Day, 1963)
The initial and the most comprehensive set of conditions for exact aggregation has been formulated by Day (1963), who defines sufficient conditions for exact aggregation as the requirements for *"proportional heterogeneity"*. These conditions are: technological homogeneity, i.e. all farms in a group should be characterized by identical technical coefficient matrices; pecunious proportionality, i.e. all farms in a group should exhibit only proportional variations in net return expectations; and institutional proportionality, i.e. all farms in a group should exhibit only proportional individual variation in resource constraints.

These conditions represents a tight restraint and results in dividing individual farms into a (very) large number of groups meeting these conditions. Exact aggregation thus seems extremely difficult to realize because of computational burden and costs (Miller and Heady, 1973). Various types of criticisms have been voiced against Day's conditions - see for example Miller (1966), Lee (1966), Paris and Rausser (1973) and Spreen and Takayama (1980)- and alternative less stringent sufficient conditions have been formulated.

Qualitatively homogenous output vectors (Miller, 1966)
Miller (1966) has formulated less binding sufficient conditions for exact aggregation by introducing the concept of *"qualitatively homogenous output vectors"*. These conditions include that all farms to be classified in one group should be characterized by: (a) identical technological coefficients; and (b) qualitatively homogenous output vectors. The set of farms that satisfy these conditions may vary in both resources and net returns, provided farms in the set

are involved in the same activities, which is defined as having qualitatively homogenous output vectors. Miller (1966) recognized some problems that were left unsolved by his theorem: the specific question how many farm groups are required to avoid aggregation bias in a given situation, and the problem of how rapidly aggregation bias accumulates as one moves away from the sufficient conditions.

Lee (1966), in his article "A discussion of Miller's theorem" discusses the practical values of Miller's work. In a fairly homogenous farming area, large groups of farmers apply similar production practices, and are faced with essentially the same alternatives. Thus, they operate with similar input-output coefficients and similar sets of activities. In addition, the analysis deals with response to a relatively narrow range of price ratios, hence the subset of farms contained in the unbiased aggregate can be easily determined. However, these practical observations may not be the most valuable results of Miller's work. Miller hinted at, but did not elaborate, an extension of his analysis, that could potentially lead to translation of the conditions of qualitatively homogenous output vectors into observable and measurable farm characteristics.

Extension of Miller's theorem (Lee, 1966)
Lee (1966) has shown that Miller's theorem does not represent the final solution to the problem of aggregation bias. One limitation is that the group of farms characterized by qualitatively homogenous output vectors is unique for each set of relative product prices. For each alternative set of prices considered, all farms have to be reclassified to determine which farms are common to a given group over the whole range of prices. This does not invalidate Miller's theorem. It does imply that a prohibitively large number of computations may be required. Another shortcoming of Miller's aggregation theorem centers around its practical applicability. The fact that his conditions can not be used to group farms simply by observing the farm characteristics, provides a less than ideal approach to farm classification. Miller recognized this.

In effect, Lee (1966) developed a new aggregation theorem as an extension to Miller's. He indicates the range over which resource ratios may vary without introducing bias. Lee's conditions for exact aggregation are that all farms classified in one group should be characterized by: identical input-output coefficients; the same net return expectations; and the same marginal revenue product which is constant over the range of resource ratios represented by the aggregated farms. Lee theorem would delineate sets of farms identical to those delineated by Miller's theorem. However, it may be more useful since it allows interpretation in terms of observable characteristics. Nevertheless, Lee recognized that the link between his theorem and its application is the empirical task of determining the exact range of resource ratios over which the marginal revenue product is constant.

Impossibility theorem of exact aggregation (Spreen and Takayama, 1980)
Spreen and Takayama (1980) found that even for a set of farms that meet Day's restrictive conditions, an aggregate estimate cannot be constructed with exact aggregation for all price vectors. They referred to this conclusion as the *"impossibility theorem of exact aggregation."* The conclusion agrees with that of Oguchi and Guccione (1979) that unconstrained, perfect aggregation is obviously impossible, except in two special cases: when the number of units to be aggregated is one, or when the systems considered are essentially linear.

Thus the possibility of exact aggregation in an empirical study is remote. This conclusion motivated Spreen and Takayama to introduce the term *"semi-exact aggregation."* They showed that under still restrictive conditions, a semi-exact aggregation can be obtained. Their conditions are that all the farms that can be classified in one group are characterized by: the same number and type of activities at each price (net return) vector; and the same binding constraints at each price (net return) vector.

The first condition is the "*qualitatively homogenous output vector*" of Miller. The second condition is an improvement in Miller's theorem because it excludes the possibility that for a given price vector, all farms satisfy the first condition, but some farms have one or more resources at their disposal, that are constraining for other farms. This possibility is excluded because in the aggregate estimate, the resources available to each farm are added with the consequence that the surplus of a resource from one farm could be transferred to another farm in the aggregate estimate. The implication of Spreen and Takayama's theorem for empirical studies is that the production patterns of farms are the proper rule for aggregation. However, its direct applicability in empirical studies is limited.

Simple rules for minimizing aggregation bias (Hazell and Norton, 1986)
Other approaches have been examined for grouping farms so as to minimize rather than eliminate aggregation bias. In practice, the aggregation criteria usually are reduced to a few simple rules (See for example Hazell and Norton, 1986). These rules are: similar proportion in resource endowments, similar yields, and similar technologies.

4.4.1.2 Description of variables used for farm classification in empirical studies

In the realm of agricultural planning and policy analysis, many variables for farm classification have been used (Table 4.1). A major problems in previous planning studies using aggregation procedures, is that farms have been classified on the basis of factors reflecting only one condition- mostly resource endowments- of the three conditions that are necessary for eliminating aggregation bias. Farm classification procedures that use only resource endowment indicators reflect insufficiently the conditions necessary for eliminating aggregation bias. Thus, if such procedures are used for planning, this can lead to quite substantial aggregation errors. hence, selection of variables that indicate the requirements for bias-free aggregation is recommended (Nafessa ,1996).

Table 4.1 Variables used for farm classification in some empirical studies.

Author	Purpose of study	Classification criteria
Marz (1990)	Quantitative assessment of the impact of new policies on farm economic performance and stability in northern Syria	Parameters reflecting farm resource base (land, labor) and intensity of production
Wossink (1994)	Support agricultural and environmental policy making in the North East Polder in the Netherlands	Variables reflecting farm resource base and cropping pattern
Jenkins (1989)	To analyze and forecast rural land use changes in agricultural regions and areas in Wales, United Kingdom	Variables reflecting land quality, land use and land use intensity
Schipper et al. (1995)	To analyze and plan sustainable land use in the Neguev settlement, Costa Rica	Resource indicators, i.e. farm size and the relative availability of soil type
Hardiman et al. (1990)	To identify farming systems in Qingyang county, central north China	Parameters reflecting resource endowments (land, labor, livestock herds), cropping pattern, topography
Alfaro et al. (1994)	To analyze and plan sustainable land use to support policy makers at regional and farm level in Costa Rica	Farmers' objectives and resource indicators, i.e. farm size and soil quality
Fox and Driver (1980)	To study production response potential of farms to factors affecting their pricing vectors, technology matrices and/or production restraints in southwestern Ontario, Canada	Factors reflecting the level of technology e.g., type of equipment used in crop production
Miller and Heady (1973)	To analyze and eliminate aggregation error based on farm programming models in Iowa, United States	Resource indicators, i.e. farm size and soil type
Ogwel and Clayton (1973)	To use aggregation procedure to construct and demonstrate a regional model for agricultural sector analysis for Kenyan agriculture	The ratio between land and labor
Monypenny and Walker (1976)	To simulate production decisions and expected financial outcomes of farm types in the State of New South Wales, Australia	Activities that produce the largest proportion of net revenue, and farm size
Kruseman et al. (1994)	To present a descriptive analysis of the options and constraints for sustainable land use and food security in the Atlantic Zone of Costa Rica	Factor endowments (access to land and capital, intensity of labor use) and goals and aspirations

4.4.1.3 Selection of operational variables for farm classification

Obviously, theoretical considerations with respect to exact aggregation are of interest, because they may indicate criteria for aggregation; on the other hand they become really relevant if they demonstrate the existence of empirical cases that satisfy the specified requirements. Hence, the quest for criteria for farm classification may be formulated as: how can sufficient conditions be specified, that are both *"not too rigid"* and *"operational"*. The term *"not too rigid"* implies that these conditions should result in an acceptable number of farm groups; *"operational"* refers to the possibility of identifying some parameters to represent and measure these conditions.

Day (1963) formulated the initial and most comprehensive conditions for exact aggregation. All other attempts originated from or are based on Day's works. Day recognized the soundness of his formulation and concluded that:

> *"As a conjecture, I would suggest that sufficient conditions for aggregation less binding than those presented in this paper, will be difficult to obtain" (Day, 1963).*

These conditions, although comprehensive, are both *too restrictive* and non-*operational*. Too restrictive in the sense that it has not been possible to find empirical cases that meet the requirements, and results in classifying farms in a very large number of groups, each meeting the tight requirements of equality and proportionality. Non-operational in the sense that no indication is provided of the way in which to measure these conditions, e.g., what parameters can be used to measure technological homogeneity?

In the present study the main purpose of the classification is to identify farm types in such a way that the resultant aggregate becomes a reasonably unbiased substitute for individual farms when used for land use planning and policy analysis. Aggregation bias can only be avoided (or minimized) if farms are classified in groups, defined according to the rigid theoretical requirements of Day (1963). Therefore, these requirements have been used as guidelines for the selection of farm classification criteria. Moreover, to allow spatial linking of resultant farm types with land units, mapping and spatial representation of the farm types is crucial. That requires incorporation of location attributes in the classification criteria. Therefore, an equally important requirement, called *"location proximity"*, is added to the proposed framework to enable the integration process.

Within these requirements, variables that are relevant within the context of land use planning and policy analysis are proposed. Since in land use planning mostly and particularly in this study, optimization models are applied, selection of the farm characteristics on the basis of these requirements allows killing three birds with one stone. In addition to satisfying conditions of exact aggregation, use of the proposed framework for farm classification offers at least three important advantages: firstly, it reflects the three main components of optimization models, i.e. objective function, technological coefficients, and (resource) constraints respectively; secondly, it results in farm types with similar land use decisions which are determined by their resource base [*corresponds to institutional similarity*], the way these resources are combined [*corresponds to technological similarity*], and efficiency of resource use [*corresponds to pecunious similarity*]; and thirdly, it enables identifying an integrated spatial unit through mapping of farm types and hence linking them with land units.

By relaxing theoretical requirements of Day (1963) it is possible to use them as criteria for farm classification. For operationalising the criteria, they are converted (or translated) into indicators or parameters, using technical information together with expert knowledge. Description of the variables proposed for farm classification is presented in Table 4.2. The logic behind, or the justification for choosing these variables is discussed below.

Table 4.2 Framework of the proposed criteria for farm classification

Classification criterion/variable	Acronym	Unit of measurement
Institutional similarity:		
Land area per farm household	LNA_FHH	Proportion to largest (%)
Land area under irrigated farming	LNA_IRF	Proportion to total land area (%)
Land area under dry farming	LNA_DRF	Proportion to total land area (%)
Land area exploited under private tenancy	LNA_PRV	Proportion to total land area (%)
Land area exploited under partnership tenancy	LNA_PRN	Proportion to total land area (%)
Farm households with farm size < 1 ha.	FHH1	Proportion to total farm households (%)
Farm households with farm size between 1 and 3 ha.	FHH1_3	Proportion to total farm households (%)
Farm households with farm size > 3 ha.	FHH3	Proportion to total farm households (%)
Ground water availability	GWA	m^3/ha
Ground water pumping capacity	GWPC	hp./ha.
Family labour availability	FLBA	mnd./ha.
Technological similarity:		
Quantity of urea applied	FRT_N	kg./ha.
Quantity of phosphate applied	FRT_P	kg./ha.
Mechanical power availability for tillage	MPA _TL	hp./ha.
Mechanical power availability for rice threshing	MPA_TH	hp./ha.
Pecunious similarity:		
Overall production efficiency	OPE	Proportion to highest (%)
Location proximity:		
Geographical longitudinal co-ordinate	LON_DM	Degree and minute
Geographical latitudinal co-ordinate	LAT_DM	Degree and minute

To ensure a reasonable conformity to Day's requirement of institutional homogeneity, variables indicating the resource endowments of each farm type are considered. Following Hazell and Norton (1986), variables selected to express the pertinent resource endowments include land, irrigation equipments and family labor. Land resource endowment is characterized by various parameters reflecting different dimensions of this resource. These parameters include (i) farm size expressed as land area per farm household as proportion of the largest farm area, and as the percentage of farm households with particular farm size; and (ii) type of land tenancy expressed as the proportion of land under private tenancy, and the proportion of land under partnership tenancy.

Irrigation capacity is expressed as the proportion of irrigated land, and the proportion of dry farming land. Accessibility to irrigation water from groundwater (wells) is indicated by two parameters: (i) well water supply in m^3 per hectare and (ii) water pumping capacity in hp. (or kW) per hectare. Well water supply is estimated on the basis of the number and types of wells and their average discharge. The energy availability for well irrigation is estimated on the basis of the number of water pumps, their nominal capacity and operating efficiency. These parameters can also indicate the (in)accessibility of river irrigation supplies.

The family labor resource is expressed in mandays per hectare. This is not as straightforward as it may seem, since some "standard man-day" or "standard man-hour" have to be defined. A man-day (mnd.) is defined as the amount of work accomplished by a male adult during one working day (Van Duivenbooden et al., 1991). It is obvious that the size of the farm household, its age structure, and sex ratio are of prime importance in estimating labor supply. Some average weighing factors, that take these aspects into account, may be of great help. This is deduced from the methodology developed by Van Heemst et al. (1981), who reviewed the "standard" sex and age weighing factors proposed in the literature. Based on these standards, the potential family labor availability per hectare is calculated.

In the present study, resource endowment is defined in terms of land, water and labor resources since these resources represent the main and most essential resources with regard to arable farming, particularly in developing countries (Ogwel and Clayton, 1973; Wossink, 1994; Schipper et al., 1995). Information on capital resources could not be assessed directly from the census data nor could it be deduced from other sources. Variables that indirectly reflect availability of these resources are considered. For example, use of agro-chemicals and availability of agricultural machinery reflect capital resources, because investment in agricultural inputs and machinery is associated with available capital (Wossink, 1994).

Farmers using different production techniques are likely to realize different input coefficients and yield may be different as well (Hazell and Norton, 1986). Hence to account for Day's requirement of technological homogeneity, variables on application rates of agro-chemicals and the potential degree of mechanization are considered. Use of agro-chemicals is expressed as the quantity of fertilizer used in kilogram per hectare. Potential mechanisation rate is estimated based on type and number of available farm machinery, their nominal power or capacity, and their operating efficiency. Based on these characteristics, the mechanical power availability is estimated in hp. (or kW) per hectare. Various indices may be used to indicate the potential for mechanisation of some farm operations. Two of these indices have been defined, i.e. mechanical power availability for tillage activities, and for rice threshing activities.

The pecunious proportionality requirement demands that all objects in one group hold similar expectations on per unit activity returns. To ensure reasonable conformity to this requirement, variables indicating output per unit resource, i.e. crop yield per hectare is considered. An average productivity index called overall production efficiency is calculated as the arithmetic mean of the production efficiencies of all crops on the farm. The production efficiency of a crop is the ratio of crop yield per hectare and the maximum yield realised in the region (Sharifi, 1978; Nafessa, 1996), expressed as a percentage. This index also mean looking out for differences in management which cause yield differences.

To locate farm types, geographical location attributes are included in the classification criteria. The geographical location is expressed by the longitudinal and the latitudinal co-ordinates in degrees and minutes. The inclusion of the location reference allows for the geo-referencing of farm types, and as a consequence, linking them with the spatial information on bio-physical (climate and soil) aspects.

Although at first sight, land use [cropping pattern] may seem a logical criterion for classification, it is not included in this study, since it forms the output of the linear programming model (Alfaro et al., 1994; Schipper et al., 1995). Instead, the classification is based on the potential for agricultural production. Jackson (1958) provides a good reasoning on this issue: "A classification according to enterprise emphasizes the nature of the existing pattern of cropping, whereas a classification according to resources emphasizes the potential pattern. The latter approach would therefore seem more suitable for use with linear programming studies, since they are concerned with finding the optimum combination of enterprises."

Having dealt with the question of which variables to use in the classification, the next question that might be considered is how many variables should be measured on each individual object to obtain "reliable" results? There is no precise answer to this question, for the appropriate number is a property of the data themselves (Sneath and Sokal, 1973; Clifford and Stephenson, 1975). The advice of Sneath and Sokal (1973) is to take as many variables as is feasible. However, Everitt (1993) observes that taking more rather than less variables may result in computational difficulties in some clustering techniques. In any case, the number of attributes should be less than the number of objects investigated (Marz, 1990). Following the practical advice of Stomph and Fresco (1991), classification is based on a limited number of measurable, quantitative variables.

4.4.2 Screening of variables

The term *"screening the variables"* refers to the process of deciding whether data exhibit a predisposition to classify into groups without identifying the groups themselves. Are the data random or does some justification exist for classification? This step is often ignored, but it is felt that it is very important (Jain and Dubes, 1988). The information gained from this step can not only prevent the inappropriate application of a classification method, but can also provide fundamental information on the structure and nature of the data.

In land use planning, including hierarchical levels of analysis, the initial screening of the variables can also be phrased as the problem of searching for an appropriate level at which some justification for classification exists. Therefore, a preliminary screening of variables is an important part of the farm classification methodology. In this study, a preliminary investigations of variables is carried out to examine associations among variables, and to test for variations among farm systems at different spatial levels to determine the level at which some justification for classification exists. Several approaches are available in the literature for such an investigation. Those, most frequently used in empirical analysis are: correlation analysis (Sneath and Sokal, 1973), coefficient of variation (Marz, 1990), standard deviation (Hardiman et al., 1990) and one way analysis of variance (Mohamed, 1997).

4.4.3 Standardization of variables

Raw data usually need some massaging before they are ready for formal analysis. The problem here is to put the data into a form suitable for classification. Preparing the data for a cluster analysis requires some sort of standardization. Romesburg (1984) gives two main reasons for standardizing data in cluster analysis. First, the units chosen for measuring attributes can arbitrarily affect the similarities among objects. By standardization, the arbitrary effects can be removed. Secondly, standardization makes attributes contribute more equally to the similarities among objects. For these reasons the data have been transformed so that all the farm classification variables are expressed in one common unit, for example a range from 0 to 1. This type of transformation is called standardization (Seyhan and Keet, 1981). For details on some of the important standardization formulas see for example Podani (1994).

4.4.4 Selection of classification strategies

A number of decisions must be made before one start the classification process, i.e.: how will similarity between objects be measured? and what clustering method(s) to be used for classifying these objects into clusters? Just as there are many measures for calculating similarity between two objects, there are many methods for classifying objects into clusters. The term "*classification strategies*" refers to a set of possible combination between similarity measures and clustering methods. Hence, several choices must be made in selecting a classification strategy. The key choices are the selection of the similarity measure and the clustering method. Some theoretical guidelines are available to choose among these measures and methods (Jain and Dubes, 1988). The procedure used to facilitate the selection of classification strategies follows the same framework as used for the selection of variables for farm classification [in step 1 of the methodology]. It consists of three steps: specification of theoretically possible proximity measures and clustering methods (*conceptual analysis*), comparison of performance of clustering methods in some empirical work (*empirical analysis*), and combining the conceptual and empirical analysis to select operational classification strategies (*operational level*).

4.4.4.1 Specification of proximity measures and clustering methods

Proximity measures

Classification requires that an index of proximity, or alikeness be established between pairs of farms since they are grouped on the basis of their "similarity". This proximity index represents either a similarity or a dissimilarity (distance). The more the objects resemble each another, the larger their similarity index and the smaller their dissimilarity index (Jain and Dubes, 1988). Therefore, similarity and difference are mutually dependent concepts that express the degree of relation between objects given the values of a set of properties common to both (Everitt, 1993). In much modern literature the term similarity applies to both.

For farm classification the question is: which similarity or distance measure should be used, since different measures may lead to different results? This question cannot be answered in absolute terms and the choice of a measure will have to be guided largely by the data type and the data scale of variables being used (Sneath and Sokal, 1973), the intuition of the investigator (Everitt, 1993), and the computer program to be used (Jain and Dubes, 1988). A wide variety of similarity measures has been proposed, and extensive lists of them are given in Sokal and Sneath (1963), Sneath and Sokal (1973) and Clifford and Stephenson (1975). Some of the distance measures are outlined below.

Euclidean Or Squared Euclidean Distance Measure. Perhaps the most commonly used distance measure and the most familiar is the Euclidean. The distance between two objects is either the sum of the squared differences in values for each variable (squared Euclidean distance) or the square root of the sum of the squared differences in values of each variable (Euclidean distance). Used on the raw data however, it may be very unsatisfactory, since its value is strongly dependent on particular scales selected for the variables. Therefore, variables are generally standardized before calculating Euclidean distance. In using Euclidean distance as a similarity measure, the question often arises whether it is appropriate if the variables selected are correlated (Lorr, 1983), as the Euclidean distance assumes that the variables are un-correlated (Everitt, 1993). One way of circumventing this problem is the use of correlation or principal component analysis.

City Block Metric Or Manhattan Metric Distance Measure. Although the Euclidean distance is the most widely used in a clustering context, other distance measures have been applied, for example, the city block metric or Manhattan metric. The distance between two objects is then the sum of the absolute differences in values for each variable. Since the differences are not squared, large differences are not weighted as heavily as in the Euclidean distance or its square. So, sometimes it is preferred over the squared Euclidean (see Sneath and Sokal, 1973; Everitt, 1993). The simplicity of this measure is advantage; however, it does exhibit several major disadvantages. It underestimates the true Euclidean distance between objects, and when some variables show small differences, and the others larger differences, it will underestimate the distance considerably. It also lacks some of the desirable attributes of the Euclidean distance or its square (Sokal and Sneath, 1963).

Mahalanobis Distance Measure. The Mahalanobis distance incorporates the correlation between variables and standardizes each variable to zero mean and unit variance (Jain and Dubes, 1988). In application in clustering methods, the Mahalanobis metric suffers from the disadvantage that the matrix is based on all the objects combined and not, as would perhaps be more meaningful, separately on the objects in each cluster that are still unknown; furthermore, its calculation is necessarily much more complex than that of the other metrics. For these reasons, Mahalanobis metric are rarely used (Spath, 1980). It is worth remarking that if the variables are standardized (as the case in this study), the Mahalanobis and the Euclidean distance are identical.

Cosine Similarity Measure. The cosine is a pattern similarity measure calculated as the cosine of the vectors of variables. Although the cosine similarity does not have many of the disadvantages of other distance measures, it can only be combined with some clustering methods.

$$Similarity\,(x, y) = \frac{\sum_i (x_i \; y_i)}{\sqrt{\sum_i (x_i^2) \sum_i (y_i^2)}}$$

Clustering methods

Hierarchical clustering methods are the most widely applied clustering methods (John and Davis, 1986; Jain and Dubes, 1988; Everitt, 1993). A hierarchical clustering may be viewed as a family of nested multilevel classes (Lorr, 1983). Hierarchical clustering methods can be subdivided in agglomerative methods and divisive methods. Agglomerative methods place each object in an individual cluster and gradually merge these clusters into larger and larger clusters until all objects are combined in one single cluster. Divisive methods reverse the process by starting with all objects in one large cluster and subdividing into smaller clusters.

Agglomerative methods build a *tree* or *dendrogram* from branches to the root; divisive methods start at the root and form a branching sequence. With such methods, divisions or fusions once made are irreversible, so that when an agglomerative algorithm has combined two objects they can not subsequently be separated, and when a divisive algorithm has made a division the objects can not be reunited. In other words once assigned to a group, the object or the cluster remains in that group (Lorr, 1983). The hierarchical agglomerative methods are the most frequently used clustering methods. There are many methods for deciding which objects or clusters should be combined at each step. All of these methods are based on the similarity measures used. Differences between methods are related to the various ways of defining similarity between an object and a cluster containing several objects, or between two clusters of objects (Maxwell, 1977).

Single Linkage (Nearest Neighbour) Method. One of the simplest methods is single linkage, sometimes called "nearest neighbour". According to this method, a new object is combined with an existing cluster of other objects, if it is linked to at least one member of that cluster (Seyhan and Keet, 1981). The results of this procedure are independent of the order of data entry, but highly sensitive to distortions in the data matrix. When the data in the matrix is not perfectly normally distributed, the results can become very erratic (Marz, 1990). A major property of Single Linkage clusters is what is described by Sneath and Sokal (1973) as *" chaining".* It means that two subgroups even if their constituent members share only one link do not remain apart. Thus, individual clusters can be very straggly, with two of its members having little in common but being linked through a chain of intermediate objects (Gordon, 1981).

Complete Linkage (Furthest Neighbour) Method. Another frequently used method is called complete linkage or " furthest neighbour". In this method, the distance between two clusters is expressed as the distance between their most remote or distant points. It is an intensive grouping strategy results in compact and homogenous clusters, since this algorithm tries to minimize interclass variability. Complete linkage is less sensitive to distortions in the data matrix but the results are influenced by the order of data entry.

Average Linkage Method. Methods that aiming at taking a middle position between Single Linkage and Complete Linkage are the Average Linkage methods (Gordon, 1981). These methods define the distance between two clusters as the average of the distances between all pairs of objects with one member of the pair in each of the clusters. Average Linkage, in comparative studies, produced the most homogenous and most compact clusters (Lorr, 1983). The results are relatively independent of the order of data entry .

Since various kinds of averages exist, several Average Linkage methods have been proposed by Sneath and Sokal (1973). The four most common of these methods result from the four combinations of two criteria each with two alternatives: arithmetic average versus centroid clustering, and weighted versus unweighed clustering. The centroid methods express the distance between two clusters by the distance between their centroids, i.e. centres of mass. Centroid methods should only be used when the objects are represented as patterns and the proximity measure is Squared Euclidean distance (see Sneath and Sokal, 1973; Romesburg, 1984; Jain and Dubes, 1988; Everitt, 1993). The UPGMC (unweighed pair-group method using centroid) measures distance in terms of the centroid computed from all patterns in each cluster. It has also been called, simply, the centroid method. The WPGMC (weighted pair-group method using centroid) computes distance from the centroid of the two clusters that merge to form a new cluster.

The arithmetic averageing attempts to avoid the extremes of Single-Linkage and Complete-Linkage methods. When measuring the dissimilarity between an existing cluster and a prospective cluster, the UPGMA (unweighed pair-group method using arithmetic average), and the WPGMA (weighted pair-group method using arithmetic average), use the arithmetic average of the dissimilarities. The UPGMA treats each object in a cluster equally, regardless of the size of the clusters, while WPGMA weighs the pattern in small clusters more heavily than the patterns in large clusters. UPGMA is probably the most frequently used method by researchers, because it can be used with any proximity measure, and because it evaluates the similarity between pairs of clusters in a manner less extreme than either Single-Linkage or Complete-Linkage methods (Romesburg, 1984).

Ward Method. Another frequently used method is Ward's method, also called the minimum variance method. At each, step this method merges any two clusters that will result in the smallest increase in the value of an index E, called the sum-of-squares index, or variance, or square-error criterion which are also used in divisive clustering algorithms (Romesburg, 1984). The algorithm operates directly on the similarity matrix which is just an array of numbers; hence, the entries in this matrix could be computed using any association measure for either variables or data units.

However, the properties of the resulting clusters are unknown unless the similarity is the Squared Euclidean distance. While the similarity matrix should contain Squared Euclidean distances, these distances may be computed in any desired representation space, such as one involving principal components, weighted variables, or nonlinear composites of variables. Keeping this in mind, the Ward method can be quite a versatile technique for cluster analysis (Anderberg, 1973).

4.4.4.2 Comparison of performance of clustering methods in previous studies

The comparative analysis of clustering methods presents a continuing problem for research. Hartigan (1985) provides a succinct summary of this problem: "*Different classifications are right for different purposes, so we cannot say any one classification is best.*" A thorough review of the literature has shown that some general recommendations can be made about clustering methods likely to be useful in the widest range of situations.

Various studies that have compared a variety of clustering procedures point to some methods as the most useful in practice. The Ward method and group average have been found to perform relatively well (Everitt, 1993). Similarly, Lorr (1983) and Nafessa (1996) favorably judged the Ward method, whereas the Complete-Linkage method ranked second. Other studies, however, reported that the Group Average Linkage method is the most accurate among clustering methods (Romesburg, 1984; Marz, 1990). Hartigan (1985) supplies evidence for the superiority of the Single-Linkage method over the Complete-Linkage method.

4.4.4.3 Selection of operational strategies

It should be clear that no one clustering strategy can be judged to be best in all circumstances. Following the advice of Sneath and Sokal (1973), Lorr (1983), and Jain and Dubes (1988), different classification strategies [combinations of proximity measures and clustering methods] have been examined (see Table 4.3) and the result that allows the most conclusive interpretation is to be selected. The selection of this set of classification strategies is largely based on the advantages and disadvantages of proximity measures and clustering methods in relation to the purpose of classification, and on their performance in previous classifications.

Table 4.3 Set of selected classification strategies.

No	Classification strategy		Acronym
	Proximity measure	Clustering method	
1	City block (CB)	Average linkage between groups (BG)	CBBG
2	City block (CB)	Complete linkage (CL)	CBCL
3	City block (CB)	Average linkage within groups (WG)	CBWG
4	Cosine (CS)	Average linkage between groups (BG)	CSBG
5	Cosine (CS)	Complete linkage (CL)	CSCL
6	Cosine (CS)	Average linkage within groups (WG)	CSWG
7	Squared Euclidean (SQ)	Average linkage between groups (BG)	SQBG
8	Squared Euclidean (SQ)	Complete linkage (CL)	SQCL
9	Squared Euclidean (SQ)	Ward (WD)	SQWD
10	Squared Euclidean (SQ)	Average linkage within groups (WG)	SQWG

4.4.5 Determination of the number of farm types

Since all agglomerative hierarchical techniques ultimately reduce the data to a single cluster containing all objects, the investigator searching for a solution with an "optimal" number of clusters, will have to decide at a particular stage to stop (Everitt, 1993), or alternatively, as indicated by Lorr (1983), a termination rule is required to select the optimum number of clusters. In the literature informal and formal methods have been used to deal with this problem.

An informal method often used for this purpose is to examine the differences between fusion levels in the dendrogram or the change in proximity coefficient in the agglomeration schedule. Large differences should be considered to indicate a particular number of clusters. Although this procedure is commonly used and can be helpful, the risk exists of influence from a priori expectations (Everitt, 1993). More formal approaches for the selection of the number of clusters in the context of hierarchical clustering have been suggested. Gowda and Diday (1994), for example, proposed a criterion called cluster indicator value (CIV). Their argument is that at each stage in the process of forming clusters the larger the distance, the better is the separation between the clusters.

However, Bock (1994) stated that the number of clusters problem should not be overemphasized for two reasons. From a theoretical point of view, "the true number of clusters" is often not well defined and depends largely on the selected clustering method, such that an "exact" formulation of the problem can be quite artificial from the outset. From an applied point of view, "the true number of clusters" does often not play the dominant role that is often claimed, since the question is not 'what is the real number of clusters?', but just 'how many clusters should one use for the purpose of the application?'. This calls for a trade-off between the gain resulting from more clusters, and the real or imaginary costs for this more complex model. As recommended by Hardy (1994), to solve this problem, simultaneously several (informal and formal) methods for determining the optimal number of clusters have been used and all results have been analyzed to choose the best number of farm clusters.

4.4.6 Validation of farm types

Very often, the classification process does not stop with the determination of the number of classes. There are many reasons to go beyond that. Podani (1994) mentions the very important one: there is always a possibility that alternative results may be obtained for the same set of data. Certainly, the fact that different clustering methods may yield different results when applied to the same data should make one cautious about accepting uncritically the results of a single clustering method (Gordon, 1981). Much attention needs to be given to questions of cluster validity, although such questions are rarely straightforward (Jain and Dubes, 1988).

Cluster validation refers to procedures that evaluate and interpret the results of cluster analysis in a quantitative and objective fashion (Jain and Dubes, 1988). The problem of cluster validity is inherently statistical. There is no optimal procedure for evaluating cluster results (Everitt, 1993), but some suggestions which might be helpful are used in this study. The procedure used for evaluating and interpreting the results of the classification is a step-by-step scrutinizing of the set of classifications to find the one with the most distinct clusters. It consists of four steps. The validation procedure starts by comparing the solutions produced by the different classifications (step 1). Only those classifications that produced similar results will be carried for further validation. Farm clusters produce by these classifications are to be tested for their significance of difference (step 2). Only classifications with clusters that are significantly different are to be ranked and the one with the most distinct and contiguous clusters is to be selected (step 3). Then its clusters are to be described and characterized with their particular features (step 4). Details on the validation procedure are given below.

4.4.6.1 Comparison of classification solutions

Assessing the results from a classification strategy is often dominated by personal intuition and insight (Everitt, 1993). An essential, although not always obvious component of the evaluation process is comparison (Podani, 1994). Often when carrying out a cluster analysis for a set of multivariate data, it may be necessary to compare two or more clusterings of the same set of individuals. Virtually no cases are known in which identical results are obtained when different classification methods have been used on the same set of data (Clifford and Stephenson, 1975).

Comparison of different classifications is clearly of some importance here. Reasonable confidence may be expresses in those strategies that produce very similar solutions as a basis for deciding whether the results are worth further investigations (Everitt, 1993). In other words, through comparison it is sometimes possible to discard a method completely, because the results appear nonsensical (Clifford and Stephenson, 1975).

Many formal procedures have been suggested for comparing classifications- see for example Podani (1994), Everitt (1993), Jain and Dubes (1988), Lorr (1983) and Clifford and Stephenson (1975). Rand Index is one of the most commonly used of these formal approaches. This method is used in this study for comparing the solutions produced by the different classification strategies. Rand index, R_g, may be defined as follows. Let n be the total number of objects to be clustered. Then, for a given number of clusters, g, R_g is defined as the ratio of the sum of the number of pairs of objects that cluster in the two classification strategies under comparison and the number of pairs of objects that fall in different clusters in both classification strategies, to the total number of pairs. Thus, R_g can be interpreted as the probability that two objects are treated similarly in both classification strategies. R_g may be written as (see Everitt, 1993):

$$R_g = \frac{\left[T_g - \frac{1}{2} P_g - \frac{1}{2} Q_g + \binom{n}{2} \right]}{\binom{n}{2}}$$

where

$$T_g = \sum_{i=1}^{g}\sum_{j=1}^{g} m_{ij}^2 - n$$

$$P_g = \sum_{i=1}^{g} m_i^2 - n$$

$$Q_g = \sum_{j=1}^{g} m_j^2 - n$$

and m_{ij} is the number of objects in common between the *i*th cluster (group) of the first classification strategy, and the *j*th cluster (group) of the second. The values T_g, P_g *and* Q_g can be constructed employing the so-called cross-classification table in which rows represent the groups in the first classification strategy and columns represent groups in the second. The terms m_i and m_j are appropriate marginal totals of the matrix of m_{ij} values. R_g lies in the interval (0,1), and takes its upper limit when there is complete agreement between the two classification strategies.

4.4.6.2 Testing of farm types

Various attempts have been made to replace personal judgements of the results of classification strategy with tests of significance (Clifford and Stephenson, 1975). Possibly there is a theoretical quibble regarding this procedure in that the statistical testing is applied to the same data that have already been used in a classification procedure designed to form statistically significant groups. Clifford and Stephenson (1975) find that in practice application of the tests tends to reveal that, even after classification, an important portion of the clusters produced are still insignificant. Four types of tests are used in the literature , i.e. (1) based on information theory; (2) chi-square; (3) F-test; and (4) Kruskal-Wallis test. The first three tests require that the data should be normally distributed. However, if the distribution is not known or does not appear to be normal, statistical tests that do not require assumption about the shape of the underlying distribution, possibly a nonparametric test such as Kruskal-Wallis is preferred (Norusis, 1990).

To test for statistical differences in the farm types produced by classification strategies selected for further investigation, Kruskal-Wallis test is used, a nonparametric (NPAR) alternative to the one-way analysis of variance (ANOVA). Fortunately, the Kruskal-Wallis test is approximately distributed as chi-square with *k*-1 degrees of freedom, where *k* denotes the number of classes, so the test can be readily applied to larger problems (Davis, 1986). Moreover, it has the advantage that normality and homogeneity of variances need not be assumed (Marz, 1990), i.e. significance levels can be determined regardless of the shape of the population distribution since they are based on ranks (Norusis, 1990).

4.4.6.3 Selection of a classification

Having passed the statistical significance test these classification strategies have to be compared to select the one that produces distinct and contiguous farm types. The selection has been based on the level of statistical significance, and on the contiguity of farm types, in a two-steps procedure. In the first step, the value of Kruskal-Wallis H statistics is used to establish which classification strategy is likely producing the most distinct farm types. This is based on transformation of the H statistics for each variable to values in the range from 0 to 1. Classification strategies are then ranked on the basis of the mean of the values of all these variables. In the second step, these classification strategies are visualized using Arcview 3.0 GIS to examine whether they also result in formation of contiguous farm types. Then results of step 1 and step 2 are compared to select a classification strategy with distinct and contiguous farm types.

4.4.6.4 Characterization of farm types

Having selected the classification that produces distinct and contiguous farm types, the next step is to interpret these types by identifying their particular characteristics. The classification of farms only makes sense when the resulting farm types are different in most of their characteristics (Marz, 1990). It is, therefore, important to describe and characterize the farm types. Two approaches are used for this purpose. Following Hartigan (1975) and Hansen et al. (1994), descriptive statistics- mean and standard deviation- are used to summarize the characteristics of each farm cluster, and subsequently Z statistics to characterize these farm types. In this approach the cluster means are compared to the overall means, and presented in standardized form (Johnston and Semple, 1983).

4.5 Operationalization of the methodology

4.5.1 Data organization and retrieval: simple data model

The methodology is illustrated for Amol sub-region, Mazandaran Province, Iran. The data used for this case study have been derived from the detailed results of the Agricultural Census obtained from the Iran Statistical Centre. The census contains information on 18662 farm-households located in 277 villages. A total of 140 farm attributes are available. These data are supplemented by data on geographical location attributes (longitude and latitude) obtained from Plan and Budget Organisation. Such a large number of data items will be of little use unless they are structured in a meaningful way (Howe, 1989). Therefore, the data have been organised in a data base so that unnecessary duplication avoided and the data can be easily retrieved in all required sequences (Benyon, 1990). Moreover data bases allow to perform tasks that involve handling this large amount of data (Date, 1990).

For the purpose of this study, the data dictionary is treated in a simplified fashion. It is used to define the data elements and their basic characteristics: type-, name- and the range of acceptable values- its domain. Since all available data refer to farm characteristics per village, it would be more convenient, and result in a more concise model, to have a single village entity type. This village entity type can be represented by one table in which each column corresponds to a single farm characteristic and each row to an individual village.

4.5.2 Investigation of the data

The result of one way analysis of variance (ANOVA) in the preliminary investigations on variation among the farm population in Amol Township has shown that within-village variation of farms is very low compared to between-village variations (Mohamed, 1997). Therefore, classification of farms is carried out at village level using characteristics of an average farm. The use of an average farm at village level is also justified by the fact that at this level there would be more possibilities for mapping farm types.

Coefficient of variation and correlation analysis have been used to elucidate the variation among farms and to identify the associations between their characteristics respectively. Since only variables with high variability should be used for classification (Marz, 1990; Nafessa, 1996), variables showing very little variation have been removed, because they do not discriminate. Following the advice of Sneath and Sokal (1973), variables showing very high correlation coefficient have been removed. This procedure resulted in a total of 14 variables that are used in the classification procedure. The high variation among these variables justifies the need for grouping. Because the selected variables are expressed in different units, the data are standardized to "Z-score" in order to represent all variables in one common measurement unit.

4.5.3 Classification results

Ten different classification strategies are performed using SPSS for Windows computer program. The output of these classification strategies is printed in agglomeration schedules, plotted in dendrograms and saved in cluster membership. Results of various methods for determining the appropriate number of farm types are presented in Table 4.4. The selected number of farm types, is seen as a compromise among these methods. Smaller than the selected number of farm types would combine very heterogeneous farms, while larger than the selected number of farm types would not lead to significantly more homogenous groups.

Table 4.4 Number of farm types for the various classification strategies as determined by different methods.

Classification strategy	Method			Selected number
	AS	DG	CIV	
CBBG	3	3	8	3
CBCL	3	7	3	3
CBWG	5	5	3	5
CSBG	4	4	6	4
CSCL	6	4	4	4
CSWG	3	3	4	3
SQBG	3	4	3	3
SQCL	4	4	3	4
SQWD	3	3	4	3
SQWG	4	4	5	4

Notes: Method: AS, Agglomerative Schedule method; DG, Dendrogram method; CIV, Cluster Indicator Value method. Classification strategy: see Table 4.3.

Table 4.5 shows a summary of the results of the various classification strategies in terms of the selected number of farm types. Informal inspection of farm types produced by these classification strategies reveals that strategies CBBG, CBCL, and SQBG result in poor distribution within the clusters of farm types. These classification strategies are therefore discarded. All other classification strategies produced relatively fair sizes of farm clusters and are, therefore, subjected to formal and objective validation procedures.

Table 4.5 Distribution (%) of farms among farm types distinguished by various classification strategies

Classification strategy	FT1	FT2	FT3	FT4	FT5	Total
CBBG	99.8	0.1	0.1			100
CBCL	54.2	41.5	4.3			100
CBWG	21.4	28.7	6.8	32.6	10.4	100
CSBG	41.4	25.0	27.9	5.6		100
CSCL	31.9	19.9	31.1	17.1		100
CSWG	33.6	36.6	29.8			100
SQBG	98.5	1.4	0.1			100
SQCL	46.7	31.7	7.4	14.2		100
SQWD	44.4	29.2	26.4			100
SQWG	30.3	41.4	17.8	10.4		100

Note: Classification strategy: see Table 4.3.

The agreement among the remaining classifications has been compared on the basis of the Rand index (see Table 4.6). Agreement among these classification strategies is clearly very good which inspires confidence in the relevance of the farm types produced by these classification strategies. Therefore, these classifications are carried on for further validation.

Table 4.6 Calculated Rand index between various classification strategies

Classification strategy	SQWG	SQWD	SQCL	CSCL	CSWG	CSBG
SQWD	0.69					
SQCL	0.72	0.73				
CSCL	0.62	0.69	0.63			
CSWG	0.70	0.78	0.68	0.70		
CSBG	0.69	0.75	0.67	0.69	0.83	
CBWG	0.74	0.68	0.69	0.70	0.72	0.72

Note: Classification strategy: see Table 4.3.

The statistical significance of farm clusters produced by the various classifications strategies is tested using Kruskal-Wallis *H* statistics. The test is simply applied to each of the classification strategies in turn. For each classification strategy farms are split in groups distinguished in that strategy and the groups are then tested per variable. The summary in Table 4.7 shows the values of the Kruskal-Wallis *H* statistics and the associated significance level of the farm clusters obtained by these classification strategies.

Table 4.7 Testing the significance of farm types distinguished by various classification strategies.

Variable	CBWG		CSBG		CSCL		CSWG		SQCL		SQWD		SQWG	
	H	Sig.	H	Sig.	H	Sig.	H	Sig.	H	Sig.	H	Sig.	H	Sig.
LNA_FHH	61	0	55	0	46	0	58	0	68	0	59	0	66	0
FHH_1	118	0	86	0	65	0	93	0	86	0	91	0	85	0
FHH1_3	68	0	47	0	43	0	42	0	27	0	34	0	41	0
FHH_3	64	0	44	0	35	0	54	0	73	0	55	0	57	0
GWA	41	0	39	0	40	0	41	0	23	0	25	0	25	0
GWPC	32	0	28	0	45	0	33	0	28	0	27	0	20	0
FLBA	54	0	46	0	33	0	51	0	62	0	52	0	62	0
FRT_N	47	0	41	0	83	0	31	0	45	0	54	0	38	0
FRT_P	44	0	39	0	74	0	24	0	40	0	49	0	33	0
MPA_TL	28	0	21	0	26	0	18	0	11	0.01	7	0.03	46	0
MPA_TH	28	0	21	0	26	0	19	0	12	0.01	7	0.03	46	0
OPE	44	0	51	0	50	0	56	0	39	0	63	0	40	0
LON_DM	84	0	76	0	101	0	40	0	12	0.01	49	0	47	0
LAT_DM	68	0	82	0	172	0	86	0	58	0	85	0	47	0

Notes: Variable: see Table 4.2. Classification strategy: see Table 4.3. H, Kruskal-Wallis *H* statistic; Sig, significance level.

Since the significance levels for all variables in these classification strategies are very low (mostly zero), the hypothesis that the farm types produced by these classification strategies, are identical is rejected. Hence, the farm types identified by these classification strategies are significantly different Therefore, these classification strategies are subsequently ranked according to the value of Kruskal-Wallis *H* statistics to identify the one likely producing the most distinct farm clusters, following transformation of the values per variable to a value within the range 0 to 1, i.e. each *H* statistic value of a variable is divided by its highest value (Table 4.8).

Table 4.8 Ranking the classification strategies

Variable	CBWG	CSBG	CSCL	CSWG	SQCL	SQWD	SQWG
	Classification strategy						
LNA_FHH	0.90	0.81	0.67	0.85	1.00	0.86	0.97
PFHH_1	1.00	0.73	0.55	0.79	0.73	0.77	0.72
PFHH1_3	1.00	0.68	0.63	0.61	0.39	0.50	0.60
PFHH_3	0.87	0.60	0.48	0.74	1.00	0.75	0.78
GWA	0.99	0.93	0.97	1.00	0.54	0.60	0.60
GWPC	0.71	0.61	1.00	0.72	0.62	0.60	0.44
FLBA	0.88	0.74	0.53	0.83	1.00	0.84	1.00
FRT_N	0.56	0.50	1.00	0.37	0.54	0.64	0.45
FRT_P	0.44	0.70	1.00	0.37	0.54	0.88	0.40
MPA_TL	0.60	0.45	0.56	0.40	0.24	0.15	1.00
MPA_TH	0.60	0.45	0.56	0.41	0.26	0.15	1.00
OPE	0.70	0.81	0.79	0.88	0.61	1.00	0.64
LAT_DM	0.40	0.48	1.00	0.50	0.34	0.50	0.27
LON_DM	0.83	0.75	1.00	0.40	0.12	0.48	0.47
Total score	0.75	0.66	0.77	0.63	0.57	0.62	0.67
Rank	2	4	1	5	7	6	3

Notes: Variable: see Table 4.2. Classification strategy: see Table 4.3.

Amongst the classification strategies tested CSCL ranks first followed by CBWG, SQWG and CSBG as second, third and fourth, respectively. These classifications are subsequently visualized using Arcview 3.0 GIS to examine which one produces the most contiguous farm types. The picture shows that classification CSCL produces the most contiguous farm types. The same results can be obtained by ranking the classification strategies on the basis of transformed H statistics of location parameters. As CSCL produces the most distinct and contiguous farm types, this classification has been selected.

Subsequently, Z statistics have been used to characterize the farm types selected (Table 4.9). The Z statistics provide a standardized measure of the degree to which the characteristics of a farm type deviate from those of the population from which it has been separated (Johnston and Semple, 1983). In this way, the particular features or characteristics of each farm type are emphasized.

Table 4.9 Z statistics for the farm types distinguished by CSCL classification strategy

Variable	FT1	FT2	FT3	FT4
LNA_FHH	-2.1	3.6	-2.8	1.8
FHH_1	2.4	-6.2	3.5	-0.5
FHH1_3	-0.4	5.2	-3.2	-0.9
FHH_3	-3.4	3.1	-1.2	2.0
GWA	3.0	0.3	-2.7	-0.7
GWPC	2.3	0.7	-2.5	-0.5
FLBA	0.2	-2.7	4.2	-2.1
FRT_N	-3.4	-1.1	5.6	-1.1
FRT_P	-3.6	-0.8	6.6	-2.3
MPA_TL	3.0	-1.1	-2.9	0.8
MPA_TH	3.0	-1.1	-2.9	0.8
OPE	-3.4	-3.7	5.6	1.2

Notes: Variable: see Table 4.2. Z statistics: the larger the Z statistic the greater the difference between the farm type and the population means on that variable (characteristic). Positive values of Z statistics indicate that the farm type mean is above the population mean; the reverse in the case of negative values.

The main characteristics of the farm types distinguished in the CSCL classification strategy can be summarized as follows:

Farm type 1 (FT1) is characterized by a relatively small land area per farm household, and a relatively large potential family labor availability per hectare. This group has a relatively high irrigation possibilities from wells which is an indication for scarcity of river irrigation possibilities. Farmers in this group use relatively small amounts of agro-chemicals and have high mechanical power availability for tillage, irrigation and threshing activities. The overall production efficiency of this farm group is low.

Farm type 2 (FT2) is characterized by a large land area per farm household and a very small potential family labor availability per hectare. This group has slightly above average irrigation possibilities from wells, i.e. moderate possibilities for river irrigation. Farmers in this group use slightly below average amounts of agrochemicals and have a slightly below average potential for mechanization of tillage and rice threshing activities. The overall production efficiency of this group is relatively low.

Farm type 3 (FT3) is characterized by a relatively small land area per farm household, and a very high potential family labor availability per hectare. This group has relatively low irrigation possibilities from wells, i.e. large possibilities for river irrigation. Farmers in this group use large amounts of agrochemicals. The potential for mechanization of tillage and rice threshing activities is low. The overall production efficiency of this group is relatively high.

Farm type 4 (FT4) is characterized by above average land area per farm household, and a low potential family labor availability per hectare. This group has slightly below average irrigation possibilities from wells, i.e. moderate availability for river irrigation possibilities. Farmers in this group use below average amounts of agrochemicals and have a slightly above average potential for mechanization of tillage and rice threshing activities. The overall production efficiency of this group is above average.

Chapter 5

An Integrated Unit for Land Use Planning and Policy Analysis: Conceptualization and Operationalisation

5.1 Introduction

For more effective land use planning and policy analysis a more complete integration of socio-economic and bio-physical disciplines is required. Though the procedure to realize this is not clear yet, it is perceived that a necessary initial step is to create an integrated interdisciplinary unit of analysis. In land use planning and policy analysis, many obstacles or challenges make defining and mapping an integrated unit a difficult task. Major obstacles are: different nature and focus of disciplines involved; different units of analysis used; different hierarchical levels at which they operate or exist; difficulty in aggregating or integrating levels of analysis; and difficulty in spatially linking these disciplines. These challenges have been described and analyzed in Chapter 2.

What is important here is that conceptually any attempt in search for an integrated unit should start with the identification of these obstacles. In this chapter an attempt is made to develop and operationalise a conceptual and methodological framework that removes these obstacles in search for defining and mapping an integrated unit of analysis. The chapter consists of three main sections. In the first section, the concept of an integrated unit is developed. Methods and procedures for operationalising this concept are described and presented in the second section. The third section identifies changes that might occur in farm types variability when imposing location parameters in the classification procedure with the purpose of facilitating mapping farm types.

5.2 Conceptualisation of the integrated unit

The conceptual approach presented here starts from the disciplinary units. Then concepts and definitions for integrating these disciplinary units into an integrated unit are developed. It uses the logic of the so called bottom-up approach of system development (Van Dyne and Abramsky, 1975). This has the advantage of visualizing and having a feel for the disciplinary units being integrated. However, this advantage may be offset by the difficulties in integrating these disciplinary units.

5.2.1 Disciplinary components and units

Because land use problems generally have two major dimensions: socio-economic and bio-physical, the integrated unit should comprise socio-economic and bio-physical components which can be called disciplinary components. Building up the integrated unit from its bio-physical and socio-economic disciplinary components requires defining a unit of analysis for each. From a socio-economic point of view the guiding principle for land use decision-making are linked to the aspiration of the farm-household. Hence, the farm has been proposed as a meeting point or level between bio-physical and socio-economic disciplines (Hengsdijk and Kruseman, 1993; Alfaro et al., 1994; Stomph et al., 1994; Stoorvogel et al., 1995). Therefore, the farm type has been selected as the unit of analysis for the socio-economic disciplinary component. Following the Framework for Land Evaluation (FAO, 1976), land use from a bio-physical point of view is described in terms of and linked to land units that can be used to discriminate between alternative land use types. Having identified the disciplinary components and units, the next step is to develop the concept that links these units into an integrated unit.

5.2.2 The concept of "farm type land unit"

A land unit (LU) is an area of land demarcated on a map and possessing specified land characteristics and/or qualities (FAO, 1976; Fresco et al., 1992). These land characteristics and qualities are described in bio-physical terms. Similarly, Zonneveld (1997) defines a land unit as a tract of land that is bio-physically relatively homogenous at the scale level concerned. Common in all these definitions is that land units are described in terms of only specified bio-physical characteristics. Purely socio-economic characteristics are not included in the concept of land. The role of actors is reserved for land itself: the land performs, the land qualities act (Van Diepen et al., 1991). This creates the difficulty of using the socio-economic specifications in an operational way in land use systems evaluation. In other words, land use types require socio-economic characteristics, that their supply is not known in respective land units. Obviously, land has very strong socio-economic components, that are not dealt with in the land unit concept. This land unit can therefore be called a boi-physical land unit.

Following the argument of Kruseman et al. (1993), the concept of land in a socio-economic sense is linked to the farm. Therefore, the (bio-physical) land unit needs to be adapted to include farm types (FTs). For this purpose the concept of "farm type land unit (FTLU)" or alternatively "integrated unit (IU)" has been introduced. The concept developed here is based on the fact that land unit may not be homogenous in socio-economic terms, i.e. at the farm level, one particular land unit is normally shared by two or more farm types. Similarly, one particular farm type may be found in more than one land unit. Hence, the use of land unit as a unit of analysis may result in bio-physically, but not necessarily socio-economically homogenous units. On the other hand, the use of farm types as a unit of analysis may result in socio-economically but not bio-physically homogenous units.

Therefore, a more integrated unit is desirable. This integrated unit can exist at a lower aggregation level than land unit and farm type. Therefore, land units need to be disaggregated by farm type or the reverse. For this purpose, the concept of "farm type land unit (FTLU)" is introduced. A FTLU is considered to be a farm type's share in a particular land unit or, alternatively, a land unit share of a particular farm type. To illustrate the concept of FTLU, consider a region with two land units: LU1 and LU2 and two farm types: FT1 and FT2 as depicted in Figure 5.1.

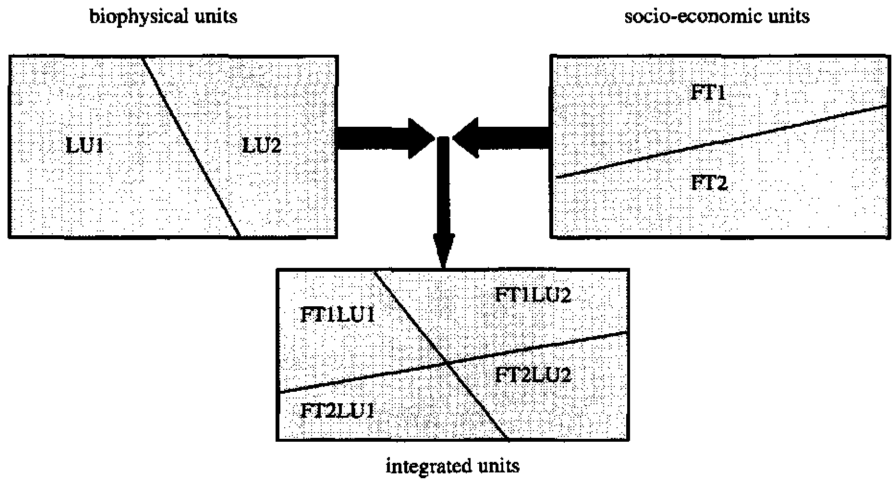


Figure 5.1 Schematic presentation of the concept of "Farm Type Land Unit (FTLU)"

Each LU is homogenous in terms of specific bio-physical characteristics, but shared by two different farm types. Likewise, each FT is homogenous in terms of predefined socio-economic conditions but, comprises two different land units. Combination of land units and farm types can result in four units. Each possible combination between a LU and a FT is distinguished as a separate unit. Such a combination is referred to, here, as a "farm type land unit (FTLU)". Each FTLU is homogenous in terms of both socio-economic and bio-physical characteristics. FTLUs exist at an aggregation level lower than both land units and farm types. FTLUs, therefore, can be aggregated to yield both farm types or land units. A particular land unit, therefore, equals the sum of its area in the respective farm types e.g., LU1=FT1LU1+FT2LU1. A specific farm type equals the sum over the respective land units e.g., FT2=FT2LU1+FT2LU2.

5.2.3 How to map farm types?

The discussion so far covers only small part of the mapping of farm types. The concept of FTLU implicitly assumes that both farm types and land units can be mapped. While land units can easily be georeferenced and presented on a map, information on farm types does generally not include those characteristics. Without georeferencing of farm types it is quite difficult or even impossible to link farm types and land units. In the literature, two terms that are applied to mean mapping: *zoning and regionalisation*. In farming system development (FAO, 1990) the term zoning is used to indicate partitioning of an area in units (or zones), based on selected farming system characteristics or variables.

In geography, the term regionalisation is used. Johnston (1976) distinguishes between regional types and regions. The difference is that the regional type comprises places that are similar with respect to certain predetermined characteristics, a region must comprise a spatially conterminous unit. In this study the term mapping is used to mean geo-referencing and the spatial or geographical representation of farm types. The end products of a mapping are called farm type units. One farm type can contain, or can be part of, more than one farm type unit. No matter what term may be used for the end products of mapping farm types, there will always be the important question of how to map.

In the farming system development approach of FAO (1990), delineation or mapping of farming system zones has been identified as one of the practical limitations in farming system zoning. LEFSA (Fresco et al, 1992) recognizes the difficulty of mapping farming systems but does not provide any procedure to solve it. LEFSA recommends further research to solve or reduce this problem and indicates some promising methods in this respect. In geography two basic approaches have been suggested to create contiguous regions (Johnston, 1976). The first suggests that a classification procedure should be developed, and that following the identification of groups, tests should be performed to see whether they also form contiguous regions or units. The alternative approach introduces a contiguity constraint in the grouping procedure. Criteria for selection of an approach to use include the end-products the researcher desires, and the by-products it will produce.

The approach, used for the mapping of farm types in this study, borrows from both approaches. Firstly, geographical location parameters (X and Y coordinates) are included as contiguity constraints in the classification procedure; secondly, when farm types have been identified, tests are performed to examine whether they indeed form contiguous units. In addition, results of the selected classification strategy using this approach are compared to the results of the same strategy without imposing geographical location parameters in the classification procedure (Section 5.4).

5.3 Operationalisation of the concept

The conceptual approach presented here, has been operationalised in a three-step procedure. In step 1, a procedure for farm classification and mapping has been developed and implemented. Subsequently, land units have been delineated (step 2). Step 3 then integrates the mapped farm types, and delineated land units in farm type land units (FTLUs).

5.3.1 Farm classification and mapping

To facilitate mapping farm types, a (partial) link has been established between the geographical information system (GIS) and classification models. This link is based on the general framework for the GIS-model link suggested by Stoorvogel (1995). GIS supplies input data for the classification models and accepts modeling results for further processing, analysis and presentation. Mapping of farm types comprises a five-step procedure presented below.

Step 1: Organization and storage of farm systems information in a GIS database and creation of a base map. In this step, the available farm systems information has been organized and stored in a GIS database using the ARC/INFO software package. In this database, each entity or feature (village in this case) is characterized by spatial data and thematic attributes, that are linked by a unique identifier (village code). Spatial data comprise location information, describing X and Y coordinates (longitude and latitude) of each village. Thematic attributes include the socio-economic characteristics of farm systems. The result of this step is a base coverage (map) containing point geographical features (villages) together with attribute data (socio-economic characteristics).

Step 2: Exporting data from GIS and performing mathematical and statistical operations. In this step, the identifier (village code) and its corresponding socio-economic and location attributes are organized in a table and exported from GIS to the data manipulation and analysis (DMA) model. Based on the procedures developed for the selection and screening of variables used in farm classification (Chapter 4), a number of mathematical and statistical operations are performed in DMA in such a way that attributes exported from the GIS database are converted in specific input parameters required for farm classification. The result of this step is the set of parameters selected for farm classification.

step 3: Development and implementation of farm classification methodology. In this step, a farm classification methodology has been developed as outlined and described in Chapter 4. Based on this methodology, classification model runs have been carried out using ten alternative classification strategies. During the classification runs the identifiers to the original GIS database file are preserved, to link the classification results to the base map in GIS. Cluster memberships at specified cluster level of the alternative classifications have been saved as new variables in the active SPSS file. In other words, for each village, a value indicating the cluster to which the village belongs in a given solution, is stored in a specified variable name. For example, a new variable CSCL indicates the cluster to which each village belongs when four clusters are produced using the classification strategy that combines a proximity measure cosine (CS) and a clustering method complete linkage (CL). These new variables are used in subsequent analyses for validating alternative classifications, and for testing the significance and contiguity of farm types produced by these classifications. Based on these analyses the alternative classifications have been compared, tested, and ranked.

Step 4 : Linking classification results back to GIS for further analysis. In this step, cluster memberships that have been stored as new variables in the active SPSS file, are saved as an SPSS output file which in turn is converted to text file format. The text file is loaded directly into Arc View GIS as a table. Then the tabular data are added to the base map by joining it to the attribute table of its theme. The definition of the joint is saved by saving the project containing the joint procedure. The joining is based on a common field "the identifier: village code" that is part of both tables. By joining, all the fields from the tabular data are appended to the attributes of the base map. In this way, Arc View GIS is used to visualize results of the alternative classifications to check whether they form contiguous farm units. Based on this visual analysis, combined with the result of the statistical testing and ranking performed in step 3, one classification strategy, that is CSCL, has been selected.

Step 5: Mapping of farm types. This step consists of mapping the farm types produced by the selected classification strategy CSCL. In this step new polygon features are created by merging point features (villages) that have the same value for cluster membership and that clustered in spatially contiguous units into one polygon using Arc Edit. Merging has been performed on screen using a mouse. The base map, which includes cluster memberships as new attributes, is used as a background coverage and the farm types are displayed in different colors to show their boundaries. Arcs have been drawn to approximate these boundaries. A new map is created by merging villages clustered in the same farm type and forming a spatially contiguous unit in one polygon (Figure 5.2). Following this procedure, it is necessary to reclassify some villages that fall inside a specific farm unit, but belong to a different farm type. Reclassification of these villages was performed by changing their cluster membership in the SPSS file created in step 3. Then statistical testing is carried out again to assure the significance of these clusters.

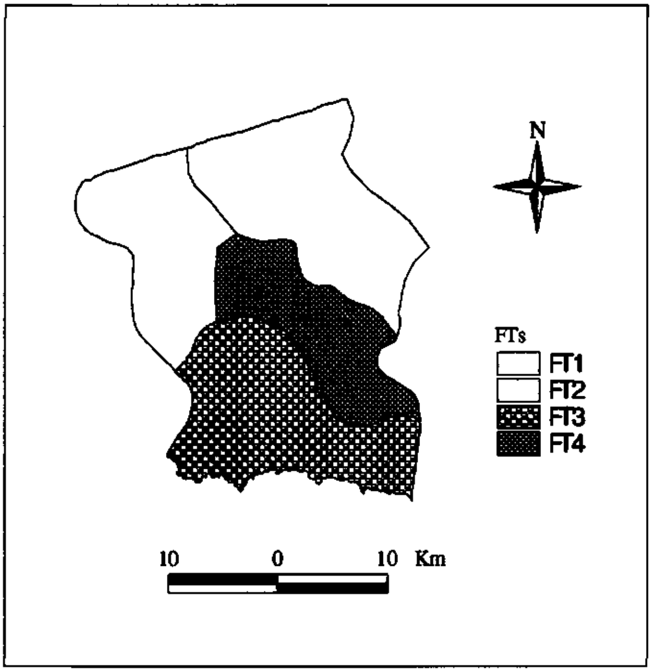


Figure 5.2. Mapping farm types (FTs)

5.3.2 Delineation of land units (LUs)

For delineation of land units, the intention is to make use of existing information from previous studies carried out in the sub-region. Land units are defined, in this study, as a combination of agro-climatic zones and soil series. The procedure for mapping land units consists of three steps. In the first step agro-climatic zones (ACZs) are delineated; then soil series (SSs) are mapped in the second step; and finally, in the third step, land units are identified by overlying the two coverages.

Recent activities to inventorize and analyze the climatic resource in the region are carried out jointly by the Ministry of Agriculture of the Islamic Republic of Iran and FAO using the FAO-Agro-Climatic Zoning methodology and procedures. These activities are documented in Taazimi (1995). The purpose of these climatic resource inventories is to provide the necessary information for analysis of production potential of agricultural crops in the region. On the basis of these technical reports, three climatic zones have been distinguished in the study area. The soils of the region have been studied in many surveys, that are documented in various reports. By collating and correlating several of these surveys, King (1995) developed a classification of soil series of the region. On the basis of this report, the soils of the study area are classified into five series. Two coverages, comprising the geographical distribution of soil series (SSs) and the agro-climatic zones (ACZs), are stored in GIS together with attribute data. A map overlay is carried out using ARC/INFO software, which results in a map with new units (Figure 5.3). These units, containing similar soils and climates, are referred to as land units (LUs). Each LU is a unique combination of a soil series (SS) and an agro-climatic zone (ACZ). These LUs form the bio-physical component of the integrated unit.

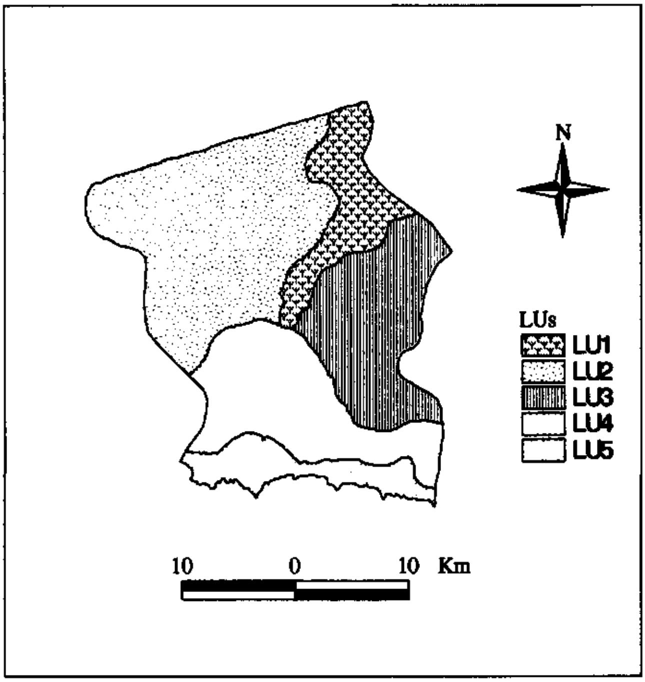


Figure 5.3 Delineation of land units (LUs)

5.3.3 Identification of the integrated units

Having mapped farm types (FTs) and identified land units (LUs), the next step is to integrate these two disciplinary units. Integration has been performed through spatial linking of FTs and LUs. The link has been established in a GIS environment through a map overlay procedure. Two maps, a map of farm types and land units map are combined in an overlay procedure to establish the location of farm types in the various land units. Each unique combination of FT and LU is referred to as a farm type land unit (FTLU) or alternatively integrated unit (Figure 5.4). Nine FTLUs are identified, each one is homogenous in terms of both socio-economic and bio-physical characteristics. This integrated unit forms the basis for definition, description and analysis of land use systems.

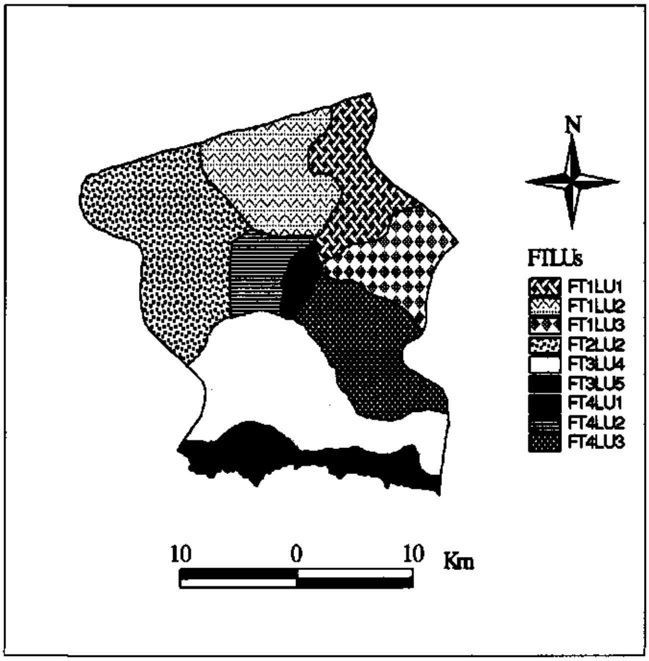


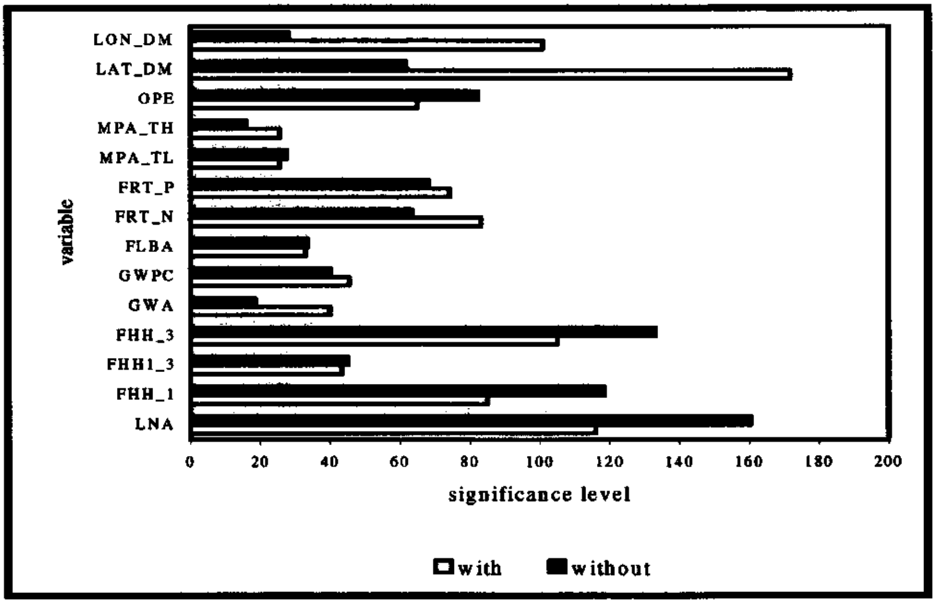
Figure 5.4 Identification of integrated units (IUs).

5.4 Grouping vs. mapping

As defined already, classification is the grouping of similar objects. For land use planning, however, the problem of farm classification is two-fold: grouping and mapping. Therefore, a special approach is needed for the identification of farm types that are both "distinct" and "contiguous". The term "distinct" implies that the resultant farm types should be statistically significantly different. "Contiguous" indicates that these farm types must form spatially conterminous units. To illustrate conflicts that may arise between these two requirements, two classification approaches are applied. The first introduces location parameters as a contiguity constraint to the classification procedure, while the second adopts a classification procedure without this constraint.

Results of the two approaches: "with" and "without" are compared to indicate gains or losses that might incurred when imposing a contiguity constraint in the classification procedure. The comparison has been made in terms of the agreement between the two classification approaches; and in terms of changes in the level of statistical significance of their farm types. The agreement is tested using Rand index, while Kruskal-Wallis H statistics are used to examine the change in the statistical significance of farm types.

The comparison indicates good agreement between the results of the two approaches. The probability, expressed in the Rand index, that two cases are treated alike in both approaches is as high as 0.7. Introduction of the location parameters in the classification procedure has resulted in an increase in the statistical significance in terms of some variables and a decrease of others (Figure 5.5). Although imposing a contiguity constraint in the classification procedure, results in some changes in the level of statistical significance, the statistical difference among farm types in terms of all variables is still significant.



Notes: Variable: see Table 4.2. With, location parameters included in the classification procedure; Without, without imposing location parameters in the classification procedure.

Figure 5.5 Change in the significance level of farm types in terms of selected variables.

Chapter 6

An Integrated Approach to Definition, Description and Quantification of Land Use Systems

6.1 Introduction

Analysis and planning of land use requires defining, describing and quantifying land use systems. There is no agreement on how land use systems should be defined (Beek, 1978) and the methods for describing and quantifying land use systems are subjects of continuing discussion (FAO, 1983; Stomph et al, 1994; Jansen and Schipper, 1995). However, for effective land use planning and policy analysis, it is recommended to consider land use systems as integral systems that includes both bio-physical and socio-economic elements (Stomph et al., 1994); to describe them in terms of chronological order of their operation sequences (Stomph et al., 1994; Jansen and Schipper, 1995; Schipper, 1996), and to quantify their input and output coefficients (Driessen and Konijn, 1992; Van Diepen et al., 1991; Van Duivenbooden et al., 1991; Stomph and Fresco, 1993; Stomph et al., 1994; De Koning et al., 1995; Jansen and Schipper, 1995; Schipper, 1996).

To deal with this complexity, an integrated approach to define, describe and quantify land use systems is presented in this chapter. It contains three main sections. In the first section, on the basis of a review of the concept land use system, and identification of the limitations of previous contributions in defining this concept, an alternative concept called "integral land use system" is introduced. This concept forms the basis for describing land use systems in section two. Finally, an approach for quantifying input and output coefficients for land use systems is proposed in section three.

6.2 Definition of land use systems

6.2.1 The concept of land use system (LUS): theory and practice

As such, the term land use system (LUS) can be used for any description of land use on land unit level. The Framework for Land Evaluation (FAO, 1976) defines the land use system (LUS) as a combination of a land unit (LU) and a land use type. A land unit can be defined as a mapped area of land that is homogenous in terms of specified bio-physical characteristics and/or qualities

(FAO, 1976; Fresco et al., 1992; Zonneveld, 1997). Land use can be defined at different levels of detail. The Framework recognizes two levels of detail at which land use can be defined (FAO, 1976). It uses the term "major kinds of land use" for a major subdivision of rural land use, such as rainfed agriculture, irrigated agriculture, etc., whereas the term "land utilization type" is used to refer to any type of land use defined in a degree of detail greater than that of a major kind of land use. There is no agreement whether land use types should be defined in broad terms or in narrow terms. The first may be too broad for proper analysis, while the latter easily leads to too many land use types for analysis, especially, if different levels of technology are distinguished (Schipper, 1996).

Aware of the need for precisely defined kinds of land use in land use system analysis, Beek (1972) introduced the concept 'land utilization type' which was adopted in the Framework for Land Evaluation (FAO, 1976). A land utilization type (LUT) is a specific way of using the land, actual or alternative, described in the following terms or key attributes: produce (e.g. kind of crop), labour, capital, management, technology, and scale of operations. All published FAO documents on land evaluation (FAO, 1976; 1983; 1984; 1985; 1987) agree that land utilization types should be described according to "key attributes" and "requirements". The Framework defines requirements of the land use as the set of bio-physical conditions that is related to the efficient functioning of a land use type. These requirements are grouped in three sets: crop or ecological requirements; management requirements and conservation requirements.

Fresco et al. (1992) define a land use type differently as "a specific kind of land use under stipulated bio-physical and socio-economic conditions (current or future), seen as a sub-system of a farm". In this way they proposed to describe land use type, as part of land use systems, according to its setting, technical specifications and requirements. The setting refers to some general socio-economic, technological, and agro-ecological descriptors, while technical specifications refer to more detailed agronomic and socio-economic descriptors. For practical reasons, Schipper (1996) proposes to describe land use types by cultivation practices, operations and input quantities, thus restricted to agronomic descriptors. In combination with price, these descriptors allow calculation of economic descriptors. But the economics of land in these terms are reduced to a few concepts of prices and costs.

Land use systems are defined differently in various studies, depending largely on their purpose. With the aim of exploring possible agricultural developments in the European Community, De Koning et al. (1992) define land use systems completely on a bio-physical basis neglecting farm specific characteristics and individual decisions of farmers. Land use systems are defined on the basis of the assumption that the best available production techniques, "the best technical means", are being used. This implies that both the available knowledge and the available means of production are optimally applied, which precludes any waste or inefficient use of resources. Land use systems are defined as a combination of what it is called a land evaluation unit (LEU), i.e. a unit comprising a unique combination of soil unit, climatic zone and administrative region, and a land use type described in terms of specific production technology, i.e. a unique combination of production level (e.g., potential and water limited) and production orientation (e.g., yield oriented or environment oriented).

Some authors as Beek (1978), FAO (1976), FAO (1983), Driessen and Konijn (1992) and Van Lanen (1991) define land use systems in a general way: a certain crop or variety with a set of management attributes combined with a land unit defined in terms of soil type. To distinguish different production methods or techniques within a land use system, in some studies such as those of Van Duivenbooden et al. (1991), Jansen and Schipper (1995) and Schipper (1996) different levels of technology are assumed. For exploring development possibilities in the fifth region of Mali, Van Duivenbooden et al. (1991) define land use systems as a combination of a soil type and a production technique (land use type at particular technology). Various production techniques (current, alternative and potential) are differentiated on the basis of: fallow periods, oxen traction, application of farmyard manure, and application of chemical fertilizer. Jansen and Schipper (1995) and Schipper (1996) take one further step and introduce the concept of 'Land Use System at a defined Technology' (LUST) for a specific form of describing land use system, that includes specification and quantification of the technology applied.

6.2.2 The missing links

Common in the definitions illustrated in the preceding sub-section is that land units are defined only with specified bio-physical characteristics. Purely socio-economic characteristics are not included in the concept of land. The role of actor is reserved for land itself: the land performs, the land qualities act (Van Diepen et al., 1991). This creates necessity of introducing the socio-economic specifications, when included in the description of land use types, in an operational way in land use planning and policy analysis. In other words, land use types demand socio-economic requirements that are not supplied from the respective land units. Obviously, land has a very strong socio-economic component that is not dealt with in the land unit concept. This land unit may therefore be called bio-physical land unit.

Although theoretically many definitions recognize that land use types are parts of farm systems, and therefore not independent, in practice they only assess the suitability of land units for specific land use types, without taking into account the farm as a unit of decision making. In a way they look at land use at (sub-)

regional level, omitting the farm level. Many land use system assessments, although still relevant, are therefore less applicable for land use planning and policy analysis, and certainly as a basis for implementing a proposed land use change (Polman et al., 1982; Fresco et al., 1992; Erenstein and Schipper, 1993). Although the concept of LUST can be considered a step forward in linking land use type and farm system, yet the interaction between socio-economics and bio-physics is loosely represented as the only link is an assumed level of technology, but socio-economic characteristics receive little or no attention. Moreover, as socio-economic conditions are defined at farm type level, and the bio-bio-physical conditions at land unit level, the use of farm types (which are socio-economically but not necessarily bio-physically homogenous units) as units for land use modeling may still result in serious aggregation errors.

6.2.3 The concept of integral land use system (ILUS)

To deal with the above mentioned omission parts in the definition of land use system, the concept of integral land use system (ILUS) is introduced (Figure 6.1). The concept of ILUS is based on the logical argument of Stomph et al. (1994) that land use systems, no matter at what level they are defined, are integral systems and their description should include both bio-physical and socio-economic characteristics. Only then can one compare what land can supply with what land use demands. Land can supply not only bio-physical characteristics, but also socio-economic conditions. Land use demands both bio-physical and socio-economic requirements.

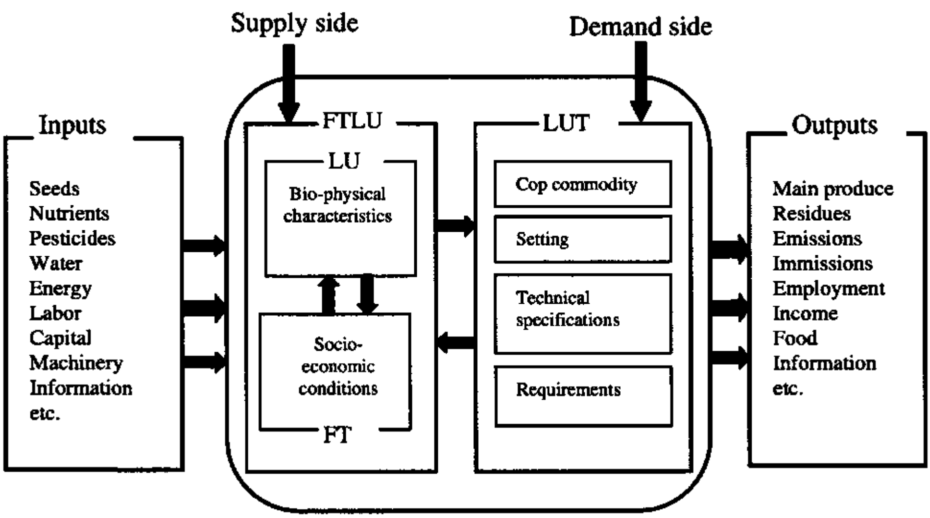


Figure 6.1 Simplified diagram of an integral land use system

In accordance with the definition of systems, inputs and outputs can be defined and the transformation processes from inputs to outputs in the system are identified and quantitatively described. The simplified diagram presented in Figure 6.1 illustrates some of the important components considered. ILUS itself is not a closed system but a sub-system of a larger system at a higher level of aggregation.

Efforts towards the quantitative description of the bio-physical aspects of land use systems have been sufficient and satisfactory (Stomph and Fresco, 1991; Stomph et al., 1994), but their description of socio-economic aspects is an issue that needs further investigation. In the present study a contribution is made towards the description of the socio-economic sub-system of the integral land use system. To deal with the socio-economic sub-system within the integrated framework, the approach starts from the farm: the decision making unit with respect to land use and from there describes the integral land use system. This is in line with the methodology proposed in the DLV framework (Hengsdijk and Kruseman, 1992) and in the frameworks developed by Kruseman et al. (1993) and Schipper (1996).

Following the argument of Kruseman et al. (1993), the concept of land in a socio-economic sense is linked to the farm. Therefore, the (bio-physical) land unit needs to be adapted to include the farm system. This has been conceptualized by introducing the concept of farm type land unit (Chapter 5), that links farm type and land unit into an integrated unit (Figure 6.1).

In general, land use types are part of farm systems and, therefore, are not mutually independent. In the present study land use types are described in relation to farm type land units. Any land use type can be practiced in various socio-economic and bio-physical settings, depending on the farm type land unit. Various (agronomic and socio-economic) technical specifications can be defined for a given land use type dictated by different bio-physical and socio-economic settings. Combining information on the settings and specifications with information on type of land use (e.g., crop commodity) allows description of land use types with both bio-physical requirements and socio-economic requirements. This description then form the basis for quantification of input and output coefficients of the ILUS.

6.3 Description of land use systems

The "integral land use system" (ILUS), the basis for the description of the land use systems, is a unique combination of a farm type land unit (FTLU), a land use type (LUT), and a production technique. Amol sub-region is classified into nine farm type land units (Chapter5) each one is unique in terms of bio-physical characteristics and socio-economic conditions. Various land use types can be practiced on these farm type land units, depending on the bio-physical and socio-economic settings. Land use systems identified in this study are crop systems. Three crops are considered: rice, wheat, and barley. Rice is grown under irrigated conditions, while wheat and barley are grown under non-irrigated conditions. For rice as the main crop in the sub-region, two major varieties are considered: the local variety Tarom, and the improved variety Amol 3.

Land use types as components of integral land use systems are described in terms of agronomic technical specifications and operation sequences (Stomph et al., 1994; Jansen and Schipper, 1995; Schipper 1996). Individual operations are never isolated events but form part of a series of measures planned by the farmer to adapt or modify the land use system (bio-physical sub-system) in such a way that the intended goals are more fully attained. This implies that operation sequences must be described as entities (Stomph et al., 1994).

Within the integral land use system, most operations have to be carried out in a given order or sequence, determined by the growth and development pattern of a particular crop. In this study this order has been maintained in describing land use types as part of land use systems in terms of the operations involved (Van Heemst et al., 1981; Van Heemst, 1986): land preparation, preparation of plant material, planting/seeding, fertilizer application, irrigation, weeding and thinning, biocide application, harvesting and threshing.

The degree of detail of the operation sequence varies depending on the scale of the land use system. For an analysis at sub-regional level as in this study, operation sequences are defined at the level of farm type land units. Operation sequences are characterized by the integral land use systems to which they refer and the quantitative description of their constituent operations. The following attributes, as proposed by Stomph et al. (1994), fully define any operation sequence: timing of operations; types and quantities of applied material inputs; types of implements; type and quantity of traction power source; and types of outputs exported from the system;

Operation sequences in this study have been identified on the basis of farm surveys, agricultural statistics and reports, agricultural census, expert knowledge and results of theoretical and empirical studies in similar or other regions. For each of the operations, various methods or techniques may be used depending on farm type land unit and crop commodity. Many alternative techniques exist to execute each field operation: they are distinguished by different types of traction, equipment and materials, different inputs of labour and materials, and differences in timing of the operation. Generally, three major types of alternative techniques can be distinguished. The first criterion refers to the timing of the operation, the second to the amount of non-factor input per unit of area, e.g., amount of fertilizers per hectare, the third to factor substitution relations, such as might occur when choosing among different levels of mechanization.

It is not feasible to incorporate all possible combinations, and here the identification has focused on the description of techniques differentiated on the basis of the use of the major constraining production factors in the study area. To create more flexibility, several sub land use types have been defined for a given land use type distinguished by different production techniques. These techniques are incorporated in a linear programming model as different types of land use activities. Hence, the model provides ample scope to choose an appropriate technique (Hazell and Norton, 1986). Identification of the different production techniques is based on data from farm surveys, agricultural statistics and local expert knowledge.

The unique combination of farm type land unit (FTLU), land use type (LUT) and production technique constitutes an integral land use systems (ILUS). In theory, an infinite number of ILUSs could be created, on the basis of differences in farm type land units, land use types, and possible production techniques. In practice, however, limits are imposed on the number of ILUSs that can be handled by the users, among others due to restrictions in the tools for analysis of land use systems.

Often it does not suffice to describe only the land use systems currently practiced. Then, alternatives should be identified and described as well. Both *current* and *alternative* land use systems are taken into account in the analysis. Current land use systems represent the prevailing (in many cases agro-ecologically non-sustainable) land use systems, while alternative land use systems are defined in such way that they are technically feasible and aimed at maintaining the natural resource base and protecting the environment.

6.4 Quantification of input and output coefficients

6.4.1 General procedure

Land use systems are described in terms of operation sequences (Stomph *et al.*, 1994; Jansen and Schipper; 1995, Schipper 1996). Combining information contained in operation sequences with information on integral land use systems allows description of land use systems in terms of these operation sequences. Such a description then serves as a basis for the calculation of the required input-output coefficients. This has the advantage, that land use systems do not have to be described again for each change in the calculation of the coefficients. Each unique operation sequence within an ILUS can be interpreted as a specific (land use) activity. Each activity is defined and described quantitatively in terms of input and output coefficients which quantify the relation between inputs of production and the outputs, desired as well as undesired.

The basis for the determination of input and output coefficients of *current* land use systems is the information derived from the detailed farm survey. The farm survey contains a total of 112 attributes for each of 676 farms. The available farm survey information has been organized and stored in a database. In this database, each farm is characterized by various attributes, that are linked by a unique identifier, the farm code. For each farm, an attribute indicating the village to which the farm belongs is preserved to link the farm survey information to the GIS database that contains information on farm type land units, created in the process of mapping farm type land units (Chapter 5).

The farm survey information, converted to a text file format, have been loaded directly into Arc View GIS as a table. These tabular data has been added to the GIS database, by joining it to the attribute table of the GIS database theme. The definition of the joint is saved by saving the project containing the joint procedure. The joint is based on a common field "the identifier village code" included in both tables. By joining, all the fields from the tabular data are appended to the attributes of the GIS database. This enables to locate sampled farms in various farm type land units. Subsequently, for each farm type land unit, input and output coefficients can be calculated as described below.

Before using actual data derived from the farm survey, some statistical analyses and tests have been applied to indicate correlation, variability and normality in the data. Correlation analysis reveals that crop yields are relatively highly positively correlated with inputs levels of labour, fertilizers and pesticides, while very small correlation exists between yield and other inputs. Variability in crop yield (per crop commodity) between and within farm type land units has been tested using analysis of variance. The results show that the within-unit variations are relatively small compared to between-unit variations. Checks for the normality of the frequency distribution of crop yield per farm type land unit using skewness and kurtosis indices show that these distribution can be regarded as normal.

These tests imply the following, provided that crop yield variation within farm type land unit is low and the distribution is normal: 95.45% of the farms located in each farm type land unit produce between 2 standard deviations below and above the average, i.e. between the values $\mu - 2\sigma$ and $\mu + 2\sigma$. To represent this ranges, three levels are identified: low, i.e. $\mu - 2\sigma$, medium, i.e. μ, and high, i.e. $\mu + 2\sigma$. These values are useful as indicators of the scatter of actual yields about the average, but they only provide information for whole numbers of standard deviations. On the basis of actual yield figures for each crop per farm type land unit, sampled farms are allocated to one of three classes: low, medium, or high yield, using discriminant analysis.

Descriptive statistics were used to calculate average yield in each class per crop commodity and farm type land unit. Input levels corresponding to these yield levels were calculated on the basis of an assumed operation sequence and specified production technique. Three types of techniques have been distinguished. Those related to timing of operations, those related to the level of a variable input use per hectare, and those related to the combination of factors used (e.g., labour and machine) in producing a unit of a given crop (Hazell and Norton, 1986). The first type of techniques have been incorporated by including different timings of operations associated with different crop commodities, different climatic conditions and various farm types. The second type of techniques has been included by specifying different levels of input/output combinations for a given crop, cultivated on a given farm type land unit. The third type of techniques is incorporated through alternative mechanization options at identical yield levels.

To specify sufficiently wide range of land use systems, it may be necessary to look beyond those actually observed for a given farm type land unit. Therefore, alternative production techniques are specified and described. Those represent technically feasible production techniques that are not yet widely practiced by farmers in the region, and that aim at maintaining the resource base and protecting the environment. For quantification of alternative land use systems, a so-called target oriented approach is applied, in which the combination of inputs to realize a specific level of outputs is estimated based on knowledge of the underlying bio-physical processes. Hence, yield levels form the starting points in calculating land use system coefficients, i.e. derive yield level first and subsequently determine the input combination required to achieve this yield. Actual yield levels are used as target yield levels for the alternative land use systems. Quantification of input requirements is based on actual figures obtained from the farm survey, recommendations from extension services, expert knowledge, and the underlying bio-physical processes affecting the agro-ecological sustainability of the systems.

The approach described, specifies land use systems as discrete points in a continuous space of input-output relations. In the short or medium run, a continuous production function may not be a very accurate representation of reality at the micro level. Discrete choices represented by alternative sets of input-output vectors (or their linear combinations) usually are more realistic. In this case the continuous production function is an approximation to the reality of discrete functions, and not vice-versa (Hazell and Norton, 1986). Developing production function in discrete form is called process analysis or activity analysis.

The unit for the calculation of the input and output coefficients of an ILUS activity is one hectare [ha]. All inputs and outputs are expressed as physical quantities or monetary values or time or power per hectare. This analysis provides quantitative information for each of the considered combinations of land use system and operation sequences on material, water and labour input requirements and their distribution over the year; time and power needed in terms of implements and traction sources other than human; costs of operation sequences in terms of material, water and labour inputs and machinery services and their distribution over the year; amounts and prices of harvested products; and amounts of other outputs exported from the system.

6.4.2 Crop yields

Crop yields comprise main products (grains) and by-products (crop residues). Estimation of crop yield of various land use systems is based on the actual production figures in the region. Three yield levels (low, medium, and high) for each crop on each farm type land unit are identified on the basis of the procedure outlined in Sub-section 6.4.1. Total above-ground biomass yields corresponding to these three levels are derived on the basis of harvest indices for the various crops obtained from the literature (FAO, 1978; Doorenbos and Kassam., 1979; Van Duivenbooden, 1995; Perry and Taazimi, 1995). Crop residues are calculated by subtracting crop yield from total above-ground biomass. Fresh marketable yields are converted in dry matter yield by assuming fixed dry matter contents for the relevant plant parts available from the literature (EUROCONSULT, 1989; Purseglove, 1987; Landon, 1991; De Koning, 1992).

6.4.3 Labour input

Description of the land use systems requires fairly detailed knowledge of their labour requirements. Following Van Heemst et al. (1981) and De Koning et al. (1992), labour requirements are defined in terms of "task-times", that is the time required to carry out an operation under standard conditions by a skilled male adult working at normal pace and with maximum efficiency. In this study, only task times for operations have been taken into account. For each particular operation the task (i.e. operation) time is expressed in man-days per hectare. This is not as straightforward as it may seem, since some "standard man-day" has to be defined. A man-day (mnd) is defined as the amount of work accomplished by a male adult during one working day (Van Duivenbooden et al., 1991).

The labour demand is defined in terms of a crop calendar to obtain insight in the fluctuating labour demand of a particular land use system in the course of time (Van Heemst et al., 1981; Van Duivenbooden et al., 1991). The timing of operations is crucial. If labour requirements are specified only in terms of annual labour demand, it may appear that there is a substantial labour surplus, when in fact seasonal shortages of labour may make targeted production levels infeasible (Hazell and Norton, 1986). Harvesting, for example, may place heavy demand on available labour within a very limited time-period and may thus be a constraining factor for expansion of the cultivated area or intensification of the land use system. In such periods, labour supply may become a constraint in land use activities. To account for the occurrence of periods with peak labour demands, labour requirements have been specified on a monthly basis. Labour requirements for both current and alternative land use systems have been quantified per operation, on the basis of the information derived from the farm survey.

6.4.4 Nutrient inputs and outputs

Quantification of nutrient input and output coefficients for current land use systems is based on current practices in the region as derived from the farm survey data, whereas nutrient coefficients for alternative land use systems are based on an assumed equilibrium situation (i.e. nutrient inputs fully compensating nutrient export in crop products) for the nutrient balances of the macro elements. The procedure for calculating these coefficients is based on methodologies described in Driessen and Konijn (1992), Van Duivenbooden et al. (1991), Van Duivenbooden (1995), De Koning et al. (1992), Smaling (1993) and Bessembinder (1997). Inputs of nutrients are in the form of chemical fertilizer, and in atmospheric deposition. The roots of all crops are supposed to be in equilibrium and are therefore not included in the calculations (De Koning et al., 1995). Outputs of nutrients are losses and removal in crop products.

In this study, inputs and outputs of potassium have been neglected under the assumption that for this element an equilibrium situation exists in the region (Taazimi, 1995). As no quantitative information is available on the availability of nutrient elements from natural sources in various soil types in the region, calculations proceed from target yield towards fertilizer requirements. The methodology used for calculation of nutrient inputs and outputs per land use system is presented in the following steps:

Step 1: Calculation of nutrient uptake. Nutrient uptake is calculated on the basis of the dry weight of both target yield (crop products) and crop residues (by-products), and their nutrient concentrations:

$$Nu = (Wp * CNp) + (Wr * CNr)$$

In which Nu is nutrient uptake [kg ha^{-1}]; Wp is dry weight at harvest of crop product [kg ha^{-1}]; CNp is nutrient concentration in the dry matter of crop product [kg kg^{-1}]; Wr is dry weight at harvest of crop residues (excluding roots) [kg ha^{-1}]; and CNr is the nutrient concentration in the dry matter of crop residues [kg kg^{-1}]. The data required to calculate nutrient uptake are, therefore, dry weight and nutrient concentrations of crop products and crop residues. Dry weights of crop products and crop residues are calculated as shown in Sub-section 6.4.2. Data on nutrient concentrations are widely available, and will be dealt with in the following.

Pot trials and field experiments have shown that plants can not grow normally if they can not maintain specific minimum concentrations[5] of nutrients in crop product and crop residue (Driessen and Konijn, 1992). Different crops have different concentrations. Literature provides many data on indicative values of nutrient concentrations in various crops (see for example, Van Keulen, 1986, Nijhof, 1987, Stoorvogel and Smaling, 1990a, Van Duivenbooden et al., 1991, De Koning et al., 1992 and Van Duivenbooden, 1995). Comprehensive listings are available from Nijhof (1987) and Stoorvogel and Smaling (1990a) who extensively reviewed the literature. Based on these reviews, nutrient concentrations have been derived and used for calculating nutrient uptake for the various land use systems.

Step 2: Calculation of the required nutrient input into the system. Total required nutrient input into the system is calculated on the basis of the apparent nutrient recovery fraction of the applied nutrient element:

$$Ni = Nu/ANR$$

in which Ni is the required nutrient input into the system [kg ha^{-1}]; Nu is the nutrient uptake [kg ha^{-1}]; and ANR is the apparent nutrient recovery fraction [%]. The recovery of a nutrient by a crop can be determined experimentally by comparing uptake in fertilized plots with uptake in unfertilized control plots. Thus, nutrient recovery can be defined mathematically as:

$$ANR = (Nf - Nn) / ARf$$

in which ANR is the nutrient recovery fraction [%]; Nf is nutrient uptake from fertilized plot [kg ha^{-1}]; Nn is nutrient uptake from unfertilized plot [kg ha^{-1}]; and ARf is application rate of nutrient fertilizer to fertilized plot [kg ha^{-1}]. Theoretically, ANR ranges in value from close to 0 to close to 1.0; it expresses the efficiency with which a certain fertilizer is taken up. In practice, it is often

[5] Note that a crop can take up more than the minimum but this would not result in more production or yield ('luxury consumption'). It could possibly improve the quality of product (Driessen and Konijn, 1992).

difficult to attain a higher recoveries than 0.8 kg kg^{-1}. The actual nutrient recovery depends on the competitive position of the plant relative to processes in the soil-plant-atmosphere system that contribute to losses of nutrients from the system (Van Keulen and Van Heemst, 1982; Driessen, 1986; De Wit, 1991; Van Duivenbooden et al., 1991; De Koning et al., 1992; Van Duivenbooden, 1995).

Nutrient recovery, first of all, is crop-specific, because rooting systems differ in their efficiency of nutrient uptake. In sandy soils, leaching may be considerable, hence recoveries are lower than in heavier soils. At very high soil moisture contents ANR tends to be lower than in drier soil, as losses due to leaching and dentrification (for nitrogen) are higher. Although qualitatively the main processes and factors influencing the efficiency of fertilizer uptake are well understood, reliable quantification of the magnitude of these processes is still difficult. This difficulty is expected since the relevant processes are very complex, and the required input data are generally not available (Van Keulen and Van Heemst, 1982). In situations where such information is lacking, an alternative procedure should be used.

Analysis of crop response to the supply of macro elements (Van Keulen and Van Heemst, 1982), shows a wide variation in responses among sites and seasons resulting from varying relations between fertilizer application and nutrient uptake. It is shown that for nitrogen, recovery fractions vary, irrespective of the application rate, from 0.10 under unfavorable conditions to 0.80 in very favorable circumstances. For phosphorus, recovery fractions are generally low, seldom exceeding 0.30. Similar results are obtained by Van Duivenbooden (1995) who evaluates, among other relations, that between fertilizer application and nutrient uptake in five major cereals, i.e. millet, sorghum, maize, rice and wheat. The average recovery of nitrogen for each of the five crops appears to be close to 0.38, but with a high standard deviation of about 0.19. The recovery of phosphorus is much lower than that of nitrogen, with an average value of 0.14.

For the fifth region of Mali (Van Duivenbooden et al., 1991), the recovery fraction is determined on the basis of an assumed distribution of the applied nutrients among the various processes influencing nutrient dynamics. For each combination of soil type and nutrient element that distribution has been assessed separately, with nitrogen recoveries ranging between 0.20 and 0.50 and phosphorus recoveries ranging between 0.15 and 0.30. A similar approach is followed by De Koning et al. (1992) in establishing nitrogen recoveries for various cropping systems in the European Community. For each crop, a range of nitrogen recovery values is defined as a function of precipitation deficit and soil texture, based on expert knowledge. Depending on soil type and climate, the average nitrogen recoveries for various crops under favorable conditions are set at ranges between 0.50 and 0.85.

Based on literature data and following the approach of Van Duivenbooden et al., 1991 and De Koning et al. (1992), nutrient recoveries have been established in this study. For each crop, a range of nutrient recoveries is defined on the basis of the combination of soil texture and rainfall. Although in reality nutrient recoveries not only depend on plant properties and bio-physical conditions, but also on management practices (Van Keulen and Van Heemst, 1982; Driessen, 1986; Van Duivenbooden, 1995), but ranges have not been adjusted to indicate management differences in farm type land units, because information on nutrient management on these units is lacking.

Step 3: Determination of nutrient availability from atmospheric deposition (AD). In addition to nutrients originating from mineralisation during decomposition of old soil organic matter, nutrients from other natural sources are available. Considerable amounts of nutrients can be supplied to the soil by wet and dry deposition. Data on measurement of wet and atmospheric deposition are scarce. Approximate ranges mentioned in Stoorvogel and Smaling (1990a) are 0.5-16.3 kg N kg ha^{-1} yr^{-1}; and 0.2-5.3 kg P ha^{-1} yr^{-1} in Africa. Rates are high in industrialized countries. In the European Community, De Koning et al. (1992) assume an average annual atmospheric deposition of 30 kg ha^{-1}.

Regression equations, linking deposition to the square root of rainfall, derived by Stoorvogel and Smaling (1990b) from the study of sub-Saharan Africa, are used to calculate the atmospheric deposition in this study. Based on these equations, nutrient supply from atmospheric deposition is calculated as:

For nitrogen	$AD = 0.14 * R^2$
For phosphorus	$AD = 0.053 * R^2$

AD is the amount of atmospheric deposition [kg ha^{-1}]; and R is annual rainfall [mm yr^{-1}].

Step 4: Calculation of immobilization and residual effect. In the equilibrium situation, nutrient input not taken up by the crop (Nm) equals:

$$Nm = Ni * (1 - ANR)$$

Nm values calculated according to this equation are often substantially higher than measured values (Prins et al., 1988). This is due to losses during the growing season and/or temporary immobilization in the organic matter store. Part of these nutrients may become available for subsequent crops. The amount of nitrogen temporarily immobilized is calculated on the basis of the amount of nutrient not taken up by the crop and the relative nutrient fixation or immobilization rate:

$$IMM = FIX * Nm$$

in which IMM is the amount of nutrient immobilized in the soil and available for the next crop [kg ha^{-1}]; and FIX is the relative nutrient fixation or immobilization rate [%]. Based on data of De Koning et al. (1992), Van Duivenbooden et al. (1991) and Bessembinder (1997), the calculated Nm values have been multiplied by a relative fixation rate (FIX) to arrive at the quantity of nutrients subject to losses. The value of FIX is crop-specific and is about 0.3.

Phosphorus immobilization in soils is complex and difficult to predict. Therefore, rather than immobilization, a residual phosphorus effect is calculated. The quantitative relations of the processes involved are poorly understood, and it is difficult to use comprehensive models in practical situations. To calculate the residual effect of phosphorus in the years after application, a generally valid simple equation developed by Janssen and Wolf (1988) is used:

$$Rt = (0.8 - R1)^{t-1} * R1$$

Where Rt and R1 are the recovery fractions in year *t* and year 1, respectively. The residual effect of phosphorus is calculated on the basis of the amount of nutrient not taken up the crop and the fractional residual effect:

$$RE = FRE * Nm$$

in which RE is the amount of residual phosphorus [kg ha^{-1}]; and FRE is the fractional residual effect [%]

Step 5: Quantification of losses and irreversible. For nitrogen, the fraction of Nm that is not immobilized, is subject to losses. The amount of nitrogen that is lost is calculated as:

$$NL = FL * Nn, \text{ where: } Nn = (1\text{-}FIX) * Nm$$

in which NL is amount lost [kg ha^{-1}]; FL is fraction lost [%]; and Nn is amount of nutrient that is not immobilized [kg ha^{-1}]. The remainder of Nm (NR) that is not lost, is available for the uptake in subsequent year:

$$NR = (1 - FL) * Nn$$

The main processes responsible for losses of nitrogenous compounds from the soil system are dentrification, volatilization and leaching (Van Keulen and Van Heemst, 1982). These processes are still poorly understood and have inadequately been quantified, both theoretically and experimentally (De

Koning et al., 1992). Some preliminary, but still inconclusive, data are available in the literature. Therefore, losses have been calculated on the basis of a number of very general assumptions, and further research is necessary for a more accurate quantification of leaching and dentrification.

Van Duivenbooden et al. (1991) determined the amount of nutrients lost through leaching and dentrification on the basis of assumed fractions varying per soil type. These fractions range between 5 and 25% and 0 and 30% of the total fertilizer input, for leaching and dentrification, respectively. According to De Koning et al. (1992) between 42 and 100% of Nm is lost through leaching and dentrification, depending on precipitation surplus and soil type. Similarly, Smaling (1993) calculates these losses as a function of rainfall and soil texture. Leaching losses are estimated between 15 and 40% of total fertilizer input. Stoorvogel and Smaling (1990b) estimated nitrogen leaching by a multiple regression equation, including rainfall, soil fertility, total fertilizer input and total crop uptake. In this study, these reviews and procedures have served as the basis for estimating nitrogen losses. Therefore, the magnitude of nitrogen leaching and dentrification is estimated on the basis of generally accepted determinants of climate and soil. For each combination of rainfall and soil texture, a loss fraction is assumed.

For phosphorus, the amount of Nm that is not immobilized becomes available only over a long period of time (more than 15 years), or is fixed irreversibly by the soil (Janssen and Wolf, 1988). This amount is assumed to be unavailable to the crop (Bessembinder, 1997) and is calculated as:

$$UN = (1 - FRE) * Nm$$

in which UN is unavailable amount of phosphorus [kg ha^{-1}]

Step 6: Derivation of nutrient input and chemical fertilizers requirements. The required nutrient input for nitrogen and phosphorus is calculated as:

$$\text{For nitrogen: } NAP = Ni - AD - IMM - NL$$
$$\text{For phosphorus: } NAP = Ni - AD - RE$$

in which NAP is the required nutrient application rate [kg ha^{-1}]. Then, on the basis of the derived nutrient inputs, the chemical fertilizers requirements are calculated as follows:

$$Rf = NAP/NCf$$

in which Rf is amount of fertilizer required [kg ha^{-1}]; and NCf is the nutrient concentration in fertilizer [kg kg^{-1}]. A list of nutrient concentrations of commercial fertilizers is found in Driessen and Konijn (1992).

6.4.5 Pesticide inputs and outputs

Quantitative treatment of pesticide use, which includes here all chemicals applied in crop protection, is possible as only limited number of products are actually applied in the sub-region. Quantification of pesticide use in current land use systems is based on the data derived from the farm survey. The actually applied quantities of pesticides in kg ha^{-1} are much higher than the recommended rates in the region. Abazari (1991) attributed these high rates to the favorable climatic conditions for propagation of pests and diseases and to the disregard of farmers for the recommendations by the extension experts. Information on recommended pesticide rates in kg ha^{-1} in the sub-region have been used to estimate pesticide use in alternative land use systems. Estimated rates are different for various crops, but no distinction has been made among farm type land units. Calculations were performed for all land use systems that require pesticides.

Undesired pesticide outputs are practically inevitable in land use activities. Emission occurs when using pesticides. Pesticides are designed to control localized groups of organisms. The ideal pesticide therefore should have a highly specific effect and disappear rapidly from the environment. Many agents, however, are broadacting and persistent, so that in practice there are nearly always toxic effects. Apart from poisoning organisms other than the target organisms in the agricultural areas, toxic effects may occur outside the agricultural areas, through incorporation in the food chain.

In the framework of the present study, the most preferable common denominator would be an integrated measure of environmental impact of the various land use systems. However, such a measure has, to our knowledge, not been developed so far, and in addition not only the primary agent would have to be taken into account, but also the many metabolites that are formed during its decomposition (De Koning et al., 1992). Insufficient knowledge is available for such a treatment.

Nevertheless, an index has been proposed by Rao et al. (1985) and applied by Bessembinder (1997) to measure the risk of pesticide leaching in the Northern Atlantic Zone of Costa Rica. However, the information on the parameters necessary for operationalising the index is scarce in the study area. Following De Koning et al. (1992), the amount of "active ingredient" expressed in kg ha^{-1} has been applied, irrespective of toxicity, persistency, mobility, etc. In a further refinement more attention would have to be paid to these aspects, as this measure tells us nothing about the ecological effects. Little is known about losses, so that for the purpose of this study, the input of crop protection agents has been used as a qualitative measure for the undesired output of pesticides emission.

6.4.6 Machinery input

Theoretically, machinery requirements can be calculated on the basis of working width and speed of machines, and by applying a factor for turning and overlapping (ILACO, 1981). In practice, however, the requirements are much higher because one has to take into account the efficiency of the operations. This efficiency is affected by many factors such as operator, distance to work place, climate, soil interruptions because of rain, maintenance, etc. In developing countries, the overall efficiency is usually 40-60% (ILACO, 1981).

Machinery requirements for the various land use systems have been assessed in a simplified way, due to lack of pertinent information, and have been expressed as power requirements per ha. The calculation procedure has been carried out for the various land use systems and for each mechanized operation. Power requirements have been calculated for two operations: land preparation and rice threshing, both for current and alternative land use systems. Mechanization of rice transplanting and harvesting operations has been considered when evaluating the impact of a policy measure aimed at introducing technological change. For that purpose, the model's set of column vectors has been expanded to include two additional vectors that represent the power requirements for these two operations.

Machinery power requirements (MPR) for land preparation, transplanting and harvesting operations for the various land use systems have been calculated as:

$$MPR = (10000*P)/(S*W*F*E)$$

where: P is nominal power (hp h^{-1})
S is speed (m h^{-1})
W is width (m)
F is factor for turning and overlapping (%)
E is efficiency (%)
The factor 10000 appears to convert hp requirements per m^2 to hp requirements per ha.

Machinery power requirements (MPR) for threshing for the various land use systems has been calculated as:

$$MPR = P/(C*F*E)$$

where: P is nominal power (hp h^{-1})
C is nominal capacity (kg h^{-1})
F is factor for turning and overlapping (%)
E is efficiency (%)

Values for the parameters used in the calculation of the machine power requirements for the various land use systems have been derived from values reported in the Second Five Year Plan for Agricultural Mechanization (SGPAM, 1994) or estimated on the basis of local expert knowledge. Both, the efficiency and the factor for turning and overlapping have been based entirely on sub-regional averages as no information was available to relate them to farm type land units.

6.4.7 Water input

Water requirements for the various land use systems have been calculated using CROPWAT (Smith, 1992). Since irrigation is never 100 percent efficient, allowance must be made for losses during conveyance and application (Doorenbos and Pruitt, 1984). To account for losses of water incurred during conveyance and application to the field, an efficiency factor has been included when calculating irrigation requirements. Efficiency values for the various stages of water distribution and application have been based on both, figures reported in the feasibility study on the Irrigation and Drainage Development Project in the Haraz River Basin carried out by JICA (1991) in the region and on the basis of information derived from the agricultural census.

Irrigation efficiency (E) has been calculated for each farm type land unit.

$$E = (ESc*ESf)*AS + (EGc*EGf)*AG$$

where:
- ESc conveyance efficiency for surface irrigation (%)
- ESf field application efficiency for surface irrigation (%)
- AS percentage of area irrigated by surface water (%)
- EGc conveyance efficiency for groundwater irrigation (%)
- EGf field application efficiency for groundwater irrigation (%)
- AG percentage of area irrigated by groundwater (%)

Total irrigation requirements (IRt) for the various land use systems on a monthly basis have been obtained by:

$$IRt = IRn/E$$

in which IRn stands for net irrigation requirements in $m^3 ha^{-1} month^{-1}$

Chapter 7

Development and Validation of an Integrated Model for Land Use Planning and Policy Analysis (ILUPPA)

7.1 Introduction

The model presented here is part of a methodology to integrate agro-ecological and socio-economic information for the formulation and evaluation of policy options aiming at sustainable land use at regional and farm level, geared to decision support for policy makers. The purpose of the integrated land use planning and policy analysis (ILUPPA) model is to analyze the possible effects of policy measures on farm household land use decisions and their consequences for realization of regional agricultural development policy objectives.

The chapter contains six sections. It starts from the description of the approach used for modelling land use planning and policy problem (first section). The second section explains the different aggregation levels included in the model. Description of the model's basic structure and an overview of its components is presented in section three. Algebraic formulation of the model is given in section four, followed by a sensitivity analysis of the model's results for different assumptions with respect to the coefficients. Before using the model for generating land use policy scenarios, it has been validated in section six.

7.2 The modelling approach

Frequently the land use planning/policy problem is illustrated in terms of alternative allocations of resources to attain specified policy objectives. Sometimes it is perceived in terms of finding the cropping patterns that will contribute most to predetermined policy objective(s). Conceiving the planning/policy problem in either of these ways is incomplete and is not likely to lead to realistic prescription for policy, because of an important omission: the producers' reaction to policy changes. Finding the optimal cropping patterns from a point of view of policy may not be very useful unless ways are also suggested to induce farmers to adopt these cropping patterns (Hazell and Norton, 1986).

For a better understanding of the effectiveness of different policy measures on agricultural development, a micro-oriented, integrated analysis of farm-level response is indispensable (Van Keulen et al., 1998) The effects of policy instruments on farm household and regional objectives can then be established, through examination of the adjustments in land use. Therefore, for simulating the sector's response to possible policy changes, a positive (or behavioural) linear programming (LP) model, rather than a normative model has been used.

Linear programming models are generally believed to be normative, as opposed to behavioural (or positive), because they are governed by an objective function. However, Samuelson (1952) showed that in the context of mathematical programming, an objective function exists that yields results fulfilling the conditions of a competitive market and by implication, that programming models may be used to explore and simulate market behaviour. The notion that such models might prove useful as market simulation devices, and at the same time be efficient tools for the analysis of alternative policy options in agricultural planning, has led to a number of important empirical applications. Examples are agricultural sector analysis in Tunisia by Condos and Capi (1990); a programming model of Mexican agriculture by Duloy and Norton (1990); a quantitative approach to agricultural policy planing by Bassoco and Norton (1990).

In carrying out policy analysis, it is important that (policy) goal variables do enter the model's objective function and that their levels are not constrained (Hazell and Norton, 1986). To include goal variables in the objective function would be to override its simulating (positive) role. The same comments apply to constraining the levels of goal variables. At the margin, constraints dominate the solution; only after they have been satisfied scope is created for improvement of the objective function. When the model includes farm level input and output choices, the inclusion of policy goal variables in the objective function is equivalent to simulating the situation in which land use decisions are made by policy makers, not farmers. The same would apply when placing constraints on the level of policy goal variables.

Such procedures are inappropriate for land use policy analysis. These possibilities of mis-applications came to the fore, when the models were imprecise with respect to the relation between decision units and objective function, as in maximizing agricultural employment over a set of farm cropping activities. In the absence of a mechanism that guarantees that the resulting cropping systems also serve the best interests of the farmers as they perceive them, the model analysis in such cases remains a merely formalistic exercise, missing predictive ability and value as a policy guide (Condos and Capi, 1990).

However, maximizing a policy goal variable directly, can serve one analytical purpose, i.e. to find the frontier, or the maximum level of the goal that is conceivably attainable. But even this frontier may not be very useful, because it may show little relationship to the points that are attainable under the market systems. On the other hand, policy measures such as subsidies, can be handled effectively as parametric variations in the effective costs to producers and can thus be introduced without inconsistency in the objective function (Condos and Capi, 1990).

These considerations reinforce the arguments for using a positive model, via a sequence of experiments involving changes in policy parameters, rather than using a frontier to address policy issues. In all solutions, the same objective function is used, the sum of producers' net benefits. This ensures that the optimal solution will be applicable to a competitive market equilibrium (Duloy and Norton, 1990). The model has not been solved under any policy goal maximization. Rather, the implications of specific policy measures for policy goal attainment have been simulated.

7.3 Spatial aggregation levels

At regional level, analysis of the agricultural sector can be approached from a regional perspective, such as in De Wit et al. (1988); or from a farm type point of view, such as in Schipper et al. (1995). An adequate sector model must be based on farm level information, yet should primarily address sector-wide issues. Decision-making with respect to land use is primarily the prerogative of farmers. Individual farmers are the final decision-makers in agricultural production: they own the resources and are able to change their use (Stoorvogel et al., 1995). This implies for land use planning and policy analysis at regional level, that interactions between different aggregation levels must be taken into account (Kruseman et al., 1993; Rabbinge and Van Ittersum, 1994), and that inclusion of farm level information is a prerequisite (Ruben et al., 1994). By including information at this level, it is possible to explore options to gain insight in limitations. In this respect, a sector model can be considered as a device for translating micro level information into more aggregate economic statements (Hazell and Norton, 1986). Hence, the sector model developed in this study departs from the farm level.

Important aspects of the ILUPPA model are the differentiation of and linkages between different levels of aggregation. The model is based on integral land use systems (ILUSs) as core units at the activity level. The first level of aggregation is ILUS at the farm type land unit (FTLU), that is defined at an aggregation level lower than both farm type (FT) and land unit (LU). Therefore, FTLUs can be aggregated to a LU level, based on respective FTs, or to a FT level, based on respective LUs. In this way, aggregation of FTLUs yields land units with strong socio-economic components, or farm types with strong bio-physical components. And finally, FTs or LUs can be aggregated to the sector at sub-regional level.

7.4 Structure and overview of the ILUPPA model

It is often helpful to use a model to study the sector's reactions to policy changes (Hazell and Norton, 1986). Linear programming models, used as tools for land use planning at the (sub-)regional level can be viewed or classified as (mini) agricultural sector models, as they include only the agricultural sector of a region (Erenstein and Schipper, 1993), and, potentially are useful for policy analysis with regard to land use and related sustainability issues in agricultural development (Schipper et al., 1995).

Hazell and Norton (1986) argue that, implicitly or explicitly, the structure of each sector model contains the following five elements: (i) a description of producers' economic behaviour; (ii) a description of the production functions, or technology sets, available to producers in a region; (iii) a specification of the resource endowments of each group of producers; (vi) a specification of the market environment in which the producer operates; and (v) a specification of the policy environment of the sector. These five elements of the sector model structure are specified and operationalised below in the description and formulation of the ILUPPA model.

7.4.1 Farmers' economic behaviour

For evaluation of different policy options, a descriptive or positive (can also be called behavioural) objective function in land use planning models is desirable. This function should mimic a postulated objective of farmers, thereby introducing an aspect of farmers' behaviour in the model. Identification of farmers' objectives is often not easy and may reflect one's own perceptions. Nevertheless, to ignore objectives, simply because they do not lend themselves to precise identification would be a serious mistake (FAO, 1990).

Objectives vary among farmers and for the same farmer at different stages of his life (Gypmantasiri et al., 1980). Although different farmers may have different objectives, in general, most farmers pursue one or some combination of the following objectives (Upton, 1987): earning a cash income to meet needs, securing adequate and stable supply of food, having time for leisure and other non-agricultural activities, providing for the future; and achieving of status within the community.

Farmers often have a strong element of economic calculation in their behaviour. The simplifying assumption often made, is that the farmer's sole objective is profit maximization. Although this is not always the case, many economists present some sort of justification. For example, Upton (1987) gives three arguments to justify the assumption: there is little doubt that profit maximization is one of the farmer's objectives, and that it gains importance with increasing penetration of the market economy into rural areas; other objectives may be satisfied indirectly by maximizing cash income; and objectives may be viewed as constraints.

Farmers in Amol Township are assumed to be market oriented. This assumption is supported by information from key informants and resource persons and by careful observations of the cropping patterns. Therefore, the sum of net benefits over all farm type land units has been used as a first approximation for the objective function of the model. Such an objective function calculates all benefits and costs from the farmers' point of view.

7.4.2 Production functions

The ILUPPA model includes a wide range of production activities (sometimes referred to as columns or vectors), representing not only different crops, but also different ways of producing them and at different farm type land units. In land use models, these production activities are called land use activities (sometimes referred to as land use systems). Land use systems are the core activities in the ILUPPA model. They are defined for combinations of farm type land units (FTLU) and land use types (LUT), with specified production technique.

Many production techniques exist. Schematically, three major types can be distinguished: The first type involves different timing of the operations. The second type relates to differences in the amounts of non-factor input use per unit of area, e.g., amount of fertilizers per hectare. The third type involves factor substitution relations, such as that might occur when choosing among different levels of mechanization for individual cultural operations. To create more flexibility, various sub-land use types are defined for the same land use type, differentiated according to production technique. These techniques are incorporated in the model as different types of land use activities. By defining several land use activities, the model provides ample room to choose an appropriate technique (Hazell and Norton, 1986).

While the majority of the production vectors will not enter the optimal basis in any solution, the possibilities of the model to respond to changes in the parameters is determined largely by the range of production vectors that it contains. In the terminology of production economics, moving from one production vector per product to several is equivalent to moving from an Lshaped Leontief isoquant to several points along an isoquant with some curvature (Hazell and Norton, 1986).

Two main types of production activities are included: current land use systems and alternative land use systems. As noted earlier, land use systems consist of a farm type land unit, a land use type and a specific production technique. Specification of actual land use systems is based on farm level observations of current farming practices of a given farm type land unit. To supply a sufficiently broad range of production techniques, it may be necessary to go beyond those actually observed for a given farm type land unit. Therefore, alternative land use systems, defined as technically feasible production systems, aiming at maintaining the natural resource base and protecting the environment, are specified and described.

Land use systems represent discrete choices, represented by alternative input and output coefficients (or their linear combinations). Modelling production functions as discrete points is called 'process analysis' or 'activity analysis'. In the short or medium run, a continuous production function may not be a very accurate representation of reality at the micro level. Discrete points, usually, are more realistic. In this case the continuous production function is an approximation of the reality of discrete functions, and not vice-versa (Hazell and Norton, 1986).

7.4.3 Resource endowments

One of the first steps in the construction of an agricultural sector model is the design of homogenous production units. Here, production units are farm type land units (FTLUs). Resource endowments of farmers in each of the farm type land units include land, irrigation water, family labour, and farm machinery. Separation of resource supply sources is the basic rule under which ILUPPA has been specified. In the current approach, resource supply sources are called farm type land units (FTLUs).

It is not only necessary to differentiate resource supply sources in space, but also by resource type and over time. The land resource is differentiated as irrigated and non-irrigated when relevant. Irrigation water supply is differentiated by supply source, and labour supply into family and hired labour. The timing of production activities is crucial. If seasonal patterns of resource availability are ignored in constructing a model, it is likely that the solution obtained will be unrealistic by showing surplus of a resource when in fact seasonal shortages in resource supply may make derived production levels infeasible. Hence, land, irrigation water and labour resource availability has been specified on a monthly basis. Seasonality in resource availability is easily incorporated in the model by adding more rows that reflect certain time intervals. Time thus enter the model as a characteristic of resource inputs.

Introducing seasonality in this way will further restrict the model solution and will likely lead to lower values of the objective function. It is therefore important to also include in the model any options the farmer has for reducing seasonal bottlenecks in resource availability (Hazell and Norton, 1986). This has been done, by including complementary resource supplies at different aggregation levels. Family labour supply, for example, is constrained at the farm type land unit level, whereas hired labour supply is constrained at the sub-regional level.

In ILUPPA, resources are supplied through a separate set of variables (called activities or columns), and balance equations are incorporated to ensure equilibrium on factor markets. The most elegant way to combine resource supply variables with resource constraints is, to introduce resource balance equations, in which the demand for the resource by land use activities is balanced by the supply of the resource per farm type land unit, resource type and month.

7.4.4 Market environment

The market form is assumed to be a competitive one. As used here, a competitive market implies that no producer has a sufficiently large scale of operations to be able to influence the market price (Hazell and Norton, 1986). It is sometimes called the otomistic market, in which each producer is a price-taker, even though at the aggregate level prices may be influenced by the volume of production. Purely as a descriptive matter, the competitive market mechanism is closer to the actual processes that determine production in Amol sub-region, and, therefore, has been adopted as a basis for the model.

When used in this sense, a competitive market does not imply absence of market imperfections. Market imperfections have been incorporated in the model via inclusion of spatial price differentials, based on actual patterns of product prices. Different observed farm-gate product prices for farmers in different farm type land units, as obtained from the farm survey data are incorporated exogenously in the model. These price differentials could originate from imperfect market conditions, such as poor transportation facilities in some areas, lack of market information, local monopoly of marketing, inadequate storage facilities, etc. Incorporation of these exogenous product prices provides a more realistic description of the market conditions faced by farmers.

Land use systems are characterized by output coefficients and input coefficients. Therefore, land use activities in the model constitute input demand activities as well as product supply activities, i.e. two market functions are implicit in land use activities: product supply function and input demand function. These functions are part of the model's structure, though they are unknown when the model is being constructed. Appropriate variables and balance equations are defined to calculate total input demand and output supply. In the balance equations, these variables are set equal to the values of land use activities multiplied by the coefficients representing the relevant demand or supply quantities.

Product supply is calculated through commodity balances, specified per product type, for the sub-region as a whole, as well as for any particular farm type or farm type land unit within the sub-region. Also input demand is calculated per input type at monthly intervals or on an annual basis (depending on input type) and at different levels of aggregation: farm type land unit level, farm type level, or sub-regional level. The demand for land, irrigation water, and labour is defined on a monthly basis. All other inputs are considered on an annual basis, including services of farm machinery.

The manageability of sector models is enhanced considerably if output pricing and input costing activities are kept separate from land use activities, even though this requires use of additional input and output balances (Hazell and Norton, 1986). Many sector models contain coefficients representing net economic or financial return to each production activity. This structure makes it awkward to perform experiments with varying input or output prices: changing a single price, of fertilizer for example, could require changing hundreds of net-return coefficients. Therefore, in this study frequent use has been made of separate balances.

Unlike input demand functions, that are implicit in the land use activities, input supply functions are explicitly specified in the model structure. The supply functions for many factors are simple: either perfectly inelastic or perfectly elastic. Land is a factor for which the supply function typically is perfectly inelastic in the short run. Irrigation water fits in the same category. Purchased inputs are examples of inputs that usually are perfectly elastic in supply at the given price. However, for some factors supply functions fall between these two extremes. Labour supply often is elastic but not perfectly elastic. Fertilizers and pesticides are other examples, as these inputs are subsidized up to a fixed qoutum and beyond that, there is no subsidy.

Two types of factors may be distinguished in ILUPPA: those supplied at the level of the farm type land unit, and those supplied at the sub-regional level. At the level of the farm type land unit, the fixed factors supplied are land, water from sources other than the river, family labour, farm-owned machinery, and subsidized fertilizers and pesticides. Factors supplied at sub-regional level include hired labour, river water, services from rented agricultural machinery, and non-subsidized fertilizers and pesticides.

All purchased inputs and services are priced at observed prices, except for those that are explicitly subsidized, such as fertilizers and pesticides. For the latter, both subsidized and non-subsidized (or market) prices are included. For resource inputs whose availability is fixed in the short run, such as land, water, and family labour, the question arises as to whether the input should be priced explicitly in the primal version of the model (Hazell and Norton, 1986). For land, the implicit opportunity cost is represented by its productivity in the most remunerative agricultural use. Agricultural land is not priced, as it is assumed that it has no value outside agriculture in the short run, but the solution of the model yields the value that accrue to the land. Similarly, the endowments of water are not priced, but the costs of tapping the water supply and providing it to farms are included in the production costs that are charged against the objective function.

Hired labour wages are set to the current market levels for each of the farm type land units. For inputs of family labour that is not explicitly paid for, inclusion of a factor price in the primal model is equivalent to specifying a positive vertical intercept in the labour supply function. For determination of the value of this intercept, the relevant question is: what is the minimum return for which family labour will be available for agricultural work? (Hazell and Norton, 1986). This minimum expected return to family labour is often referred to as the "reservation wage". In narrow terms, the reservation wage may be regarded as a measure of the disutility of this work; in other terms it is the minimum productivity at which farmers will undertake additional tasks on their farms (Bassoco and Norton, 1990). Despite the underemployment, that is often a characteristic of agriculture, farmers' time always has an opportunity cost. This cost may reflect either the production forgone or the opportunity to engage in traditional social activities (Duloy and Norton, 1990).

That return, or the implicit wage, almost certainly exceeds zero, but is also likely to be below the market wage. Since the reservation wage shows seasonal variation, it does not represent farmers' income, but rather the minimum return for which they would be willing to work in one season, considering the fact that benefits will accrue in another season. Hence, it is difficult to assess *a priori* (Duloy and Norton, 1990). It is an area where estimation would be helpful (Hazell and Norton, 1986). Analyses by, for example, Duloy and Norton (1990) and Bossoco and Norton (1990) suggested that, for Mexico, the reservation wage for family labour is 30-70% of the market wage. In this study, the model has been structured in such a way that the ratio of farmers' reservation wage to hired labour can be introduced exogenously.

It is useful to separate input demand activities, and their costs, from the production (land use) activities, so that the production columns in the model have no cost entries in the objective function. In the current model, each input has its balance row and its demand column(s). The advantages of this specification are: input supplies can be both costed and bounded if appropriate; multistep, upward sloping input supply functions can be introduced, and changes in input prices or supply conditions can be relatively easily introduced, often by changing one parameter in the model, instead of hundreds or thousands of aggregate cost coefficients for all production vectors. An additional advantage is the transparency of the structure in the tableau.

7.4.5 Policy environment

To allow analysis of the impact of the policy environment in the model, various policy objectives have been included. Subsidized input prices are included in the construction of the model. Both, rates of input subsidy and amounts of inputs available at subsidized rates are specified. To allow execution of policy experiments, involving variations in subsidy rates, initial rates are specified. Various land use scenarios corresponding to different policy measures are defined. Policy measures (policy instruments) are represented in the ILUPPA model structure by a set of parameters: coefficients in the matrix, the right hand side, and/or the objective function. The policy instruments have been tested by solving ILUPPA under alternative assumptions with respect to the values of the policy parameters. On the basis of these scenarios, the model simulates the impact of policy changes on the various policy objectives.

7.5 Mathematical representation of ILUPPA

In this section the algebraic formulation of the model is given. A list of the model's sets or indices is given in Table 7.1, while in Tables 7.2 and 7.3, respectively, the variables and coefficients are explained. As mentioned earlier, the objective function is the sum of producers' surpluses. Therefore, the sum of net benefits over all farm type land units has been used as a first approximation of the objective function of the model (Eqn. 7.1). Such an objective function calculates all benefits and costs from the farmers' point of view. All monetary values are expressed in *Rials*, the currency of the Islamic Republic of Iran.

$$\text{Max OPTIM} = \sum_{f} \sum_{l} \left(GVPFL_{f,l} - VPCFL_{f,l} \right) \qquad (7.1)$$

The objective function is maximized subject to a number of conditions. Except for the objective function, all model equations (rows) can be classified according to the dichotomy of balances and constraints (Hazell and Norton, 1986). Balances are required to equate supply and demand, where both quantities are endogenous to the system, or to perform summation and other accounting roles. Balances always take the form of equalities in the solution, even though they may be written as inequalities in some cases. Constraints (or restraints, restrictions, limits, or bounds, in other terminologies) are inequalities that represent limitations on the availability of resources and institutional and behavioural bounds. They do not necessarily take the form of equalities in the solution. The ILUPPA model comprises 99 groups of equations (constraints and balances). A complete specification of these equations follows.

Resource constraints and other restrictions

The total area of land occupied by irrigated ILUSs, per farm type land unit, and month, should not exceed irrigated land availability, per farm type land unit and month:

$$\sum_{r}\sum_{t} LNO_{r,t,f,l,m} X_{r,t,f,l} \leq LNA_{f,l,u} \quad \forall f, l, m, u = irr \qquad (7.2)$$

The total area of land occupied by ILUSs, per farm type land unit, and month, should not exceed total land availability, per farm type land unit and month:

$$\sum_{j}\sum_{t} LNO_{j,t,f,l,m} X_{j,t,f,l} \leq \sum_{u} LNA_{f,l,u} \quad \forall f, l, m \qquad (7.3)$$

The total quantity of water required for irrigated ILUSs, per farm type land unit and irrigation month, should be balanced by the sum of water use from irrigation sources other than river water, per farm type land unit and irrigation month, plus river water use, per farm type land unit and irrigation month:

$$\sum_{r}\sum_{t} WTR_{r,t,f,l,a} X_{r,t,f,l} \leq \sum_{w} WTUFL_{f,l,a} + RWTUFL_{f,l,a} \quad \forall f,l,a \qquad (7.4)$$

Water use from sources other than river water, per farm type land unit, irrigation source and month, should not exceed water availability from these sources, per farm type land unit, irrigation source and month:

$$WTUFL_{f,l,w,a} \leq WTAFL_{f,l,w,a} \quad \forall f,l,w,a \qquad (7.5)$$

Total river water use over all farm type land units, per irrigation month, should not exceed river water availability in the sub-region, per irrigation month:

$$\sum_{f}\sum_{l} RWTUFL_{f,l,a} \leq RWTA_{a} \quad \forall a \qquad (7.6)$$

Total labour requirements of ILUSs, per farm type land unit and month, should be balanced by the sum of both family and hired labour use, per farm type land unit and month:

$$\sum_{j}\sum_{t} LBR_{j,t,f,l,m} X_{j,t,f,l} \leq FLBUFL_{f,l,m} + HLBUFL_{f,l,m} \quad \forall f,l,m \qquad (7.7)$$

Family labour use, per farm type land unit and month, is constrained by family labour availability, per farm type land unit and month:

$$FLBUFL_{f,l,m} \leq FLBA_{f,l,m} \quad \forall f,l,m \qquad (7.8)$$

Hired labour use, per farm type land unit and month, should not exceed hired labour availability[6], per farm type land unit and month:

$$HLBUFL_{f,l,m} \leq FLBA_{f,l,m} MHLBA \quad \forall f,l,m \qquad (7.9)$$

Total hired labour use over all farm type land units, is constrained by total hired labour availability[7] for the sub-region:

$$\sum_{f}\sum_{l}\sum_{m} HLBUFL_{f,l,m} \leq THLBA \sum_{f}\sum_{l}\sum_{m} FLBA_{f,l,m} \qquad (7.10)$$

Farm machinery requirements of ILUSs, per farm type land unit and mechanized operation, should be balanced by the sum of both own farm and rented machinery use, per farm type land unit and mechanized operation:

$$\sum_{j}\sum_{t} MNR_{j,t,f,l,o} X_{j,t,f,l} \leq OMNUFL_{f,l,o} + RMNUFL_{f,l,o} \quad \forall f,l,o \qquad (7.11)$$

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[6] Monthly hired labour availability is estimated as a percentage of family labour availability, on the basis of the maximum percentage of monthly labour hiring in the sub-region as reported in JICA (1991).

[7] Annual hired labour availability is estimated on the basis of the maximum percentage of annual labour hiring in the sub-region as reported in JICA(1991).

Own farm machinery use, per farm type land unit and mechanized operation, should not exceed own farm machinery availability, per farm type land unit and mechanized operation.

$$OMNUFL_{f,l,o} \leq OMNA_{f,l,o} \quad \forall f,l,o \qquad (7.12)$$

Fertilizer requirements of ILUSs, per farm type land unit, crop commodity and fertilizer type, should be balanced by the sum of both subsidized and non-subsidized fertilizer use, per farm type land unit, crop commodity and fertilizer type:

$$\sum_{t} FRR_{j,t,f,l,n} X_{j,t,f,l} \leq FRSU_{f,l,j,n} + FRMU_{f,l,j,n} \quad \forall f,l,j,n \qquad (7.13)$$

Subsidized fertilizer use, per farm type land unit, crop commodity and fertilizer type, is constrained by subsidized fertilizer availability, per farm type land unit, crop commodity and fertilizer type:

$$FRSU_{f,l,j,n} \leq FRSQ_{j,n} LNA_{f,l} \quad \forall f,l,j,n \qquad (7.14)$$

Pesticide requirements of ILUSs, per farm type land unit, crop commodity and pesticide type, should be balanced by the sum of both subsidized and non-subsidized pesticide use, per farm type land unit, crop commodity and pesticide type:

$$\sum_{t} PSR_{j,t,f,l,c} X_{j,t,f,l} \leq PSSU_{f,l,j,c} + PSMU_{f,l,j,c} \quad \forall f,l,j,c \qquad (7.15)$$

Use of subsidized pesticides, per farm type land unit, crop commodity and pesticide type, is constrained by subsidized pesticide availability, per farm type land unit, crop commodity and pesticide type:

$$PSSU_{f,l,j,c} \leq PSSQ_{j,c} LNA_{f,l} \quad \forall f,l,j,c \qquad (7.16)$$

Product balances

Product balances are differentiated per crop commodity and product type and calculated at three aggregation levels: farm type land unit level (Eqn. 7.17), farm type level (Eqn. 7.18) and sub-regional level (Eqn. 7.19).

$$QFL_{j,p,f,l} = \sum_{t} YLD_{j,p,t,f,l} X_{j,t,f,l} \quad \forall j,p,f,l \qquad (7.17)$$

$$QF_{j,p,f} = \sum_{t}\sum_{l} YLD_{j,p,t,f,l} X_{j,t,f,l} \quad \forall j,p,f \qquad (7.18)$$

$$Q_{j,p} = \sum_{t}\sum_{f}\sum_{l} YLD_{j,p,t,f,l} X_{j,t,f,l} \quad \forall j,p \qquad (7.19)$$

Input balances

Land input balances are expressed per crop commodity and specified per farm type land unit and month (Eqn. 7.20), per farm type land unit (Eqn. 7.21), per farm type and month (Eqn. 7.22), per farm type (Eqn. 7.23), per month at sub-regional level (Eqn. 7.24), and for the whole sub-region (Eqn. 7.25).

$$LNIFLM_{f,l,j,m} = \sum_{t} X_{j,t,f,l} LNO_{j,t,f,l,m} \quad \forall f,l,j,m \qquad (7.20)$$

$$LNIFL_{f,l,j} = \sum_{m}\sum_{t} X_{j,t,f,l} LNO_{j,t,f,l,m} \quad \forall f,l,j \qquad (7.21)$$

$$LNIFM_{f,j,m} = \sum_{t}\sum_{l} X_{j,t,f,l} LNO_{j,t,f,l,m} \quad \forall f,j,m \qquad (7.22)$$

$$LNIF_{f,j} = \sum_{m}\sum_{t}\sum_{l} X_{j,t,f,l} LNO_{j,t,f,l,m} \quad \forall f,j \qquad (7.23)$$

$$LNIM_{j,m} = \sum_{t}\sum_{f}\sum_{l} X_{j,t,f,l} LNO_{j,t,f,l,m} \quad \forall j,m \qquad (7.24)$$

$$LNI_{j} = \sum_{m}\sum_{t}\sum_{f}\sum_{l} X_{j,t,f,l} LNO_{j,t,f,l,m} \quad \forall j \qquad (7.25)$$

Water input balances are specified per farm type land unit and irrigation month (Eqn. 7.26), per farm type and land unit (Eqn. 7.27), per farm type and irrigation month (Eqn. 7.28), per farm type (Eqn. 7.29), per irrigation month, for the whole sub-region (Eqn. 7.30), and total for the whole sub-region (Eqn. 7.31).

$$WTIFLM_{f,l,a} = \sum_{r}\sum_{t} WTR_{r,t,f,l,a} X_{j,t,f,l} \quad \forall f,l,a \qquad (7.26)$$

$$WTIFL_{f,l} = \sum_{r}\sum_{t}\sum_{a} WTR_{r,t,f,l,a} X_{r,t,f,l} \quad \forall f,l \qquad (7.27)$$

$$WTIFM_{f,a} = \sum_{r}\sum_{t}\sum_{l} WTR_{r,t,f,l,a} X_{r,t,f,l} \quad \forall f,a \qquad (7.28)$$

$$WTIF_{f} = \sum_{r}\sum_{t}\sum_{l}\sum_{a} WTR_{r,t,f,l,a} X_{r,t,f,l} \quad \forall f \qquad (7.29)$$

$$WTIM_{a} \sum_{r}\sum_{t}\sum_{f}\sum_{l} WTR_{r,t,f,l,a} X_{r,t,f,l} \quad \forall a \qquad (7.30)$$

$$WTI = \sum_{r}\sum_{t}\sum_{f}\sum_{l}\sum_{a} WTR_{r,t,f,l,a} X_{r,t,f,l} \qquad (7.31)$$

Balances for family labour input are aggregated at farm type land unit level (Eqn. 7.32), at farm type level (Eqn. 7.33), and at sub-regional level on both monthly (Eqn. 7.34) and annual (Eqn. 7.35) basis.

$$FLBIFL_{f,l} = \sum_{m} FLBUFL_{f,l,m} \quad \forall f,l \qquad (7.32)$$

$$FLBIF_{f} = \sum_{l}\sum_{m} FLBUFL_{f,l,m} \quad \forall f \qquad (7.33)$$

$$FLBIM_{f} = \sum_{f}\sum_{l} FLBUFL_{f,l,m} \quad \forall m \qquad (7.34)$$

$$FLBI = \sum_{f}\sum_{l}\sum_{m} FLBUFL_{f,l,m} \qquad (7.35)$$

Balances for hired labour input are aggregated at farm type land unit level (Eqn. 7.36), at farm type level (Eqn. 7.37), and at sub-regional level on both monthly (Eqn. 7.38) and annual (Eqn. 7.39) basis.

$$HLBIFL_{f,l} = \sum_{m} HLBUFL_{f,l,m} \quad \forall f,l \qquad (7.36)$$

$$HLBIF_{f} = \sum_{l}\sum_{m} HLBUFL_{f,l,m} \quad \forall f \qquad (7.37)$$

$$HLBIM_{f} = \sum_{f}\sum_{l} HLBUFL_{f,l,m} \quad \forall m \qquad (7.38)$$

$$HLBI = \sum_{f}\sum_{l}\sum_{m} HLBUFL_{f,l,m} \qquad (7.39)$$

Total labour input balances are specified on monthly basis at three aggregation levels: farm type land unit level (Eqn. 7.40), farm type level (Eqn. 7.41), and sub-regional level (Eqn. 7.42). Balances for total annual labour input are also calculated at three aggregation levels: farm type land unit level (Eqn. 7.43), farm type level (Eqn. 7.44) and sub-regional level (Eqn. 7.45).

$$LBIFLM_{f,l,m} = \sum_{j}\sum_{t} LBR_{j,t,f,l,m} X_{j,t,f,l} \quad \forall f,l,m \qquad (7.40)$$

$$LBIFM_{f,m} = \sum_{j}\sum_{t}\sum_{l} LBR_{j,t,f,l,m} X_{j,t,f,l} \quad \forall f,m \qquad (7.41)$$

$$LBIM_{m} = \sum_{j}\sum_{t}\sum_{f}\sum_{l} LBR_{j,t,f,l,m} X_{j,t,f,l} \quad \forall m \qquad (7.42)$$

$$LBIFL_{f,l} = \sum_{j}\sum_{t}\sum_{m} LBR_{j,t,f,l,m} X_{j,t,f,l} \quad \forall f,l \qquad (7.43)$$

$$LBIF_{f} = \sum_{j}\sum_{t}\sum_{l}\sum_{m} LBR_{j,t,f,l,m} X_{j,t,f,l} \quad \forall f \qquad (7.44)$$

$$LBI = \sum_{j}\sum_{t}\sum_{f}\sum_{l}\sum_{m} LBR_{j,t,f,l,m} X_{j,t,f,l} \qquad (7.45)$$

Farm machinery input balances are specified per type of mechanized operation and calculated at three aggregation levels: farm type land unit level (Eqn. 7.46), farm type level (Eqn. 7.47) and sub-regional level (Eqn. 7.48).

$$MNIFL_{f,l,o} = \sum_{j}\sum_{t} MNR_{j,t,f,l,o} X_{j,t,f,l} \quad \forall f,l,o \qquad (7.46)$$

$$MNIF_{f,o} = \sum_{j}\sum_{t}\sum_{l} MNR_{j,t,f,l,o} X_{j,t,f,l} \quad \forall f,o \qquad (7.47)$$

$$MNI_{o} = \sum_{j}\sum_{t}\sum_{f}\sum_{l} MNR_{j,t,f,l,o} X_{j,t,f,l} \quad \forall o \qquad (7.48)$$

Seed input balances are expressed per crop commodity at farm type land unit level (Eqn. 7.49), farm type level (Eqn. 7.50) and sub-regional level (Eqn. 7.51).

$$SDIFL_{j,f,l} = \sum_{t} SDR_{j} X_{j,t,f,l} \quad \forall j,f,l \qquad (7.49)$$

$$SDIF_{j,f} = \sum_{t}\sum_{l} SDR_{j} X_{j,t,f,l} \quad \forall j,f \qquad (7.50)$$

$$SDI_{j} = \sum_{t}\sum_{f}\sum_{l} SDR_{j} X_{j,t,f,l} \quad \forall j \qquad (7.51)$$

Fertilizer input balances are calculated per fertilizer type and aggregated at farm type land unit level (Eqn. 7.52), farm type level (Eqn. 7.53) and sub-regional level (Eqn. 7.54).

$$FRIFL_{n,f,l} = \sum_{t}\sum_{j} FRR_{j,t,f,l,n} X_{j,t,f,l} \quad \forall n,f,l \qquad (7.52)$$

$$FRUF_{n,f} = \sum_{t}\sum_{j}\sum_{l} FRR_{j,t,f,l,n} X_{j,t,f,l} \quad \forall n,f \qquad (7.53)$$

$$FRI_{n} = \sum_{t}\sum_{j}\sum_{l}\sum_{f} FRR_{j,t,f,l,n} X_{j,t,f,l} \quad \forall n \qquad (7.54)$$

Pesticide input balances are specified per pesticide type and aggregated at farm type land unit level (Eqn. 7.55), farm type level (Eqn. 7.56) and sub-regional level (Eqn. 7.57).

$$PSIFL_{c,f,l} = \sum_{t} PSR_{j,t,f,l,c} X_{j,t,f,l} \quad \forall c,f,l \qquad (7.55)$$

$$PSIF_{c,f} = \sum_{t}\sum_{l} PSR_{j,t,f,l,c} X_{j,t,f,l} \quad \forall c,f \qquad (7.56)$$

$$PSI_{c} = \sum_{t}\sum_{f}\sum_{l} PSR_{j,t,f,l,c} X_{j,t,f,l} \quad \forall c \qquad (7.57)$$

Pricing and costing balances

Balances for gross value of production are calculated at three aggregation levels: farm type land unit level (Eqn. 7.58), farm type level (Eqn. 7.59) and sub-regional level (Eqn. 7.60).

$$GVPFL_{f,l} = \sum_{j}\sum_{t}\sum_{p} X_{j,t,f,l} YLD_{j,t,f,l,p} PP_{j,p,f,l} \quad \forall f,l \qquad (7.58)$$

$$GVPF_{f} = \sum_{j}\sum_{t}\sum_{l}\sum_{p} X_{j,t,f,l} YLD_{j,t,f,l,p} PP_{j,p,f,l} \quad \forall f \qquad (7.59)$$

$$GVP = \sum_{j}\sum_{t}\sum_{f}\sum_{l}\sum_{p} X_{j,t,f,l} YLD_{j,t,f,l,p} PP_{j,p,f,l} \qquad (7.60)$$

Balances for family labour costs are calculated at three aggregation levels: farm type land unit level (Eqn. 7.61), farm type level (Eqn. 7.62) and sub-regional level (Eqn. 7.63).

$$FLBCFL_{f,l} = \sum_{m} FLBUFL_{f,l,m} MWG_{f,l} PRWG \quad \forall f,l \qquad (7.61)$$

$$FLBCF_{f} = \sum_{l} \sum_{m} FLBUFL_{f,l,m} MWG_{f,l} PRWG \quad \forall f \qquad (7.62)$$

$$FLBC = \sum_{f} \sum_{l} \sum_{m} FLBUFL_{f,l,m} MWG_{f,l} PRWG \qquad (7.63)$$

Balances for hired labour costs are calculated at three aggregation levels: farm type land unit level (Eqn. 7.64), farm type level (Eqn. 7.65) and sub-regional level (Eqn. 7.66).

$$HLBCFL_{f,l} = \sum_{m} HLBUFL_{f,l,m} MWG_{f,l} \quad \forall f,l \qquad (7.64)$$

$$HLBCF_{f} = \sum_{m} \sum_{l} HLBUFL_{f,l,m} MWG_{f,l} \quad \forall f \qquad (7.65)$$

$$HLBC = \sum_{m} \sum_{l} \sum_{f} FLBUFL_{f,l,m} MWG_{f,l} PRWG \qquad (7.66)$$

Balances for total labour costs are calculated at three aggregation levels: farm type land unit level (Eqn. 7.67), farm type level (Eqn. 7.68) and sub-regional level (Eqn. 7.69).

$$LBCFL_{f,l} = FLBCFL_{f,l} + HLBCFL_{f,l} \quad \forall f,l \qquad (7.67)$$

$$LBCF_{f} = FLBCF_{f} + HLBCF_{f} \quad \forall f \qquad (7.68)$$

$$LBC = FLBC + HLBC \qquad (7.69)$$

Balances for machinery service cost are calculated at three aggregation levels: farm type land unit level (Eqn. 7.70), farm type level (Eqn. 7.71) and sub-regional level (Eqn. 7.72).

$$MNCFL_{f,l} = \sum_{o} OMNUFL_{f,l,o} OMNP_{f,l,o} + \sum_{o} RMNUFL_{f,l,o} RMNP_{f,l,o} \quad \forall f,l \qquad (7.70)$$

$$MNC_{f} = \sum_{o}\sum_{l} OMNU_{f,l,o} OMNP_{f,l,o} + \sum_{o}\sum_{l} RMNUFL_{f,l,o} RMNP_{f,l,o} \quad \forall f \qquad (7.71)$$

$$MNC = \sum_{o}\sum_{l}\sum_{f} OMNUFL_{f,l,o} OMNP_{f,l,o} + \sum_{o}\sum_{l}\sum_{f} RMNUFL_{f,l,o} RMNP_{f,l,o} \qquad (7.72)$$

Balances for fertilizer costs are calculated at three aggregation levels: farm type land unit level (Eqn. 7.73), farm type level (Eqn. 7.74) and sub-regional level (Eqn. 7.75).

$$FRCFL_{f,l} = \sum_{j}\sum_{n} FRSU_{j,n,f,l} FRSP_{n,f,l} + \sum_{j}\sum_{n} FRMU_{j,n,f,l} FRMP_{n,f,l} \quad \forall f,l \qquad (7.73)$$

$$FRCF_{f} = \sum_{j}\sum_{n}\sum_{l} FRSU_{j,n,f,l} FRSP_{n,f,l} + \sum_{j}\sum_{n}\sum_{l} FRMU_{j,n,f,l} FRMP_{n,f,l} \quad \forall f \qquad (7.74)$$

$$FRC = \sum_{j}\sum_{n}\sum_{l}\sum_{f} FRSU_{j,n,f,l} FRSP_{n,f,l} + \sum_{j}\sum_{n}\sum_{l}\sum_{f} FRMU_{j,n,f,l} FRMP_{n,f,l} \qquad (7.75)$$

Balances for pesticide costs are calculated at three aggregation levels: farm type land unit level (Eqn. 7.76), farm type level (Eqn. 7.77) and sub-regional level (Eqn. 7.78).

$$PSCFL_{f,l} = \sum_{j}\sum_{c} PSSU_{j,c,f,l} PSSP_{c,f,l} + \sum_{j}\sum_{c} PSMU_{j,c,f,l} PSMP_{c,f,l} \quad \forall f,l \qquad (7.76)$$

$$PSCF_{f} = \sum_{j}\sum_{n}\sum_{c} PSSU_{j,c,f,l} PSSP_{c,f,l} + \sum_{j}\sum_{c}\sum_{l} PSMU_{j,c,f,l} PSRMP_{c,f,l} \quad \forall f \qquad (7.77)$$

$$PSC = \sum_{j}\sum_{c}\sum_{l}\sum_{f} PSSU_{j,c,f,l} PSSP_{c,f,l} + \sum_{j}\sum_{c}\sum_{l}\sum_{f} PSMU_{j,c,f,l} PSMP_{c,f,l} \qquad (7.78)$$

Balances for seed costs are calculated at three aggregation levels: farm type land unit level (Eqn. 7.79), farm type level (Eqn. 7.80) and sub-regional level (Eqn. 7.81).

$$SDCFL_{f,l} = \sum_{j}\sum_{t} X_{j,t,f,l} SDR_j SDP_{j,f,l} \quad \forall f,l \qquad (7.79)$$

$$SDCF_f = \sum_{j}\sum_{t}\sum_{l} X_{j,t,f,l} SDR_j SDP_{j,f,l} \quad \forall f \qquad (7.80)$$

$$SDC = \sum_{j}\sum_{t}\sum_{l}\sum_{f} X_{j,t,f,l} SDR_j SDP_{j,f,l} \qquad (7.81)$$

Balances for water costs are calculated at three aggregation levels: farm type land unit level (Eqn. 7.82), farm type level (Eqn. 7.83) and sub-regional level (Eqn. 7.84).

$$WTCFL_{f,l} = \sum_{w}\sum_{a} WTUFL_{f,l,w,a} WTP_w + \sum_{a} RWTUFL_{f,l,a} RWTP \quad \forall f,l \qquad (7.82)$$

$$WTCF_f = \sum_{w}\sum_{a}\sum_{l} WTUFL_{f,l,w,a} WTP_w + \sum_{a}\sum_{l} RWTUFL_{f,l,a} RWTP \quad \forall f \qquad (7.83)$$

$$WTC = \sum_{w}\sum_{a}\sum_{l}\sum_{f} WTUFL_{f,l,w,a} WTP_w + \sum_{a}\sum_{l}\sum_{f} RWTUFL_{f,l,a} RWTP \qquad (7.84)$$

Balances for variable production costs are calculated at three aggregation levels: farm type land unit level (Eqn. 7.85), farm type level (Eqn. 7.86) and sub-regional level (Eqn. 7.87).

$$VPCFL_{f,l} = WTCFL_{f,l} + LBCFL_{f,l} + MNCFL_{f,l} + SDCFL_{f,l} + FRCFL_{f,l} + PSCFL_{f,l} \quad \forall f,l \qquad (7.85)$$

$$VPCF_f = WTCF_f + LBCF_f + MNCF_f + SDCF_f + FRCF_f + PSCF_f \quad \forall f \qquad (7.86)$$

$$VPC = WTC + LBC + MNC + SDC + FRC + PSC \qquad (7.87)$$

Balances for net benefits are calculated at three aggregation levels: farm type land unit level (Eqn. 7.88), farm type level (Eqn, 7.89) and sub-regional level (Eqn. 7.90).

$$NB_{f,l} = GVP_{f,l} - VPC_{f,l} \quad \forall f, l \qquad (7.88)$$

$$NBFFf = GVPFf - VPCf \quad \forall f \qquad (7.89)$$

$$NB = GVP - VPC \qquad (7.90)$$

Agro-ecological sustainability balances

Balances related to agro-ecological sustainability indicators of nitrogen input, nitrogen losses, and pesticide input are calculated. Nitrogen input balances are provided at three aggregation levels: farm type land unit level (Eqn. 7.91) farm type level (Eqn 7.92) and sub-regional level (Eqn. 7.93).

$$NIFL_{f,l} = \sum_{j}\sum_{t} NINPT_{j,t,f,l} X_{j,t,f,l} \quad \forall f, l \qquad (7.91)$$

$$NIF_f = \sum_{j}\sum_{t}\sum_{l} NINPT_{j,t,f,l} X_{j,t,f,l} \quad \forall f \qquad (7.92)$$

$$NI = \sum_{j}\sum_{t}\sum_{f}\sum_{l} NINPT_{j,t,f,l} X_{j,t,f,l} \qquad (7.93)$$

Nitrogen loss balances are provided at three aggregation levels: farm type land unit level (Eqn. 7.94) farm type level (Eqn. 7.95) and sub-regional level (Eqn. 7.96).

$$NLF_f = \sum_{j}\sum_{t}\sum_{l} NLOSS_{j,t,f,l} X_{j,t,f,l} \quad \forall f \qquad (7.94)$$

$$NLFL_{f,l} = \sum_{j}\sum_{t} NLOSS_{j,t,f,l} X_{j,t,f,l} \quad \forall f,l \qquad (7.95)$$

$$NL = \sum_{j}\sum_{t}\sum_{f}\sum_{l} NLOSS_{j,t,f,l} X_{j,t,f,l} \qquad (7.96)$$

Pesticide input balances are provided at three aggregation levels: farm type land unit level (Eqn. 7.97) farm type level (Eqn. 7.98) and sub-regional level (Eqn. 7.99).

$$PSAIFL_{f,l} = \sum_{j}\sum_{t} PSTAI_{j,t,f,l} X_{j,t,f,l} \quad \forall f,l \qquad (7.97)$$

$$PSAIF_{f} = \sum_{j}\sum_{t}\sum_{l} PSTAI_{j,t,f,l} X_{j,t,f,l} \quad \forall f \qquad (7.98)$$

$$PSAIT = \sum_{j}\sum_{t}\sum_{f}\sum_{l} PSTAI_{j,t,f,l} X_{j,t,f,l} \qquad (7.99)$$

Table 7.1 Sets[1] in the ILUPPA model

Symbol	Description of index	Remarks
f	farm type	four types: FT1 to FT4
l	land unit	five units: LU1 to LU5
j	crop commodity	Four commodities: Amol3 "improved rice variety", Tarom "local rice variety", wheat, and barley
r	irrigated crop	defined as subset of *j*: rice Amol3 and rice Tarom
d	non-irrigated crop	defined as subset of *j*: wheat and barley
t	production technique	twelve techniques: T1 to T12
p	product type	two types: main product and byproduct
m	month	twelve months: January till December
a	irrigation month	defined as subset of *m*: April till September
u	land type	two types: irrigated "irr" and non-irrigated "df"
w	irrigation source other than river	three sources: spring, pond, and groundwater
n	fertilizer type	two types: urea and diamonium phosphate
c	pesticide type	Two types: insecticides and herbicides
o	mechanized operation	four operations: tillage, transplanting, threshing, and harvesting

[1] Many other multi-dimensional sets have been defined to provide mapping possibilities for combinations of elements of different sets. For instance the multi-dimensional set *fl(f,l)* is defined to map the combination of farm types *(f)* and land units *(l)*.

Table 7.2 Variables in the ILUPPA model

Variable	Description	Unit of measurement
OPTIM	value of the objective function	Rials yr^{-1}
$X_{j,t,f,l}$	area of an ILUS	Ha yr^{-1}
$RWTUFL_{f,l,a}$	river water use, per farm type, land unit, and irrigation month	m^3 $month^{-1}$
$RWTU_a$	river water use for the sub-region, per irrigation month	m^3 $month^{-1}$
$WTUFL_{f,l,a}$	water use from sources other than river water, per farm type land unit, irrigation source and month	m^3 $month^{-1}$
$FLBUFL_{f,l,m}$	family labour use, per farm type land unit, and month	mandays $month^{-1}$
$HLBUFL_{f,l,m}$	hired labour use, per farm type land unit, and month	mandays $month^{-1}$
$OMNUFL_{f,l,o}$	own machinery use, per farm type land unit and mechanized operation	hp yr^{-1}
$RMNUFL_{f,l,o}$	rented machinery use, per farm type land unit and mechanized operation	hp yr^{-1}
$FRSU_{f,l,j,n}$	subsidized fertilizer use, per farm type land unit, crop commodity and fertilizer type	kg yr^{-1}
$FRMU_{f,l,j,n}$	non-subsidized fertilizer use, per farm type land unit, crop commodity and fertilizer type	kg yr^{-1}
$PSSU_{f,l,j,c}$	subsidized pesticide use, per farm type land unit, crop commodity and pesticide type	kg yr^{-1}
$PSMU_{f,l,j,c}$	non-subsidized pesticide use, per farm type land unit, crop commodity and pesticide type	kg yr^{-1}
$LNIFLM_{f,l,j,m}$	land input, per farm type land unit, crop commodity and month	ha $month^{-1}$
$LNIFL_{f,l,j}$	land input, per farm type land unit and crop commodity	ha yr^{-1}
$LNIFM_{f,j,m}$	land input, per farm type, crop commodity and month	ha $month^{-1}$
$LNIF_{f,j}$	land input, per farm type and crop commodity	ha yr^{-1}
$LNIM_{j,m}$	total land input for the sub-region, per crop commodity and month	ha $month^{-1}$
$LNIM_j$	total land input for the sub-region, per crop commodity	ha yr^{-1}
$WTIFLM_{f,l,m}$	water input, per farm type land unit and month	m^3 $month^{-1}$
$WTIFL_{f,l}$	water input, per farm type land unit	m^3 yr^{-1}
$WTIFM_{f,m}$	water input, per farm type, and month	m^3 $month^{-1}$
$WTIF_f$	water input, per farm type	m^3 yr^{-1}
$WTIM_m$	water input for the sub-region, per month	m^3 $month^{-1}$
WTI	total water input for the sub-region	m^3 yr^{-1}
$LBIFLM_{f,l,m}$	labour input, per farm type land unit and month	mandays $month^{-1}$
$LBIFL_{f,l}$	labour input, per farm type land unit	mandays yr^{-1}
$LBIFM_{f,m}$	Labour input, per farm type, and month	mandays $month^{-1}$
$LBIF_{f,m}$	labour input, per farm type	mandays yr^{-1}
$LBIM_m$	labour input for the sub-region, by month	mandays $month^{-1}$
LBI	total labour input for the sub-region	mandays yr^{-1}
$MNIFL_{f,l,o}$	machine input, per farm type land unit and mechanized operation	hp yr^{-1}
$MNIF_{f,o}$	machine input, per farm type, and mechanized operation	hp yr^{-1}
MNI_o	machine input for the sub-region, per mechanized operation	hp yr^{-1}
$FRIFL_{f,l,n}$	fertilizer input, per farm type land unit and fertilizer type	kg yr^{-1}
$FRIF_{f,n}$	fertilizer input, per farm type and fertilizer type	kg yr^{-1}
FRI_n	fertilizer input for the sub-region, per fertilizer type	kg yr^{-1}
$PSIFL_{f,l,c}$	pesticide input, per farm type land unit and pesticide type	kg yr^{-1}
$PSIF_{f,c}$	pesticide input, per farm type and pesticide type	kg yr^{-1}
PSI_c	pesticide input for the sub-region, per pesticide type	kg yr^{-1}
$SDIFL_{f,l,j}$	seed input, per farm type land unit and crop commodity	kg yr^{-1}
$SDIF_{f,j}$	seed input, per farm type and crop commodity	kg yr^{-1}
SDI_j	seed input for the sub-region, per crop commodity	kg yr^{-1}
$QFL_{f,l,j,p}$	production, per farm type land unit, crop commodity and product type	kg yr^{-1}
$QF_{f,j,p}$	production, per farm type, crop commodity and product type	kg yr^{-1}
Q_{jp}	Production for the sub-region, per crop commodity and product type	kg yr^{-1}
$GVPFL_{f,l}$	gross value of production, per farm type land unit	Rials yr^{-1}
$GVPF_f$	gross value of production, per farm type	Rials yr^{-1}
GVP	total gross value of production for the sub-region	Rials yr^{-1}
$WTCFL_{f,l}$	water costs, per farm type and land unit	Rials yr^{-1}
$WTCF_f$	water costs, per farm type	Rials yr^{-1}
WTC	water costs for the sub-region	Rials yr^{-1}
$FLBCFL_{f,l}$	family labour costs, per farm type and land unit	Rials yr^{-1}
$FLBCF_f$	family labour costs, per farm type	Rials yr^{-1}
$FLBC_f$	total family labour costs for the sub-region	Rials yr^{-1}
$HLBCFL_{f,l}$	hired labour costs, per farm type and land unit	Rials yr^{-1}
$HLBCF_f$	hired labour costs, per farm type	Rials yr^{-1}
$HLBC_f$	total hired labour costs for the sub-region	Rials yr^{-1}
$LBCFL_{f,l}$	total labour costs, per farm type and land unit	Rials yr^{-1}
$LBCF_f$	total labour costs, per farm type	Rials yr^{-1}
LBC_f	total labour costs for the sub-region	Rials yr^{-1}
$MNCFL_{f,l}$	farm machinery service costs, per farm type and land unit	Rials yr^{-1}
$MNCF_f$	farm machinery service costs, per farm type	Rials yr^{-1}
MNC	farm machinery service costs for the sub-region	Rials yr^{-1}
$FRCFL_{f,l}$	fertilizer costs, per farm type and land unit	Rials yr^{-1}
$FRCF_f$	fertilizer costs, per farm type	Rials yr^{-1}
FRC	fertilizer costs for the sub-region	Rials yr^{-1}
$PSCFL_{f,l}$	pesticide costs, per farm type and land unit	Rials yr^{-1}
$PSCF_f$	pesticide costs, per farm type	Rials yr^{-1}
PSC	pesticide costs for the sub-region	Rials yr^{-1}
$SDCFL_{f,l}$	seed costs, per farm type and land unit	Rials yr^{-1}
$SDCF_f$	seed costs, per farm type	Rials yr^{-1}
SDC	seed costs for the sub-region	Rials yr^{-1}
$VPCFL_{f,l}$	variable production costs, per farm type and land unit	Rials yr^{-1}

Table 7.2 Continued..

$VPCF_f$	variable production costs, per farm type	Rials yr^{-1}
VPC	total variable production costs for the sub-region	Rials yr^{-1}
$NBFL_{f,l}$	net benefits, per farm type and land unit	Rials yr^{-1}
NBF_f	net benefits, per farm type	Rials yr^{-1}
NB	total net benefits for the sub-region	Rials yr^{-1}
$NIFL_{f,l}$	nitrogen input, per farm type and land unit	kg yr^{-1}
NIF_f	nitrogen input, per farm type	kg yr^{-1}
NI	total nitrogen input for the sub-region	kg yr^{-1}
$NLFL_{fl}$	nitrogen loss, per farm type and land unit	kg yr^{-1}
NLF_f	nitrogen loss, per farm type	kg yr^{-1}
NL	total nitrogen loss for the sub-region	kg yr^{-1}
$PSAIFL_{fl}$	pesticide input, per farm type and land unit	kg a.i yr^{-1}
$PSAIF_f$	pesticide input, per farm type	kg a.i yr^{-1}
PSAIT	total pesticide input for the sub-region	kg a.i yr^{-1}

a.i., active ingredient

Table 7.3 Coefficients in the ILUPPA model

Coefficient	Description	Unit of measurement
$LNO_{j,t,f,l,m}$	land occupancy per an ILUS, per month	proportion (0-1)
$WTR_{j,t,f,l,s}$	irrigation water requirements of an ILUS, per irrigation month	$m^3ha^{-1}month^{-1}$
$LBR_{j,t,f,l,m}$	labour requirements of an ILUS, per month	mandays ha^{-1} $month^{-1}$
$MNR_{j,t,f,l,o}$	machinery requirements of an ILUS, per mechanized operation	$hp^3ha^{-1}yr^{-1}$
$FRR_{j,t,f,l,n}$	fertilizer requirements of an ILUS, per fertilizer type	kg $ha^{-1}yr^{-1}$
$PSR_{j,t,f,l,c}$	pesticide requirements of an ILUS, per pesticide type	kg $ha^{-1}yr^{-1}$
SDR_j	seed requirements, per crop commodity	kg $ha^{-1}yr^{-1}$.
$YLD_{j,t,f,l,p}$	yield of an ILUS, per product type	kg $ha^{-1}yr^{-1}$
$LNA_{f,l,u}$	monthly land availability, per farm type land unit and type of land	ha
$WTA_{f,l,w,s}$	water availability from irrigation sources other than river water, per farm type land unit, irrigation source and irrigation month	m^3month^{-1}
$RWTA_s$	River water availability in the sub-region, per irrigation month	m^3month^{-1}
$FLBA_{f,l,m}$	family labour availability, per farm type land unit and month	mandays $month^{-1}$
MHLBA	maximum percentage of hired labour availability per farm type land unit and month, in relation to family labour availability, per farm type land unit and month	%
THLBA	maximum percentage of annual sub-regional hired labour availability, in relation to annual sub-regional family labour availability	%
$OMNA_{f,l,o}$	own machinery availability, per farm type land unit, and mechanized operation	hp yr^{-1}
$FRSQ_{j,n}$	fertilizer quantity available at a subsidized price, per crop commodity and fertilizer type	kg ha^{-1}
$PSSQ_{j,c}$	pesticide quantity available at a subsidized price, per crop commodity and pesticide type	kg ha^{-1}
$PP_{f,l,j,p}$	product price, per farm type land unit, crop commodity and product type	Rials kg^{-1}
WTP_w	water price for irrigation sources other than river, per irrigation source	Rials m^{-3}
RWTP	river water price	Rials m^{-3}
$MWG_{f,l}$	observed market wage for hired labor, per farm type land unit	Rials $manday^{-1}$
PRWG	ratio of family labour (reservation) wage to hired labour (market) wage	%
$OMNP_{f,l,o}$	own machinery service price, per farm type land unit and mechanized operation	Rials hp^{-1}
$RMNP_{f,l,o}$	rented machinery service price, per farm type land unit and mechanized operation	Rials hp^{-1}
$FRSP_{f,l,n}$	subsidized fertilizer price, per farm type land unit and fertilizer type	Rials kg^{-1}
$FRMP_{f,l,n}$	market price for fertilizer, per farm type land unit and fertilizer type	Rials kg^{-1}
$PSSP_{f,l,c}$	subsidized pesticide price, per farm type land unit and pesticide type	Rials kg^{-1}
$PSMP_{f,l,c}$	market price for pesticide, per farm type land unit and pesticide type	Rials kg^{-1}
$SDP_{f,l,j}$	seed price, per farm type land unit and crop commodity	Rials kg^{-1}
$NINPT_{j,t,f,l}$	nitrogen input of an ILUS	kg $ha^{-1}yr^{-1}$
$NLOSS_{j,t,f,l}$	nitrogen loss of an ILUS	kg $ha^{-1}yr^{-1}$
$PSTAI_{j,t,f,l}$	pesticide input of an ILUS	kg a.i $ha^{-1}yr^{-1}$

7.6 Sensitivity analysis

In solving the ILUPPA model, all technical coefficients, resources, and prices are assumed to be constant. In reality, that usually is not the case. These coefficients are often subject to variability and uncertainty. The following analyses may provide information on the effects of this variability (De Ridder and Van Ittersum, 1995): *shadow price* and *right hand side ranging* for changes in resources, the *coefficients of the objective function ranging* and the *reduced costs* for changes in the contribution of the activities to the value of the objective function. Therefore, sensitivity analysis is a very important part of modelling.

Shadow prices represent the change in the value of the objective function, when fully utilized resource is alleviated by one unit. In the ILUPPA model, changes on scarce resources have different effects on the objective function depending on farm type land unit, resource type and (for some resources) month. For example, an increase of one hectare in land area of FT3LU4 will increase the objective function by *Rials* 2331.2 10^3, while the same increase in land resource of FT4LU3 will increase the objective function only by *Rials* 649.2 10^3. Labour availability is mostly a binding constraint in the period May/June or August/September. These periods correspond to the time of the most labour-demanding activities, i.e. rice transplanting and harvesting, respectively. For a given farm type land unit, shadow prices differ per labour type and per labour type for different months. For example in FT4LU2 the shadow price for family labour in May is *Rials* 56.7 10^3, while it is *Rials* 8.3 10^3 in September.

Availability of water is limiting in two months, April and July. These two months correspond to the initial stage and crop development stage of rice, respectively. Shadow prices for the water resource vary per farm type land unit, irrigation source and month. An increase, for instance, of one mcm in pond water supply in April for FT1LU1, would increase the objective function by *Rials* 359 10^3, while the same increase in water supply for the same farm type land unit in July would increase the objective function by *Rials* 217 10^3.

The discussion on shadow prices so far has concentrated around the question on how a change in resource availability would affect the objective function. Another important element here is, whether land allocation would be modified. Therefore, some sensitivity tests have been carried out for right hand sides ranging, to examine the ranges in changes that would result in changes in land allocation. Results show that land allocation decisions are relatively sensitive to a change in both water and labour supply. Land use allocations change at a relatively narrow range of change in these resources.

Variables (also called zero variables) that do not enter in the optimal solution may be characterized by what is called *reduced costs*. That indicates the quantity by which the objective function coefficient of the zero variable must be changed before it would enter (become a positive variable) in the optimal solution. In the base solution of the ILUPPA model, reduced costs of the non-selected land use systems range from *Rials* 5.2 10^3 to *Rials* 554.3 10^3 per hectare. This wide variability in reduced costs indicates the scope for policy measures to induce the desired changes, by making some of the non-selected land use systems more attractive than those currently selected. Sensitivity of land use allocation to changes in some of the coefficients of the objective function has also been examined. The most striking result from changing water prices is that a three-fold change in water price would produce no change in land use allocations. Land use allocation is very robust with respect to changes in water prices.

The reservation wage for farmers is clearly the most arbitrary parameter in the model. The empirical question to be solved is the appropriate level of the reservation wage. Establishment of this wage, requires an answer to the relevant question: what is the minimum return for which family labour will be available for farm work? That return, or the implicit wage, is almost certainly positive, but it is also likely to be below the market wage. The question about the minimum return is not easy to answer; it is an area where estimation would be helpful (Hazell and Norton, 1986; Bassoco and Norton, 1990; Duloy and Norton, 1990). The model is structured in such a way that any ratio of the farmers' reservation wage to hired labour can be introduced. Because of the arbitrary character, some sensitivity tests have been executed. The model is run with varying wage rates to examine which value would result in the most appropriate cropping patterns. The most appropriate value appears to be somewhere in the range of 55-60%; values in the ranges 0-40% and 65-100% yielded distorted results. In the solutions reported here, it has been assumed that the ratio is 0.6

7.7 Model validation

Before sufficient confidence is placed on the results of a linear programming model, the validity of these results should be carefully examined to test whether the answers are sensible (Sharifi, 1992). Although a number of tests for validating linear programming models of agricultural sectors have been suggested in the literature, it is not always obvious how the model can be validated. The profession (apparently) has not yet reached a consensus on procedures for validating a sector linear programming model (Hazel and Norton, 1986). Nevertheless, validation tests can and should be carried out for each applied model, and proof is necessary that its behaviour is in agreement with (or at least not contrary to) reality.

Sharifi (1992) recommends simply using common sense to first critically examine the results of the model. If that 'test' yields satisfactory results, the simulated results should be compared with what might be expected in the real situation. Because many of the difficulties in validating models are associated with data availability and quality, Hazel and Norton (1986) suggest that careful examination of the data must precede validation of models, to the extent possible. Then, if the results of the model with regard to some major variables are close to the observed values, (some) confidence in the model is established.

Therefore, validation often involves comparison of model results with the reported actual values of some variables. Most often, simple comparisons are made and measures of deviations are calculated. Normally, tests are carried out at aggregate level because it is claimed that the fit is better tested at that level.

There is no consensus on the most appropriate statistics to be used in evaluating the fit, but in most cases simple measures such as the percentage absolute deviation (PAD) or the mean absolute deviation (MAD) have been used (Hazel and Norton, 1986).

No explicit threshold values of PAD or MAD have been defined for unequivocal acceptance or rejection of the model. Hazel and Norton (1986) give the following rough guidelines: PAD below 10% is good, PAD of 5% would be exceptionally good, and PAD exceeding 15% indicates that the model may need improvement before it can be used. Typically, considerable variation exists among variables in the closeness of fit to the historical data, and the model builder may be willing to accept greater deviations in 'minor' variables if the predictions are satisfactory for the 'major' variables.

In the present case, tests have been performed for some major variables for which the base–year observations are fairly reliable. Three tests have been applied: tests on levels of input use, tests on production levels and tests on area cultivated. These tests consist of comparing the model's simulated values of the variables with reported actual values. Table 7.4 shows the percentages absolute deviations (PADs) associated with these tests. Input tests are performed per type of fertilizer (urea and diamoniumphospate), and per type of pesticide (insecticides and herbicides). The results indicate a satisfactory fit.

Table 7.4 Validation measures for the ILUPPA model

validation test	Input/product	Actual	Simulated	PAD[1]
input use	Fertiliser use per fertiliser type			
	Total urea use (tons)	11334	11886	4.9%
	Total diamoniumphosphate use (tons)	7950	8125	2.2%
	Pesticide use per pesticide type			
	Total insecticide use (tons)	1128	1169	3.6%
	Total herbicide use (tons)	103	108	4.7%
production	Production per crop commodity			
	Total rice (tarom) production (tons)	79695	77068	3.3%
	Total rice (amol3) production (tons)	73316	77833	6.2%
	Total wheat production (tons)	437	464	6.3%
	Total barley production (tons)	1098	1121	2.1%
Area cultivated	Area cultivated per crop commodity			
	Total rice (tarom) area (ha.)	20700	19999	3.4%
	Total rice (amol3) area (ha.)	12490	12829	2.7%
	Total wheat area (ha.)	175	181	3.4%
	Total barley area (ha.)	488	482	1.2%

[1]PAD stands for: percentage absolute deviation

Production tests are given most emphasis in many studies, and for a number of agricultural models reported validation results exist. In this study, and for better comparison, production tests have been performed per crop commodity. Results of these tests show that model results match very well with recorded data. Results of tests on levels of input use and production tests may be influenced by input and production coefficients, but also by the area cultivated; therefore input and production tests should be evaluated jointly with tests on the area cultivated. The cultivated area tests have also been carried out per crop commodity. Results show that the model results are very close to the reported values.

Thus, it may be concluded that performance of the model is satisfactory, and its results show overall reasonable agreement with reality. Hence, the predictive ability of the model with regard to land use policy impact analysis can be considered with confidence. However, building a model is a continuous process, and the most successful models have evolved over time taking into account new findings. There never is a 'final' version, but rather at any moment the model represents a kind of orderly database that reflects both the strengths and limitations of the available (quantitative) information. With these considerations in mind, model validation can be used to indicate area(s) where the model most needs improvement, and then further information can be collected in those areas.

Chapter 8

Generation and Evaluation of Land Use Policy Scenarios

8.1 Introduction

Land use policy decisions, like other types of planning decisions, are often suffer from lack of insight in the structure of the decision problem. This means that the decision environment, the available options, the political priorities, and the expected consequences of actions, are to a large extent unknown (Hinloopen and Nijkamp, 1984). Policy-makers have a large number of measures at their disposal, such as incentives and regulations to influence land use (Lutz and Daly, 1991). However, too often, the effects of these measures and other major land use determinants are unknown (Alfaro et al., 1994). A powerful tool in such cases is scenario analysis.

The purpose of this chapter is to develop a procedure for formulation and evaluation of land use policy scenarios in support of policy making. The chapter comprises three main parts. It starts with the review of some basic concepts and terminologies. Then, various land use policy scenarios corresponding to different policy measures are developed. Finally, these various land use policy options are evaluated from different perspectives of policy priorities.

8.2 Concepts and terminologies

Scenarios:

Scenarios originated in the field of drama. Scenario originally had the meaning of 'an outline or synopsis of a play, a plot outline used by actors of the commedia dell'arte, a screenplay or a shooting script'. The term was then borrowed for war gaming and large-scale simulations. Since the late sixties and early seventies, scenario analysis has been used as a tool in policy research. More recently, scenario analysis has become very popular in the realm of land use studies. 'Scenario' is a set of assumptions about the operating environment of a particular system, at a given time (Turban, 1995). In other words, a scenario is a narrative description of the setting in which the decision situation is to be examined. Scenarios are supposed to contain three elements: a description of the present situation, a number of alternative futures and a series of possible events that could lead from the present situation to its future states (Hinloopen and Nijkamp, 1984; Schoonenboom, 1995; Veeneklaas and van den Berg, 1995).

Scenarios can be distinguished into two categories: projective and prospective scenarios (Schoute, 1995). Their common characteristic is that they both aim at exploring alternative courses of development. However, they differ in the direction of the analysis. In projective scenarios, this direction runs from the past, through the present to the future. Given present dynamics, how might things change in the future? The direction of reasoning in prospective scenarios, on the other hand, goes from desired future images back to the present situation. Given future possibilities or desirable future situations, how could these be realised. In practice, however, the distinction between projective and prospective is not very sharp.

Scenarios and forecasts:
The difference in philosophy behind the forecasting and the scenario analysis is important. In the forecasting analysis the aim is not to explore possible futures or assess the feasibility of desired futures, but rather to describe the most probable future, the future to be expected (Schoonenboom, 1995). The description of both approaches is of an idealised nature, in practice, the differences are not that large. However complex reality often may be, the underlying question, in both approaches, remains very different. In a forecasting approach, one is interested in the future as determined by historical regularities. In a scenario approach, one is interested in opening or exploring plausible ranges of future possibilities, not constrained by past trends.

Land use scenarios:
In the context of land use studies, scenarios are defined as 'sets of hypothetical changes in the socio-economic and/or bio-physical environment' (Stoorvogel et al., 1995). Similarly, Alfaro et al. (1994) define scenarios as 'possible' trends in land use determinants and/or policy measures. A number of factors (socio-economic and bio-physical) determining land use can be envisaged. With regard to those factors, assumptions can be made as to how they will change in the future. Each of these assumptions is either called a scenario, or a variant of a scenario (Schipper et al., 1995). In the present study, scenarios are descriptions of a consistent series of policy instruments (or measures) that policy makers can apply or implement to, directly or indirectly, influence or guide future (sustainable) land use decisions, and consequently achieve policy objectives. Scenarios in this sense are policy scenarios.

Policy, objectives and instruments:
Here, three concepts are important: *policy, objectives and instruments*. According to Todaro (1989), a policy is the formulation of objectives and the methods of achieving these objectives. Likewise, Mollet (1990) views a policy problem as setting objectives and the choice of instruments for achieving them. An instrument, on the other hand, refers to the means by which something is done, a tool. Instruments are all those means an actor uses or can use to realise one or

more objectives. Policy instruments are tools that the government can control directly to achieve their policy objectives (Lipsey et al., 1984). Bressers and Klok (1988), in their theory of policy instruments, defined the concept of 'policy instruments' as all means that a government uses or may use to promote the implementation of policy-targeted changes in behaviour of other people without the intervention of other instruments.

Mollet (1990) distinguished between objectives as ends, and instruments as means for achieving these ends. It is true that some objectives may be considered ends in themselves, however, other objectives are simply intermediate steps in attaining desired ends. This is what Simon (1976) calls: a means-ends scheme in the decision-making process. Romero and Rehman (1989) define the concept of objectives in relation to the term attributes. The concept of objective is defined as desired improvement in one or more attributes. An attribute is a decision-maker's value related to reality. For example, a policy maker may establish his preference according to two attributes: revenue and pollution. Improvement in these attributes (the objective) can be interpreted in the sense of either "the more of the attribute (revenue), the better" or "the less of the attribute (pollution), the better". Policy objectives are, therefore, statements of desired or expected improvements in policy attributes.

Multiple attribute and multiple objective decision-making:

It is a widely accepted notion in the literature that multiple criteria decision-making (MCDM) comprises two categories (Jankowski, 1995): multiple attribute decision-making (MADM) and multiple objective decision-making (MODM). MADM refers to the choice from a moderately small set of discrete feasible alternatives, while MODM deals with the problem of design in a feasible solution space, bounded by a set of constraints. MADM is often referred to as multi-criteria analysis or multi-criteria evaluation, whereas MODM is viewed as a natural extension of mathematical programming, where multiple objectives are considered simultaneously.

Ex-ante and ex-post evaluation:

The concept of multi-criteria evaluation can be defined as a set of activities to classify and conveniently arrange the information needed for a choice, so that the various participants in the choice process can make this choice as balanced as possible. Various types of evaluations can be distinguished in a planning process (Nijkamp and Voogd, 1990). A major distinction can be made between ex-post and ex-ante evaluation. In an ex-post evaluation, attention is focused on the analysis of the actual effects of policies that have already been implemented. An ex-ante evaluation deals with expected and foreseeable effects of policies that are not (yet) implemented. Consequently, an ex-ante evaluation has a forward-looking nature, whereas an ex-post evaluation has a backward-looking nature.

Both, the ex-ante and the ex-post approach can be subdivided into a monetary and a non-monetary evaluation. A monetary evaluation is characterised by an attempt to express all effects in monetary units, whereas in contrast - a non-monetary evaluation utilises a wide variety of measurement units to assess the effects. Finally, a distinction can be made between an implicit and an explicit evaluation. In an explicit evaluation a distinct systematic analysis is pursued, whereby the activities are focused on the transparency and accountability of the final results. An implicit evaluation focuses- on the contrary- on consensus of thought, whereby attention is directed towards the participation of - and negotiations among - all parties concerned. Attention in this chapter will be focused on explicit non-monetary ex ante evaluation, i.e. an assessment of all relevant foreseeable impacts of land use policy decisions.

Alternatives, criteria and criteria scores:
An evaluation method is any procedure that supports the ranking of alternatives using one or more decision rules. An evaluation method can yield: a complete ranking, the best alternative, a set of acceptable alternatives, an incomplete ranking of alternatives, or a presentation of alternatives (Janssen, 1992). A set of rules that facilitates the ranking of alternatives will be referred to as a decision rule. Alternatives are different "courses of action". Criteria are measurable aspects of an alternative by which a decision can be made. The estimated impacts of alternatives on every criteria, are called criteria scores or effects (Jankowski, 1995). Decision is a choice between alternatives. Decision rules are the procedures by which criteria are combined. In this chapter, evaluation of land use policy scenarios is considered as a multi-criteria evaluation in which: policy scenarios are conceptualised as alternatives, policy objectives as criteria, simulations of the likely effects on a criterion, in the context of a specific policy scenario, are treated as criteria or impact scores.

8.3 Generation of land use policy scenarios

8.3.1 Identification of policy objectives

It is no simple matter to get unambiguous statements about objectives. Agricultural development objectives evidently differ among countries. They also differ in the same country at different stages of development. Agricultural development policy objectives for Amol sub-region have been distilled from national and regional agricultural plans and policy documents and from discussions with regional planners and policy makers and representatives of regional organisations. Documents on national and regional agricultural plans contain an abundance of, broadly stated, policy objectives and clear priority setting for these objectives is lacking.

In order to translate policy objectives into variables in the model, two criteria have to be met (WRR, 1992). In the first place objectives must be quantifiable, and the quantification must be linked to various forms of land use in the region. Secondly, objectives must represent conflicting choices, at least up to a certain level, if not in total. If objectives simply form an extension of one another, the model can not generate alternative allocations. If, on the other hand, the objectives are totally contradictory, the results will be meaningless since a gain in realisation of one objective will automatically mean a loss in the other. In addition, objectives should preferably be clear and concrete, rather than abstract because vagueness leads to confusion (Mollet, 1990). These requirements necessitate careful selection of policy objectives. Such a selection is made for a number of social, economic and ecological policy objectives.

Increasing agricultural production

Increasing total agricultural production to achieve self-sufficiency has been mentioned as one of the agricultural development objectives in national and regional policy documents in Iran. Production increase will particularly have to come from higher (land) productivity (yield per hectare), and to a lesser extent from expansion of the cultivated area as this possibility is often limited. To increase staple food production in the region, the government has introduced the improved rice variety Amol3, that has a relatively high yield, compared to the local traditional rice variety Tarom. Land productivity is used as an indicator for assessing agricultural production (WRR, 1992).

Land productivity is assessed by means of two indexes: overall production efficiency index and food production index. The overall production efficiency index is calculated as the weighted average of the production efficiencies of all crops. The production efficiency of a crop is the ratio of crop yield per hectare and the maximum yield realised in the sub-region, expressed as a percentage. The food production efficiency index is expressed in terms of total caloric production per hectare, which is an indicator for food security from crop production.

Increasing farm income

Improving the welfare of farmers is a major issue for policy makers in Iran. Increasing farm income and attaining equity are singled out as policy objectives for agricultural development. The term income is often used interchangeably with revenue, receipts, sales, earnings, benefit, and profit. However, each of these terms has a different connotation. Various measures of farm income are used in the literature (see for example Brown, 1979; Gittinger, 1982; FAO, 1990). Common measures are: (a) *gross output* or *gross value of production* of an activity, defined as total production in money terms, including the value of products consumed or used on the farm; (b) *gross farm income,* defined as the sum of all gross values of production of all farm activities; (c) *gross margin,* defined as the difference between the gross value of production and the variable costs of an activity; (d) *total gross margin,* defined as the difference between total gross farm income and total variable production costs of all activities; and (e) *net farm income,* defined as total gross margin minus fixed production costs. But many different measures are possible. Farm income in this study is calculated as the difference between total gross farm income and total variable production costs of inputs, including the observed hired labour costs and the imputed costs for family labour.

Increasing efficiency and reducing costs

Efficient use of resources and reduction of agricultural production costs are also among the objectives of agricultural development in Iran. Ruben et al. (1994) have pointed out the similarities and differences among different concepts of efficiency. Technical efficiency refers to the degree to which actual production performance approaches potential production performance under *ceteris paribus* conditions. Allocative efficiency, implying some possibility for substitution, is determined by the point where (input-output) price ratios equal the tangent of the production function. Ecological efficiency, a term sometimes used in discussions on agro-ecological sustainability, is part of technical efficiency, but also takes into account the consequences of resource use for the remaining resources. Financial efficiency refers to the optimisation of resource use in monetary terms, which often excludes externalities, such as pollution, erosion, etc. However, financial efficiency includes technical efficiency at market prices. Economic efficiency is similar to financial efficiency, except that the prices used in the optimisation may reflect other factors than just the market.

In principle, returns to any resource can be calculated. The standard procedure for the calculation is to take gross output in money terms and to subtract all costs except the costs of the resource to which the return is calculated (FAO, 1990). Since the concept of efficiency hinges on felt scarcity, return per unit of scarce resources would be more meaningful. Three indicators are used to express resource use efficiency: return per unit of land, return per unit of labour and return per unit of water. In addition, the efficiency can be expressed in terms of the volume of production factors concerned (WRR, 1992). At a given production level, a reduction in costs implies that a more cost-efficient production technique has to be implemented. Increasing returns per unit of resource use and decreasing production costs, therefore, are selected as the two policy objectives to be operationalised in this respect.

Improving income distribution

Closely related to the increase in farm income is the objective of greater equality or distribution of income. Of course, there is always the question how an increase in farm income, if any, is distributed among farm households. Lorenz curve and Gini coefficient are the most common measures of income distribution, used by economists (Todaro, 1989). The Lorenz curve is a mathematical description that provides a visual comparison of the extent to which the distribution of income differs from a uniform distribution. It shows the actual quantitative relationship between the percentage of income recipients and the percentage of the total income they received during a given time period. The Gini coefficient is an aggregate inequality measure that can be estimated on the basis of the shape of the Lorenz curve and can vary from 0 (perfect equality) to 1 (perfect inequality).

However, although Gini coefficients provide useful information on levels and changes in relative income inequality, based on shapes of the Lorenz curve, a problem arises when Lorenz curves cross, as one can not, in that case claim that higher coefficients imply a more unequal distribution. In geography, two more commonly used methods for measuring the degree of a variable concentration or distribution over spatial units or systems, are the location quotient and the coefficient of localisation (Van Raay et al., 1989). The difference between these two methods is that the location quotient shows the concentration of a variable in a particular part of the total (spatial) system relative to that in the whole system, whereas the coefficient of localisation illustrates the spatial pattern of a variable over the whole system. The coefficient of localisation can vary from 0 (perfect distribution) to 1 (perfect concentration). The location quotient (LQ) can take values between $0 \leq LQ \geq 1$. Values more than 1 mean high concentration, whereas values less than 1 mean low concentration. Values equal to 1 indicate normal concentration. The coefficient of localisation is used in this study to express the degree of inequality in income distribution at the aggregate sub-regional level, whereas the location quotient is used to express the income concentration in a particular farm type land unit.

Generation of employment

All agricultural development policy documents in Iran emphasise the importance of maintaining agricultural employment. In most of Asia, agriculture will have to provide more employment in the coming decades, until the middle of the 21st century, according to recent projections (Mollet, 1990). It is difficult to evaluate the rate of employment increase in a sector or a region only in terms of total mandays of employment. Seasonality is the essence of the agricultural employment problem, as the agricultural labour force is a mixture of family labour that is employed for most of the time and hired labour that only works occasionally. Following Duloy and Norton (1990), the impact on employment is, therefore, better expressed in terms of changes in the "steady" employment, as measured by total mandays per year provided by family labour and "highly-seasonal" employment, as measured by total mandays per year provided by hired labour.

Creating a balance between land use and environment
Increasing attention has recently been devoted to sustainable agriculture. Sustainable agriculture has been mentioned as one of the agricultural development policy objectives in Iran. In the policy document on the Mazandarn region, this objective is defined as creating a balance between land use and environment, through reduced use of chemicals and fertilisers. Although sustainability can hardly be defined in totally objective terms, and involves various subjective choices, that result in different concepts of sustainable land use, the current increase in the use of chemical fertilisers and pesticides in the Amol area constitutes a clear threat to the environment. By incorporating environmental requirements in the scenarios as a policy objective, an indication of the direction in which sustainability develops can be generated.

The first environmental requirements relate to the mineral surpluses generated by the intensive use of chemical nitrogen and phosphorus fertilisers. For phosphorus, equilibrium fertilisation is, in principle, possible. Averaged over a number of growing seasons, an equal amount of phosphorus can be applied in chemical form, as exported in crop products, implying no accumulation in the soil with the risk of subsequent leaching. This is possible, because phosphorus may be temporarily fixed in the soil, thus allowing to bridge the difference between application of fertiliser and absorption by the crop (WRR, 1992). In contrast, nitrate is highly mobile and can easily disappear from the soil by leaching into the groundwater, run-off in surface water or in gaseous form into the air. In terms of the sustainability objective of reducing the burden on the environment as a result of excessive use of fertilisers, nitrate is the relevant substance (WRR, 1992). The objective is a reduction in the amount of nitrogen emitted to the environment. There are various ways in which the objective can be expressed: nitrogen input or loss per hectare, or nitrogen input per unit product.

In addition to the use of mineral fertilisers, input of crop protection agents is a second major cause of land use-related environmental problems. Pesticides are designed to kill localised groups of organisms. The 'ideal' pesticide therefore should be highly specific and , moreover disappear rapidly from the environment. Many substances, however, have a are broad spectrum, and are persistent, so that in practice there are nearly always toxic effects. Apart from poisoning of organisms other than the target organisms in the agricultural areas, organisms may also be poisoned by emission of the substances out of the agricultural areas. Other organisms may suffer from toxic effects, because poisons are incorporated in the food chain. The policy objective, therefore is minimisation of the use of pesticides. The use of pesticides is expressed in kilograms active ingredients. It should be borne in mind, however, that this measure tells us nothing about the degree of toxicity in terms of ecological effects. Little is known about distribution and losses, so that for the purpose of this study, the input of crop protection agents has been used as a measure for sustainability. Once again, the objective may be defined in various ways: input per hectare to indicate the direct effects on the environment, or input per unit product to indicate the indirect effect through the food chain.

Summary of policy objectives
Various agro-technical, socio-economic and agro-ecological objectives have been identified of which nine are finally used in the evaluation procedure (Table 8.1). Although the norms found in land use studies literature have been applied, the classification of these objectives is not sharp. For instance, some of the objectives included in the socio-economic realm may have an agro-technical dimension or vice versa. However, this classification has no effect on the evaluation procedure.

Table 8.1 Policy objectives used in the evaluation procedure

Realm of objective	Objective
Agro-technical	Increase in overall production efficiency
	Increase in food production efficiency
Socio-economic	Increase in total farm income
	Decrease in total variable production cost
	Attain equitable income distribution
	Increase total "steady" employment
	Decrease total "highly-seasonal" employment
Agro-ecological	Decrease nitrogen losses per hectare
	Decrease input of pesticide per hectare

8.3.2 Identification of policy instruments

To achieve policy objectives, incentives need to be identified that influence farmers' decisions on land use and allocation of other resources. Discussion now focuses on the type of policy instruments that should be used to achieve these objectives. Van Keulen et al. (1998) discuss the influence of different policy interventions on farm household decision-making and their consequences for food security and sustainable land use at farm and regional level. Agricultural development objectives can be achieved by a variety of policy means, which can be imposed directly at the farm level, at the national level, or at some other point in the market.

Different types of policy means can be distinguished (Thorbecke and Hall, 1990; Van Keulen et al., 1998): macro-type and price policies, structural changes, and reforms. The policy problem referred to here does not involve macro-type policy instruments. It includes crop-specific and input-specific price policies, technological changes in crop production, and land consolidation measures. Specifically, five policy instruments are considered: increase in price of rice improved variety, fertiliser subsidy withdrawal, pesticide subsidy withdrawal, mechanisation of rice transplanting and harvesting activities, and consolidating the land. Each of these policy measures is expected to contribute to achievement of some of the policy objectives. They also represent perceptions of different stakeholders with respect to the policy interventions. Identification of policy instruments is based on discussions with resource persons in Amol sub-region including regional policy makers, farmers representatives, co-operative societies, and other regional organisations.

8.3.3 Procedure for generating scenarios

While ILUPPA is a mathematical programming model in terms of solution technique, it is best described as a behavioural simulation model. It attempts to describe how farmers will react, at aggregate level, to certain policy measures that aim at influencing their land use decisions. That leads to the requirement that the objective function is a behavioural characteristic, in that the model results fulfil established conditions of producers or market behaviour. Hence, the objective function formulated in the model is the sum of producers' surplus, i.e. the sum of the net benefits of all farm type land units. Policy objectives do not appear explicitly in the objective function. They have been introduced as variables in the model, or as simple transformations of model variables that have been calculated *ex post.*

To take into account the multiple and (partly) conflicting views of different stakeholders, various policy objectives have been included. Policy measures or instruments are represented in the model structure by coefficients in the matrix, the right hand side, and/or the objective function. After a base solution is obtained, various land use scenarios, corresponding to various policy measures are defined, and the model has been adapted in a way that reflects a new policy, through introduction of new values for the policy instruments. The model is then solved again, recording the new values of the variables indicating policy objectives. By proceeding in this way through a number of policy scenarios, a set of land use policy scenarios is generated, each showing the relation between policy instrument/measure and its effects on policy objectives.

8.3.4 Results

In this study, the ILUPPA model has been run for six scenarios: the base scenario (BSCN), price of improved rice scenario (SCN1), fertiliser subsidy withdrawal scenario (SCN2), pesticide subsidy withdrawal scenario (SCN3), mechanisation of rice transplanting and harvesting scenario (SCN4), and land consolidation scenario (SCN5).

BSCN: base scenario

In the base scenario, for each of the nine farm type land units a selection can only be made from land use systems that are actually practised in the region in the year 1994. The model is solved under 1994 conditions. The results of the base scenario will be presented for the three realms of policy objectives: agro-technical, socio-economic and agro-ecological. All results are presented for the sub-region as a whole and per farm type land unit. The former show sub-regional totals or averages, while the latter provide an indication of the differences among the farm type land units.

Agro-technical aspects

Land productivity is assessed through two indexes: overall production efficiency index and food production index. The overall production efficiency index is calculated as the weighted average of the production efficiencies of all crops. The production efficiency of a crop is the ratio of crop yield per hectare and the maximum yield realised in the sub-region, expressed as a percentage. The food production efficiency index is expressed in terms of total caloric production per hectare, which is an indication for food security from crop production.

The value of the sub-regional average for the overall production efficiency is 0.84 and for the food production efficiency is 168 Mcal ha^{-1} yr^{-1} (Table 8.2).There are large differences among farm type land units in terms of both indexes. In terms of both indexes, farm type land unit FT3LU4 is the most productive, while farm type land unit FT2LU2 is the least productive. Other farm type land units have either above sub-regional average productivity (such as FT1LU3, FT3LU5 and FT4LU3) or below sub-regional average productivity (such as FT1LU1, FT1LU2, FT4LU2). Farm type land unit FT4LU1 is an exception with slightly below average overall production efficiency and highly above average food production efficiency. Part of the explanation is provided by the cropping pattern: 96% of its land is used for Amol3 improved rice variety with high yields per ha.

Table 8.2 Results related to agro-technical parameters per farm type land unit: base scenario

	FT1LU1	FT1LU2	FT1LU3	FT2LU2	FT3LU4	FT3LU5	FT4LU1	FT4LU2	FT4LU3	Sub-region
Land use (ha)										
-Rice (Tarom)	3011	2175	1720	5104	2340	1368	34	1471	2776	19999
-Rice (Amol3)	608	1818	651	1745	2614	1336	786	661	2611	12830
-Wheat	0	0	0	0	0	181	0	0	0	181
-Barley	0	0	0	0	434	0	0	0	48	482
Overall production efficiency index (%)	77	75	90	69	100	96	79	85	87	84
Food sufficiency index (Mcal $ha^{-1}yr^{-1}$)	141	155	171	132	205	191	191	165	189	168

Socio-economic aspects

The sub-regional aggregate value of farm income, is 69021 M*Rials* yr^{-1} (Table 8.3), equivalent to US$ 13.8 million. The contribution per individual farm type land unit to total farm income differs, depending on its economic performance and its area cultivated. There are large differences among farm type land units with regard to the production economic results. In terms of the economic parameters farm income per hectare, return per unit labour, and return per unit water, the farm type land units FT3LU5, FT4LU1, FT4LU2 and FT1LU3 are most efficient, while the remaining farm type land units are less efficient.

Table 8.3 also show a divergence in average variable production costs among farm type land units. Among the economically more efficient farm type land units, FT3LU5 is the only farm type land unit with below sub-regional average variable cost. Part of the explanation is that this farm type land unit, although using high levels of purchased inputs, uses relatively small amounts of factor inputs and relies totally on family labour, and hence shows a high ratio of farm income to gross value of production.

Table 8.3 Economic performance per farm type land unit: base scenario

	FT1LU1	FT1LU2	FT1LU3	FT2LU2	FT3LU4	FT3LU5	FT4LU1	FT4LU2	FT4LU3	Sub-region
Total land use (ha)	3618	3992	2371	6849	5388	2885	820	2132	5435	33491
Gross value of production (MRials yr^{-1})	11510	14600	11430	25080	21180	14420	3846	10060	20930	133056
Total variable production cost (MRials yr^{-1})	6642	7569	5026	11700	11210	5433	1618	4283	10550	64030
Average variable production cost (KRials $ha^{-1}yr^{-1}$)	1836	1896	2120	1708	2081	1883	1973	2009	1941	1912
Total farm income (MRials yr^{-1})	4865	7027	6400	13380	9976	8989	2228	5773	10380	69021
Average farm income (KRials ha^{-1} yr^{-1})	1345	1760	2699	1954	1852	3116	2718	2708	1910	2061
Average return per unit labour (KRials $manday^{-1}$ yr^{-1})	31	29	41	35	33	45	44	42	31	35
Average return per unit water (KRials per m^3 yr^{-1})	50	52	89	63	61	104	92	88	62	67

Closely related to the objective of increased farm income is the objective of income distribution. The value of the coefficient of localisation (equals 0.12 in Table 8.4), used here to measure the degree of income distribution at the aggregate sub-regional level, indicates a 'fair' income distribution within the sub-region. The values of the location quotient, used here to indicate the income concentration in particular farm type land unit compared to the sub-regional value, shows variability in income concentration among farm type land units. Income is relatively more concentrated in farm type land units FT4LU1, FT4LU2, FT1LU3, FT3LU5, FT2LU2, and FT4LU3, but is less concentrated in the remaining farm type land units. On one hand, farm type land unit FT1LU1 comprises 12% of the farm population and yet earns only 7% of the total farm income. On the other hand, farm type land unit FT4LU1 represents 2% of the farm population and earns 3% of total farm income.

Table 8.4 Income distribution in the sub-region and among farm type land units: base scenario

	Number of farms	Percentage of farms (PF)	Farm income (MRials yr^{-1})	Percentage farm income (PFI)	Location Quotient (PFI/PF)	PFI-PF
FT1LU1	2200	12	4865	7	0.60	-0.05
FT1LU2	2289	12	7027	10	0.83	-0.02
FT1LU3	1275	7	6400	9	1.36	0.02
FT2LU2	3248	17	13380	19	1.11	0.02
FT3LU4	3582	19	9976	14	0.75	-0.05
FT3LU5	2049	11	8990	13	1.19	0.02
FT4LU1	361	2	2229	3	1.67	0.01
FT4LU2	1072	6	5774	8	1.46	0.03
FT4LU3	2586	14	10380	15	1.09	0.01
Sub-region	18662	100	69021	100	1.00	0.12

Notes: The value of location quotient (LQ) per farm type land unit is calculated as a ratio of percentage farm income (PFI) to percentage of farms (PF). LQ value more than 1.0 indicates a high income concentration; LQ value less than 1.0 indicates low income concentration; and LQ value equals 1.0 indicates normal concentration. The value of the coefficient of localisation for the sub-region, that is the sum of either positive or negative values of PFI-PF, is 0.12.

As mentioned earlier, at the aggregate level it is difficult to evaluate the rate of employment increase in a sector or a region only in terms of total annual employment. Seasonality is the essence of the agricultural employment problem, as the agricultural labour force is a mixture of family labour, that is employed for much of the year and hired labour that only works occasionally. Figure 8.1 shows sub-regional aggregate employment per month, for total labour, family labour, and hired labour in the base scenario. The first striking characteristic is, that employment is highly seasonal in the sub-region. The graph illustrates that the increased demand for labour is not distributed uniformly over time. Rather, labour use is increasing most rapidly in the periods May-June and August-September. These periods correspond to the most labour-intensive operations in the sub-region: rice transplanting and harvesting activities.

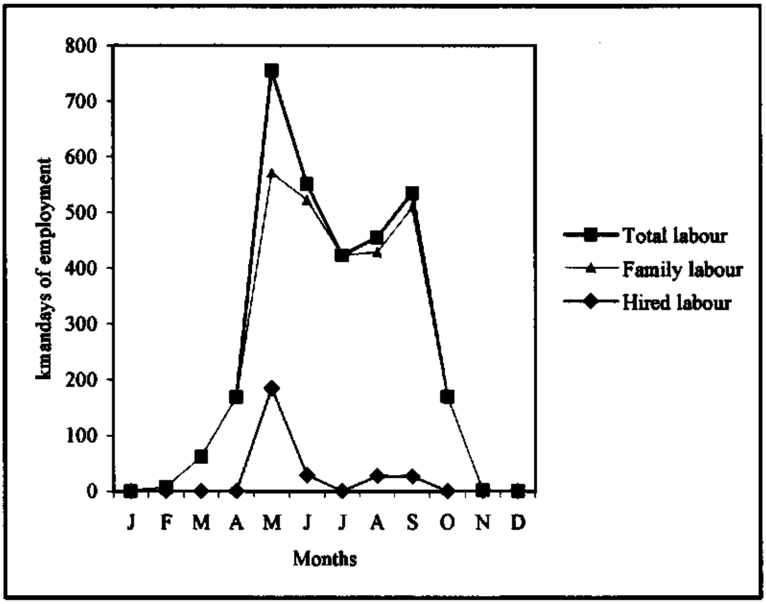


Figure 8.1 The sub-regional aggregate employment: base scenario

Employment generation varies per farm type land unit, which is reflected in the differences with respect to total labour use, family labour use, and hired labour use (Table 8.5). These results are related to average farm size, and family labour availability per hectare, but also to cropping pattern and productivity. In farm type land units FT2LU2, FT4LU1, FT4LU2, and FT4LU3 average farm size is relatively large and, consequently as family labour availability per hectare is low, hired labour use is relatively high. In farm type land units that are characterised by a relatively small farm size and a relatively large family labour potential (such as FT3LU4, FT3LU5, and FT1LU1), family labour use is relatively high, with no or little use of hired labour. In farm type land units with average land and labour resources, the use of labour resources is also intermediate.

Table 8.5 Labour use per farm type land unit: base scenario

	FT1LU1	FT1LU2	FT1LU3	FT2LU2	FT3LU4	FT3LU5	FT4LU1	FT4LU2	FT4LU3	Sub-region
Number of farms	2200	2289	1275	3248	3582	2049	361	1072	2586	18662
Average farm size (ha.)	1.68	1.90	1.86	2.20	1.50	1.41	2.43	2.09	2.10	1.84
Family labour availability (mandays ha^{-1} $month^{-1}$)	17	16	17	15	20	22	13	15	15	17
Family labour use (kmandays yr^{-1})	294	399	222	499	517	283	53	171	424	2863
Hired labour use (k mandays yr^{-1})	0	5	12	98	9	0	17	29	96	266
Total labour use (kmandays yr^{-1})	294	404	234	597	526	283	70	200	520	3129
Average labor use (mandays ha^{-1} yr^{-1})	81	101	99	87	98	98	86	94	96	93

Another explanation for the differences in labour use can be found in cropping pattern and productivity: farm type land units with a relatively high proportion of land used for rice variety Amol 3 are characterised by higher average labour use per hectare. However, also farm type land units with a relatively high proportion of land used for rice variety Tarom with relatively high yield levels (intensive), have high average labour use.

Agro-ecological aspects

The quantity of nitrogen emitted to the environment is expressed as nitrogen loss per hectare. Sub-regional average nitrogen loss is 86 kg ha^{-1} yr^{-1} (Figure 8.2). Nitrogen loss per hectare varies for the different farm type land units: farm type land units FT1LU2, FT3LU4 and FT4LU2 show above sub-regional average nitrogen loss per hectare, while the remaining farm type land units show below sub-regional average nitrogen loss per hectare.

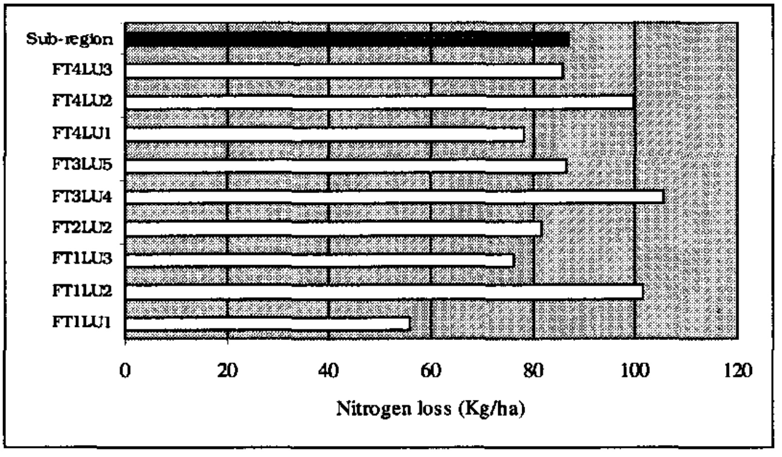


Figure 8.2 Nitrogen loss per farm type land unit: base scenario

In addition to the use of mineral fertilisers, input of crop protection agents is a major cause of land use-related environmental problems. In this study that is assessed through the level of pesticide input, expressed in kilograms active ingredient (a.i.). The criteria are: input per hectare to indicate the direct effects on the environment and input per unit product to indicate the indirect effect through incorporation in the food chain. Sub-regional average pesticide input per unit area amounts to 26 kg a.i. ha^{-1} $year^{-1}$ in the base scenario, with large differences among the farm type land units (Figure 8.3).

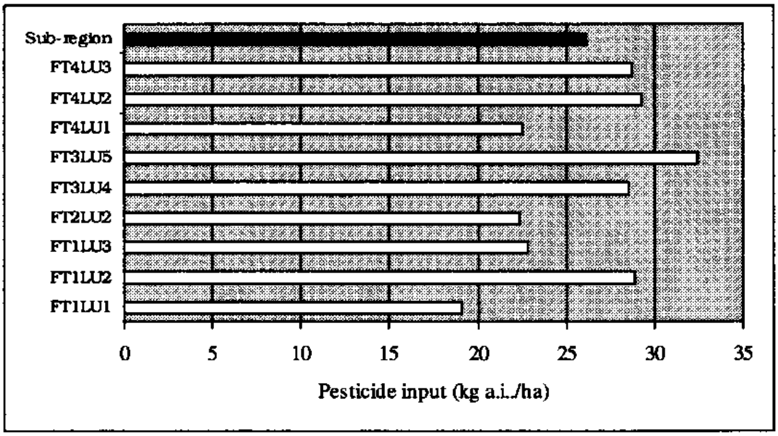


Figure 8.3 Pesticide input per farm type land unit (kg a.i./ha): base scenario.

Farm type land units FT1LU2, FT3LU4, FT3LU5, FT4LU2 and FT4LU3 show above sub-regional average use of pesticides, while the remaining farm type land units show below sub-regional average use of pesticides. In terms of pesticide input per unit of product, the sub-regional average amounts to 5.6 kg a.i. ton^{-1} yr^{-1} in the base scenario, with again large differences among farm type land units (Figure 8.4). Farm type land units FT1LU2, FT2LU2, FT3LU5, and FT4LU2 show above sub-regional average pesticide input, while the remaining farm type land units show below sub-regional average pesticide input.

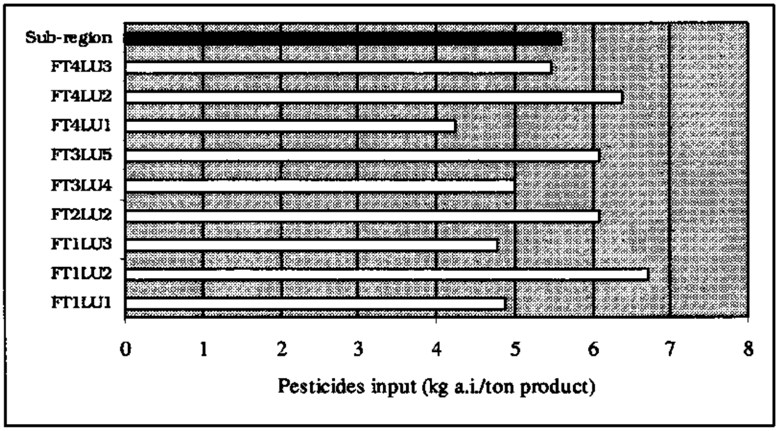


Figure 8.4 Pesticide input per farm type land unit (kg a.i./ton product): base scenario.

SCN1: price of improved rice scenario

In the 'price of improved rice' scenario, the impact of increasing the price of improved rice variety Amol3 on its cultivated area, and thus on realisation of the policy objectives, is evaluated. An increase of 20% in the price of Amol3, for example via a price guarantee, results in a drastic increase in the area cultivated with this crop (92% higher than in the base scenario), at the expense of rice Tarom (66% lower than in the base scenario). The effect of this change in land use on the socio-economic policy objectives is: 31% increase in total farm income, associated with 7% increase in total variable production cost, a more equitable income distribution and substantial increases in labour hiring, while family labour use remains relatively stable. As Amol3 is a high yielding rice variety, the increase in its cultivated area results in a 17% increase in food production efficiency, while the overall production efficiency slightly decreases. For the same reason, total nitrogen input and, consequently nitrogen loss increases.

SCN2: fertiliser subsidy withdrawal scenario

In the 'fertiliser subsidy withdrawal' scenario, the subsidy on fertilisers for rice is removed. Removal of fertiliser subsidies results in a land use change from fertiliser-intensive cropping systems to less fertiliser-demanding systems, particularly for less efficient farm type land units. This is reflected in a 34% decrease in rice Amol3 area while, the area of rice Tarom increased by 22%. This scenario results in a decrease in both nitrogen losses and pesticide input, without adversely affecting farm income, costs and production efficiency. Because less efficient farm type land units are more strongly affected by withdrawal of fertiliser subsidy, income distribution becomes more unfavourable in this scenario. In this scenario less (material) input-intensive land use systems are selected, which are also labour-intensive land use systems.

SCN3: pesticide subsidy withdrawal scenario

In the 'pesticide subsidy withdrawal' scenario, the subsidy on pesticides for rice is removed. Withdrawal of pesticide subsidies results in substitution of pesticide-intensive cropping systems by less pesticide-demanding systems, and substitution of herbicides by hand weeding. This shift in land use is more pronounced in economically less efficient farm type land units, that are characterised by low ratios between farm income and production costs. The effect of removing pesticide subsidies is a substantial decrease in pesticide use, 45% in comparison to the base scenario. The reasons for this strong response are the current high rate of subsidy and the associated large amounts of pesticides used. The effect of removing pesticide subsidies is an 8% decrease in farm income and 12% increase in production costs. As less efficient farm type land units are more strongly affected by the subsidy removal, income on these FTLUs is relatively more reduced, leading to a less equitable income distribution among farm type land units within the sub-region. The effects on production efficiency are small.

SCN4: mechanisation of rice transplanting and harvesting scenario

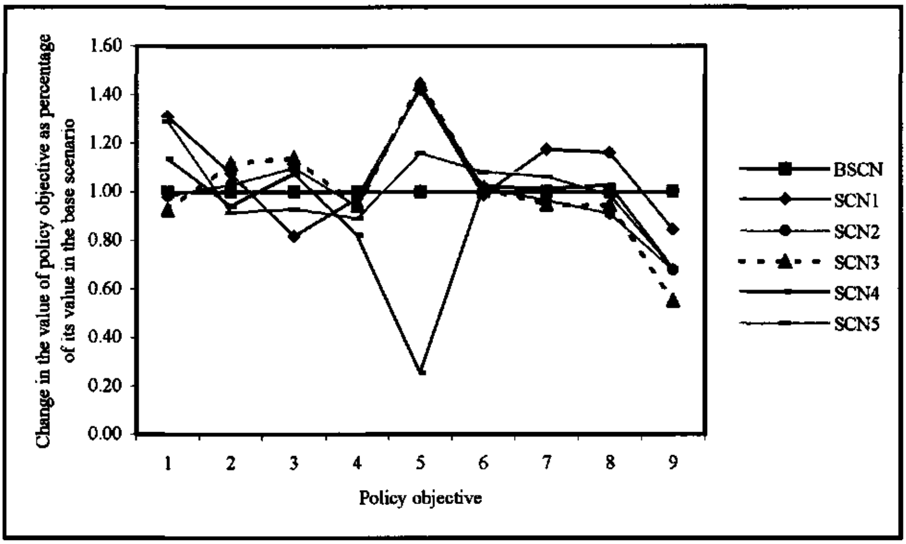
In the 'mechanisation of rice transplanting and harvesting' scenario, the most labour demanding activities are assumed to be mechanised. Mechanisation of rice transplanting and harvesting results in a drastic reduction (75%) in the hired labour for these activities, while the steady use of family labour is reduced by 18%, in comparison with the base scenario. Total variable costs are reduced as a result of the reduction in the costs of hiring labour. Reduced hired labour demand results in a slight increase in production efficiency. The increase in productivity and the reduction in costs of production combined result in a13% increase in total farm income. Most of the increase in income is concentrated in the hands of farmers cultivating the more efficient farm type land units, which results in a less equitable income distribution.

SCN5: land consolidation scenario

In the 'land consolidation' scenario, a land consolidation programme is assumed to be carried out in the sub-region. The effect is a more than 6% increase in productivity, in comparison to the base scenario. Pesticide use is reduced by 31%, while nitrogen loss is slightly reduced by 1%. Because of the increase in productivity, hired labour inevitably increases by 16%. Production costs decrease by 8%. Farm income strongly increases by 29% and is distributed 'fairly' among farm type land units: less efficient farm type land units receive a larger proportion.

Summary of scenarios

The model results point to large differences among the five policy scenarios, with substantial differences for the values of the policy objectives. (Table 8.6). The range in farm income is appreciable: the highest is some 140% of the lowest. For instance, the highest value for use of pesticides per hectare is 182% of the lowest. Seasonal employment varies widely: the highest value is 472% of the lowest. The conclusion that can be drawn from these significant differences is, that there is ample scope for policy influence. To obtain an impression of the effect of alternative policy scenarios on policy objectives, changes in the policy objectives caused by changes in policy, as a percentage of their values in the base scenario, are summarised in Figure 8.5.



Notes: Policy objective 1: farm income, 2: variable production cost, 3: income distribution, 4: steady employment, 5: seasonal employment, 6: overall production efficiency, 7: food production efficiency, 8: nitrogen loss, and 9: pesticide input

Figure 8.5 View of the results of alternative land use policy scenarios.

The figure shows that there is indeed no one single policy scenario for which the values are 'best' for all policy objectives. The 'price of rice Amol3' scenario results in the highest food production efficiency, highest farm income, most equitable income distribution, but also in the lowest overall production efficiency, and the highest nitrogen loss per hectare. The lowest nitrogen loss per hectare is achieved in the 'fertiliser subsidy withdrawal' scenario, but that is associated with the highest seasonal labour use. The 'pesticide subsidy withdrawal' scenario results in the lowest pesticide use per hectare, but the highest production costs. The lowest seasonal labour use is achieved in the 'mechanisation of rice transplanting and harvesting' scenario, while the highest overall production efficiency is attained in the 'land consolidation' scenario.

8.4 Evaluation of land use policy scenarios

8.4.1 Building a policy impact matrix

The basic principle of a multi-criteria evaluation method is very simple (Voogd, 1983): Firstly, a matrix should be built, of which the elements reflect the characteristics of a given set of alternatives, derived from a given set of criteria. A literature search revealed various names for such a matrix, for instance: project-effect matrix, score matrix, effectiveness-matrix. In this chapter, evaluation or impact matrix will be used, because the criterion scores have been expressed in different units. The policy impact matrix has been built by modifying the ILUPPA model in accordance with the new policy instrument and then solve the model again, recording the new values of the variables indicating the policy objectives (Table 8.6).

Table 8.6 Policy impact matrix

Policy objective	Unit of measurement	BSCN	SCN1	SCN2	SCN3	SCN4	SCN5
Agro-technical:							
Overall production efficiency	%	0.81	0.80	0.83	0.83	0.83	0.88
Food production efficiency	Mcal ha^{-1} yr^{-1}	168	197	162	159	170	179
Socio-economic:							
Farm income	GRials yr^{-1}	69.0	90.3	67.9	63.8	78.3	89.2
Variable production costs	GRials yr^{-1}	64.0	68.7	65.9	71.4	60.2	58.6
Income distribution	%	0.12	0.09	0.13	0.13	0.12	0.11
Steady employment	Mmandays yr^{-1}	2.86	2.78	2.69	2.70	2.35	2.55
Seasonal employment	Kmandays yr^{-1}	266	378	383	384	67	309
Agro-ecological:							
Nitrogen losses	kg ha^{-1} yr^{-1}	87	101	79	82	89	86
Input of pesticides	kg a.i ha^{-1} yr^{-1}	26.2	22.0	17.7	14.4	17.9	18.0

Subsequently, the policy impact matrix is constructed as a two-dimensional matrix including policy instruments (alternatives) and policy objectives (criteria). Each entry (effect score) in the table represents the consequence of a specific alternative for each criterion. The policy impact matrix shows that no single policy scenario is most favourable for all criteria. In every analyses, some form of standardisation of the criteria score is necessary to enable meaningful comparisons on the basis of criteria expressed in different units. Various standardisation procedures exist that normalise the criteria scores (see for example Voogd, 1983).

8.4.2 Assignment of priorities: policy views

Another important step in most multi-criteria evaluation methods is the assignment of weights or priorities, reflecting the (relative) importance attached to the various impacts considered by the user, or, in more general terms, the assessment of a preference structure. In formulating and assessing preferences, one has to take into account the limitations in human capabilities for undertaking such endeavors. It is not realistic to expect policy makers to be able to quantify the policy preferences (weights) among objectives, in advance. They are often not prepared or unable to formulate their priorities explicitly. Moreover, in scenario studies, it may be wholly inappropriate to start multi-criteria evaluation with a unique representation of policy priorities.

What is needed in that case, is identification of a number of different combinations of priorities, that together form a good representation of the possible policy views. Here, therefore, hypothetical, qualitative priority statements, linked to a particular policy view are used. The priorities have been represented through ordinal expressions (e.g., more important, equally important, less important, etc.) and, therefore can be referred to as priorities, in contrast to weights, represented by quantitative expressions (e.g., 0.15, 0.28, 0.65). By showing the consequences of various policy views, the model can provide an objective basis on which these preferences can be debated (Hazell and Norton, 1986). In this way it is possible to assist policy makers in selecting the most preferred alternative or to facilitate a movement towards a consensus.

Four possible views on priorities with respect to policy objectives, are summarized in Table 8.7. These policy views are widely divergent, so as to arrive at contesting policy visions or aspirations. Together, these policy views represent the major opinions on the desired development of the region. Each of the views indicates the objectives it prioritizes, while conceding that other objectives are also valid. In environmental protection, for instance, the attention is focused on reducing emission of harmful substances from agriculture to the environment and therefore, which requires that the use of fertilizers and pesticides is minimized.

Table 8.7 Policy views used for the evaluation of policy scenarios

Policy view	Description
Welfare of farmers	Higher priority for increasing farm income, production efficiency, low costs, and reduction of high seasonality in labour demand
Regional development	Higher priority for increasing regional employment, more equitable income distribution, and food production efficiency
Environmental protection	Higher priority for the reduction in contaminants from the agricultural sector to the environment
Compromise	Equal priority for all policy objectives considered in the evaluation process

8.4.3 Appraisal of alternatives

Many and varied multi-criteria evaluation methods or techniques exist that can be used for evaluating alternatives. A number of these techniques is given by Voogd (1983) and Janssen (1992). However, the general advise is to use a small number of alternatives and only a limited number of criteria, ideally of the order of eight alternatives and eight criteria (Voogd, 1983). The evaluation techniques link the information from the evaluation matrix with the information contained in the priority matrix. This usually results in a new matrix, called appraisal matrix, that gives an indication of the general quality of the choice possibilities under consideration.

In this study, many methods have been tried for ranking the alternative policy scenarios under the four specified policy views. The purpose of this appraisal is to answer the question: which policy instrument(s) is/are suitable (or preferable) for achieving policy objective(s) under each of the specified policy priorities. It is meant to provide the policy makers with a menu of policy instruments, with their consequences for policy objectives, under different assumptions with respect to desired policy directions and priorities. Such a menu may serve as an objective basis on which these preferences can be debated. In this way it is possible to assist policy makers in selecting the most preferred alternative or to facilitate movement towards a consensus.

The rankings of the various policy scenarios, from different policy perspectives, are presented in Table 8.8. The table shows, that, for the specific situation of Amol Township and under the assumed policy views: (a) non-price policy instruments are more effective in bringing about the desired changes and in achieving policy objectives; (b) when more priority is given to environmental protection, the present situation, as reflected by the base scenario, is ranked most unfavourable; the 'land consolidation' scenario is a good compromise among the different policy views.

Table 8.8 Summary of the ranking of the alternative policy instruments from different policy views

Policy view	Evaluation method	Policy scenario					
		BSCN	SCN1	SCN2	SCN3	SCN4	SCN5
Welfare of farmers	Weighted Summation	3	4	5	6	1	2
	Regime	4	3	5	6	1	2
	Expected Value	3	4	5	6	1	2
	Evamix	3	4	5	6	1	2
Regional development	Weighted Summation	4	1	5	6	3	2
	Regime	4	2	5	6	1	3
	Expected Value	4	1	5	6	3	2
	Evamix	4	1	5	6	3	1
Environmental protection	Weighted Summation	6	5	4	2	1	3
	Regime	6	4	5	2	1	3
	Expected Value	6	5	4	2	1	3
	Evamix	6	5	4	2	1	3
Compromise	Weighted Summation	4	3	5	6	2	1
	Regime	4	3	5	6	2	1
	Expected Value	4	3	5	6	2	1
	Evamix	4	3	5	6	2	1

Notes: Evaluation method: Weighted Summation method, Regime method, Expected Value method, and Evamix method, are evaluation methods that have different arithmetic procedures for combining the information from the evaluation matrix with the information contained in the priority matrix. This results in an appraisal matrix that gives an indication of the ranking of alternatives. For more details on these methods the reader is referred to Voogd (1983) or Janssen (1992). Policy view: description of policy views is given in Table 8.7.

8.4.4 Sensitivity analysis

In situations, where the criterion scores and priorities can be estimated with complete certainty and where all evaluation methods yield the same ranking of alternatives, there is no discussion on the ranking. However, almost always, results of multi-criteria evaluation will be wrought with a number of uncertainties, associated with the input data and technique used (Voogd, 1980). Empirical applications of multi-criteria evaluation methods in planning practice, show that inadequate treatment of these uncertainties may result in a negative assessment of the entire approach by parties involved in the planning process (Voogd, 1983). Since the aim of this evaluation is to provide policy-makers with a ranking of alternative land use policy instruments under each of the assumed policy directions, these uncertainties are only relevant in relation to their impact on the ranking.

In this section, therefore, procedures developed by Janssen (1992) are applied to: assess the sensitivity of the ranking to the evaluation method applied (*method uncertainty*); assess the influence of uncertainties in scores on the ranking of the alternatives (*scores uncertainty*); and determine the intervals within which the order of two alternatives is insensitive to changes in a score (*score interval*).

Method uncertainty
Understandably, in many real world applications of multi-criteria evaluation methods, there is often uncertainty with respect to the validity of the method chosen. However, in this study, the ranking of the alternatives proved insensitive to the methods used, provided the same scores and weights were used. From the method sensitivity it may be concluded that the rankings, as presented in Table 8.9, can be determined with sufficient certainty.

Table 8.9 Rankings of alternative policy scenarios from different policy view: method uncertainty

Policy view	Ranking of alternatives
Welfare of farmers	SCN4 > SCN5 > BSCN > SCN1 > SCN2 > SCN3
Regional development	SCN1 > SCN5 > SCN4 > BSCN > SCN2 > SCN3
Environmental protection	SCN4 > SCN3 > SCN5 > SCN2 > SCN1 > BSCN
Compromise	SCN5 > SCN4 > SCN1 > BSCN > SCN2 > SCN3

Scores uncertainty
Scores uncertainty tests have been applied to the rankings obtained under the four policy views. The test has been applied to scores of all criteria. It is assumed, that the scores of all criteria may vary by ±20% from the scores included in the evaluation matrix. The rankings for the four policy views: welfare of farmers, regional development, environmental protection and the compromise, proved very insensitive to uncertainty in scores.

Score interval
The procedure discussed first, refers to the sensitivity of the results to changes in scores. This section focuses on the score interval. The question to be answered is how much a particular criterion score must change in order to reverse the ranking between two alternatives. Certainty intervals have been calculated for four pairs of alternatives: SCN4-SCN5 under the *welfare of farmers* policy view, SCN1-SCN5 under the *regional development* policy view, SCN4-SCN3 under the *environmental protection* policy view, and SCN5-SCN4 under the *compromise* policy view. The sensitivity analysis for score interval reveals, that in all rankings under all policy views, mostly no rank reversal values are found or a substantial change must occur in criteria score before a rank reversal occurs.

Chapter 9

Discussion and Conclusions

9.1 Background

The growing concern about land resource management and the associated decline in land qualities, has led to the realisation that many problems in that domain cannot be addressed adequately through a single discipline. This awareness has resulted in renewed attention for integrated, interdisciplinary approaches. It is argued that such an integrated, interdisciplinary approach to problems of sustainable land use is specifically hampered by lack of an adequate methodology. The study reported here, deals with development and operationalisation of a methodology that integrates socio-economic and agro-ecological information in such a way that sustainable land use options at sub-regional level can be formulated and evaluated with the aim of aiding policy makers.

The structure of the basic framework of the methodology consists of six components or sub-frameworks: (i) description and analysis of the integration problem, *(ii)* farm classification methodology, *(iii)* conceptualisation and operationalisation of an integrated unit, (iv) an integrated approach to definition, description and quantification of land use systems, (v) development and validation of the an integrated land use planning and policy analysis model and (vi) generation and evaluation of land use policy scenarios. This chapter consists of three parts. A brief summary of each of the components, followed by a discussion on its strengths and weaknesses is presented in part one. Part two discusses the strengths and limitations of the overall methodology. A final conclusion is presented in part three.

9.2 Components of the methodology: discussion and conclusions

9.2.1 Challenges to integration

The basis of the proposed methodology is the identification of the challenges presented by operationalisation of the integration of socio-economic and bio-physical information in land use planning and policy analysis. A thorough literature search has been carried out to identify the impediments to such integration. From these reviews the following main constraints were distilled:

aggregation problem and difficulty of integrating levels; difficulty of identifying an integrated interdisciplinary unit of analysis; insufficient attention to (quantitative) analysis of socio-economic aspects; and multi-objective nature of land use problems.

Description and analysis of these challenges provide general clues for the approach to be followed, and assist in identification of elements and/or components to be included in the integrated methodology. This led to the conclusion that the integrated framework should: (i) follow an interdisciplinary approach; (ii) creatively deal with the problem of aggregation or integration of levels; (iii) define an integrated spatial unit for land use analysis; (iv) define and describe land use systems as integral systems; (v) use methods and techniques that allow quantitative integration of disciplines and (vi) deal with the multi-objective nature of land use problem.

9.2.2 Farm classification methodology

Integration of disciplines requires linking levels of analysis. In agricultural planning and policy making, scaling up from farm-level to sector-level may be the source of aggregation bias. The problem of aggregation, as such, has long been recognised, but the attention it received in agricultural planning, until recently, is very modest. This may be attributed to the fact that only a mixture of theoretical and empirical aspects has a chance of being successful in this field. Despite the importance of the aggregation problem in land use planning and policy analysis, objective rigor has not been used in the development of farm classification methodologies.

Farm classification methodologies for agricultural planning and policy analysis suffer from at least one of the following drawbacks: classifications are treated as ends in themselves, rather than as means to an end; lack of sound, explicit and objective criteria for classification; lack of a consistent framework or procedure for determining the appropriate number of farm types; difficulty in mapping and identifying the geographical boundaries of farm types; and use of untested and non-validated farm types making their appropriateness for a particular application uncertain.

Such methodologies, when used in agricultural planning and policy analysis may result in significant aggregation errors that could mislead planners and policy makers. Therefore, the farm classification developed in this study aims at reducing the aggregation error, while establishing links between the farm level and the sub-regional level of analysis. This farm classification methodology is a step-by-step search process through a set of possible classification strategies to identify one that serves the purpose reasonably well. It is based on cluster analysis as a means to classify farms and group them on the basis of objective criteria. It combines various clustering methods and proximity measures to group farms on the basis of operational parameters that reflect conditions necessary for exact aggregation. It allows generating and testing alternative classifications.

Most of the empirical work on farm aggregation has concentrated on methods of aggregation rather than on factors that cause aggregation error. The current methodology aims at completeness and a balanced presentation. First, it analyses and interprets the aggregation error and its possible contributing factors and then develops the methods and procedures to reduce this aggregation error. A major feature of the methodology is the incorporation of location (spatial) attributes among the variables, selected for farm classification. This allows mapping of distinguished farm types. Another feature is its flexibility, enabling incorporation of other characteristics or other objects. The methodology is also applicable for other purposes than reducing aggregation bias in farm classification. Obviously, other identifying characteristics will then be selected.

A typical characteristic of the methodology is the initial screening of the selected variables, a step often omitted in other studies. This characteristic improves functioning of the methodology, provides information on the nature of the data, and allows easy and justifiable performance of the tasks of cluster analysis. Another special feature is the objective evaluation and interpretation of its results. The method has been evaluated by comparing the various classification strategies, testing the farm clusters produced by those classification strategies retained for further investigation, and selecting the best strategy that serves the purpose reasonably well.

The methodology presented here is still under development, and hence, contains weaknesses. Although it is operational, it requires detailed data on many farm characteristics and hence enormous data collection efforts. Because of data limitations, the methodology does not include a number of variables required to represent the full range of factors that contribute to aggregation error. Another limitation is that it is synchronic (static) rather than diachronic (dynamic). However, that should not be exaggerated, because the problem of static analysis is an inherent problem in statistics in general and should be accepted as one of its major limitations (Bailey, 1994). Although, in principle, it would be possible to make this methodology dynamic (or at least partially so), that would require an enormous effort.

9.2.3 Conceptualisation and operationalisation of an integrated unit

Conceptually, any attempt to integrate agro-ecological and socio-economic realms should start from the recognition that both realms operate at various hierarchical levels with distinct differences of emphasis and focus. These differences in nature and focus lead to different units of analysis. Land use from an agro-ecological point of view is described in terms of a unit that can be used to discriminate between alternative land uses. The description is basically linked to land. From a socio-economic point of view often the guiding principle for land use decision making is linked to the aspirations of farm-households.

To define a unit of analysis at a level that is acceptable in both realms, the concept of farm type land unit (FTLU)" or alternatively the "integrated unit (IU)" has been introduced. The concept is based on the fact that land obviously has a very strong socio-economic component that is not dealt with in the land unit concept. This land unit therefore, might be called a bio-physical land unit. This creates the difficulty of using the socio-economic specifications in an operational way in land use systems evaluation. In other words, land use types require socio-economic characteristics, that are not specified in the land unit definition. In a socio-economic sense, the concept of land is linked to the farm. Therefore the (bio-physical) land unit has been extended, to include farm type. A unique combination of a land unit and a farm type is referred to as a farm type land unit. Each FTLU is homogenous in terms of both socio-economic and bio-physical characteristics.

The discussion on similarities and differences in units of analysis is closely linked to that between the disciplines from which they originate. While both land unit (LU) and farm type (FT), when used as unit of analysis in land use planning, have merits of their own and are to some extent complementary, their separation imposes distinct limitations. The concept of LU is based on the bio-physical potentials for the use of land, has a strong geographical orientation and emphasises mapping. However, it deals with socio-economic aspects in very general terms and particularly omits the farm as a decision-making unit and neglects the intrahousehold allocation of resources. The concept of FT, on the other hand, gives insight in farm level constraints and potentials, provides a basis for dialogue with farmers that are the real decision makers on land use, and permits analysis of policy options by relating macro and micro levels. However, it hardly provides bio-physical details, and lacks the geographical orientations.

This study explores the possibilities of integrating these units in a new unit, designated "farm type land unit" that removes some of the limitations of both units and combines their strengths. The rationale behind an integrated unit is that land use decision are directly related to the socio-economic conditions, but are also affected by the bio-physical conditions. The concept of FTLU recognises the fact that land has strong socio-economic components, that are not dealt with in the land unit concept and therefore the concept of farm type has been included. This integrated unit, defined as a combination of FT and LU results in a unit similar to that of the farm type, but with a strong bio-physical component or to that of the land unit but with a strong socio-economic component.

As FTLUs are defined at an aggregation level below both FT and LU, they can be aggregated to LU level by combining FTs (e.g., LU1=FT1LU1+FT2LU1), or to FT level by combining LUs (e.g., FT1=FT1LU1+FT1LU2). In this way, aggregation of FTLUs yields land units with strong socio-economic components, or farm types with strong bio-physical components. The concept of FTLU recognises the farm as the level where both bio-physical and socio-economic conditions determine agricultural production. Hence, the farm represents a system that converts inputs into outputs in a particular socio-economic setting (e.g., resource base, technology, management efficiency) under explicitly defined bio-physical conditions (e.g., land resources).

The concept of FTLU has a strong geographical orientation. It emphasises mapping of both, FTs and LUs, and integrates them through spatial linking. Spatially linking farm types and land units can improve the relation between farming systems analysis and land evaluation to the benefit of both approaches. As FTLUs are described in terms of a set of bio-physical properties and socio-economic characteristics, these socio-economic characteristics can be included in an operational way in land use planning and policy analysis. The concept of FTLU also has its limitations. Although it is operational, it needs detailed data, and may add to the complexity of the modelling approach to land use planning and policy analysis.

9.2.4 An integrated approach to definition, description and quantification of land use systems

Analysis and planning of land use requires defining, describing and quantifying land use systems. An integrated approach that defines land use systems as integral systems, describes them in terms of operation sequences, and uses that description in quantification of their input and output coefficients, is developed. Land use systems are defined differently in various studies, depending largely on the purpose. Common in most definitions is that sufficient attention has been paid to quantitative description of the bio-physical aspects of land use systems, however, little or no attention to the description of their socio-economic characteristics. To deal with the socio-economic sub-system within the integrated framework, the approach starts from the farm: as the decision making unit with respect to land use and proceeds with the description of the integral land use system.

To deal with the indicated omission in the definition of land use system, the concept of integral land use system (ILUS) is introduced. The "integral land use system" (ILUS) is a unique combination of a farm type land unit (FTLU), a land use type (LUT), and a production technique. Both, current and alternative land use systems are taken into account in the analysis. Land use systems are described in terms of operation sequences. That description then serves as the basis for the calculation of the required input-output coefficients. The basis for determination of these input and output coefficients is the information derived from the sampled farms. A combination of GIS and statistical techniques has been used for the quantification of these coefficients. Alternative land use systems are defined in such a way that they are technically feasible and aiming at maintaining the resource base and protecting the environment. For quantification of alternative land use activities, a so-called target-oriented approach is applied, in which the combination of inputs required to realize a specific level of outputs is estimated, based on insight in the underlying bio-physical processes.

The description in terms of operation sequences has the advantage, that land use systems do not have to be described again for each change in the calculation of the coefficients. These descriptions can be easily updated on the basis of additional information on described operations or attributes, or by adding or removing operations or attributes. The approach allows for the description of various techniques for single operations for the same land use system, but does not allow description of complex operations, comprising combinations of two or more types of management practices. However, despite this limitation, by explicitly describing the operations and their inputs and outputs, the assumptions underlying quantification of land use systems have been made transparent, and as such can be improved (Jansen and Schipper, 1995).

The approach describes land use systems as discrete points in a continuous space of input-output relations. The definition of discrete technical input-output coefficients implies that marginal factor productivity cannot be determined and direct factor substitution is ruled out (Van Keulen and Kuyvenhoven, 1997). Despite the, apparently restrictive, assumption of discrete land use systems, close approximations can be obtained by incorporating various types of production techniques for the same combination of land use type and farm type land unit. Following the advice of Hazell and Norton (1986), a range of production techniques has carefully been incorporated to considerably enhance the ability of the model to mimic factor substitution.

In the short or medium run, a continuous production function may not be a very accurate representation of reality at the micro level. Discrete choices, represented by observed input and output coefficients (or their linear combinations), usually, are more realistic. In this case, the continuous production function is an approximation of the reality of discrete combinations, and not vice-versa (Hazell and Norton, 1986). The approach builds up the input-output coefficients on the basis of observations of sampled farms. These observed input-output combinations may be more realistic than those obtained by econometric approaches, using continuous production functions, that usually neglect the synergistic characteristics of agricultural inputs. By including production techniques that are not yet widely practiced in the region, the approach allows consideration of alternative land use systems with promising prospects for the region.

For land use planning and policy analysis, description and quantification of input and output coefficients of current and alternative land use systems is needed. Generally, quantification of such coefficients involves many uncertainties. Bessembinder (1995; 1997) identifies three sources or types of uncertainties: lack of knowledge of processes involved, lack of data for quantification and spatial and temporal variation. Description of current land use systems is based on current farming practices, and sufficiently reliable data from the study area have been collected for quantification of the input and output coefficients. Therefore, uncertainties due to lack of knowledge on processes involved or lack of data for quantification are minimized.

Uncertainty due to spatial variation is also minimized through the delineation of different spatial units. Coefficients have been calculated at the farm type land unit spatial scale. However, the use of sub-regional average parameters for estimation of some coefficients at farm type land unit scale, ignores their possible spatial variation (Bouman, 1995). To account for variation within the same farm type land unit, different production levels (averages and possible ranges of values) and their corresponding inputs have been included in the quantification of the coefficients.

For alternative land use systems, quantification of some coefficients (e.g., related to nutrients) is based on knowledge of the underlying bio-physical processes, which enables description of technically feasible production systems, that are not yet widely practiced by farmers in the sub-region, and that aim at maintaining the resource base and protecting the environment. However, insight in these processes is sometimes fragmentary, and information necessary for quantification of known processes may be partial or not available for the region. Quantification of these coefficients is, therefore, based on data from similar regions and/or theoretical rules. That introduces a degree of uncertainty in these coefficients. However, these coefficients are not included (directly) in the objective function and, therefore, can not directly influence land use allocation. Nevertheless, some sensitivity analyses have been carried out to analyze the effects of uncertainties in these coefficients on the conclusions.

The approach, as presented here, is static in nature. It assumes absence of temporal variations in input and output coefficients. Differences within year have been taken into consideration by including averages and ranges of possible values in calculating yields and their corresponding inputs. Normally, differences in these coefficients do occur over time due to weather fluctuations, interactions, changes in external factors, and growth and ageing of crops (Bessembinder, 1997). Although it is possible to make this approach dynamic (or at least partially), that would require an enormous effort and a large amount of data. Uncertainties, originating from temporal variations in some coefficients have been treated through sensitivity analyses.

9.2.5 Development and validation of an integrated model for land use planning and policy analysis (ILUPPA)

ILUPPA is a mathematical programming model in terms of solution technique, however, it is best described as a behavioural simulation model. It attempts to describe how farmers will react to certain classes of policy instruments that may influence their land allocation decisions. ILUPPA is considered useful as a simulation devise and at the same time as an efficient tool for the analysis of alternative policy options. A distinct feature of ILUPPA is the emphasis placed on design of meaningful policy experiments with a model that simulates market equilibrium, subject to specified policy interventions.

Apart from formal questions of model design, development of ILUPPA has been guided by a number of distinct principles. Considerable emphasis was placed on flexibility in model structure, in order to facilitate adaptations of the structure. The reasoning was, that to be useful for policy analysis, the model would have to be solved many times, with variations in structure and data. A model can be said to have strong explanatory characteristics, if it satisfactorily tracks and replicates the performance and behavior of the system it presents (Thorbecke and Hall, 1990). ILUPPA has been shown to be able to simulate fairly well the behavior of farmers in the Amol sub-region in Iran over the period for which it has been built and tested.

Many sector models contain coefficients representing net economic or financial return to each production activity. Such a description makes it awkward to perform experiments by varying input prices. However, the manageability of ILUPPA is enhanced considerably by keeping pricing and costing activities separate from input and production activities, even though this requires use of additional equations. The advantages of this specification are, that input supplies can be both costed and bounded if appropriate, multistep, upward sloping input supply functions can be introduced, and changes in input prices or supply conditions can be easily introduced, often by changing one parameter in the model instead of hundreds or thousands of aggregate cost coefficients in all production vectors. Another advantage of this specification is the transparency of the structure in the tableau.

A major concern for agricultural policy makers is the future rate of input use in agriculture. By virtue of its detail descriptions on the input side, ILUPPA is a useful instrument for calculating the input requirements associated with different policy measures. Input requirements can be calculated per farm type land unit, per farm type, or at sub-regional level. Furthermore, factor input requirements can be calculated on a monthly basis. This can help in identifying the major sources and times of demand for inputs and give guidance to programs for supplying those inputs. Of particular interest is the projected growth in input demand associated with different policy interventions. Special interest in agricultural planning resides in seasonal labour patterns, that often show large peaks. The model generates seasonal agricultural employment, a characteristic that is not easily obtained directly from surveys in developing countries

An important aspect of ILUPPA is the representation of spatial variability in the delineation of production units. Here, production units are farm type land units. Specification of both input and output coefficients and the source of supply is based on these units. ILUPPA has been formulated as a single-period static model. Differences within year have been taken care of by inclusion of seasonality in both input demand and input supply. Time thus enters the model only as a characteristic of resource inputs. ILUPPA, however, can be applied to different points in time, provided data and appropriate projections of exogenous parameters are available

The ILUPPA model only considers the production side of the farm household, and linkages between production and consumption decisions, characteristic for farm households operating under imperfect markets, are not included. These consumption decisions are especially important, since farm households' implicit priorities can be derived from an analysis of consumptive choice and time allocation. An example of a model that integrates household production and consumption in land use policy analysis, can be found in Ruben et al. (1998).

As risk obviously plays an important role in farmers' decisions, absence of risk variables is a major omission in the ILUPPA model. Various methods for incorporation of risk in linear programming models exist (see for instance Hazell and Norton, 1986), defined in dependence of the nature and type of risk (e.g., yield, price, etc.), the identified attitude of the farmers towards risk (e.g., risk takers, risk avertors, etc.), and data availability. It is beyond the scope of this study to elaborate on this issue. However, inclusion of yield variability and sensitivity analysis may partially reduce the deviations, associated with the absence of risk in the ILUPPA model structure.

In the ILUPPA model, the increasingly recognized role of non-agricultural income in farm household decision-making is not taken into account. This could be handled by extending the model structure to incorporate non-agricultural factor use and migration (Van Keulen et al., 1998).

9.2.6 Generation and evaluation of land use policy scenarios

The approach used in the development and evaluation of land use policy options consists of two major components. Firstly, the linear programming technique has been used to simulate (generate) the possible effects of alternative policy instruments on predefined policy objectives. Secondly, these alternative policy options have been evaluated using a multi-criteria evaluation technique under various policy priorities.

Against the background of much recent debate on the effectiveness of various policy instruments, the proposed methodology is a useful tool for evaluating the consequences of different policy options at three levels of aggregation: farm type land unit (FTLU) level, farm type (FT) level, and sub-regional level. This allows targeting of instruments for a specific FTLU or FT. The methodology can also be used in the so-called consensus-oriented policy making process, because different policy objectives are formulated explicitly, different priorities may be given to the objectives, and the trade-offs between these objectives are formulated in tangible terms.

However, identification of policy objectives and policy instruments to be used in land use policy analysis, is often difficult and controversial. Ideally, identification of the policy objectives and instruments to be included in the analysis should be the result of interaction between the stakeholders, be it policy makers or farmers, and analysts (Thorbecke and Hall, 1990). Although some interaction has taken place through discussions with some stakeholders, the ideal situation is difficult to achieve given the complexity of policy making and the multiple objectives in many developing countries. Explorative studies can play a role in formulation of policy objectives (Van Ittersum et al., 1998).
In generating land use policy scenarios, policy instruments are generally tested individually, i.e. only one policy change is examined at a time. This has the advantage of permitting identification of the effect of each individual policy change. However, occasionally it may be desirable to simulate the effects of a package of policies, as the interactive effects of several policy changes is likely to be different from the sum of effects of individual changes (Hazell and Norton, 1986).

In the current approach it is assumed that, if an alternative (sustainable) land use system is selected it can immediately and easily be implemented by land users without cost. However, the assumption of costless and immediate adoption of alternative (sustainable) technology needs modification (Van Keulen et al., 1998). This might be solved by feedback from the models to agricultural research, to suggest testing of promising options on which further experimental research should be focused.

9.3 Discussion on the methodology

The proposed methodology suggests an interdisciplinary approach to land use planning and policy analysis, because it integrates information from socio-economic and agro-ecological disciplines, by combining various tools and techniques, borrowed from many specialisations. It allows generation and evaluation of many policy scenarios, that correspond to different policy instruments and their consequences for development policy objectives. It allows evaluation of these scenarios under different policy priorities.

A major advantage of this methodology is, that scale effects are well represented. It includes three spatial aggregation levels: farm type land unit level, farm type level, and sub-regional level. The farm type land unit has been selected as the unit for land use modelling. This use of FTLU in land use planning and policy analysis offers the following important advantages: it facilitates the integration procedure by combining socio-economic and bio-physical aspects in the description and quantification of land use systems; it simulates the probable behaviour of farmers at the micro level; it permits analysis of the impact of policy options at various levels, FTLU, FT, and sub-region, thus relating macro and micro levels; and it reduces the causes of aggregation bias by allowing restrictions on resource mobility, by allowing for differences in technologies of production, and by incorporating spatial differentials in prices and costs.

Data bases created during farming systems research are generally insufficiently used for policy simulations at local and regional levels (Van Keulen et al., 1998). In contrast, an important characteristic of the present methodology is the design of a large farming systems database, to easily retrieve data in all required sequences and formats, and to perform tasks of data analysis and presentation without loosing details stored in the information. Moreover, the inclusion of location parameters as attributes in the farming systems database permits explicit georeferencing and subsequent linking of socio-economic data with the bio-physical ones, using a combination of GIS and statistical methods.

It has often proved difficult, if not impossible to relate socio-economic information obtained from farming systems analysis with bio-physical information derived from land evaluation, because the former does not contain any georeferencing. The procedure developed within the proposed methodology for the explicit georeferencing (or mapping) of the farm types, is indeed a significant improvement in land use planning approaches, as it provides an essential missing link between the socio-economic and agro-ecological information.

The methodology forms the basis for improved interaction between agricultural research and information management. By identifying data needs and requirements for effective agricultural planning and policy analysis, the methodology may guide data collection and stimulate development of improved appropriate databases and information systems. Additionally, the methodology may also direct agricultural research to areas that fill gaps in the required information.

Strong point of the methodology is the use of a quantitative approach that permits integration of agro-ecological and socio-economic information in support of policy analysis. Additionally, the methodology is explicit in the assumptions and relationships underlying the quantification of various parameters. In this way, the methodology is more transparent than many qualitative tools. However, various aspects of land use decisions are less easy (if not impossible) to quantify. This applies to many sociological, cultural, and even ecological variables and relationships, that can play an important (or even decisive) role.

Further refinement of the methodology is required, however, to cope with major limitations: absence of temporal variation, absence of the risk dimension in farm household decision making, absence of the consumption side in farm household modelling, absence of factor substitution possibilities in the quantification of land use systems, and absence of the increasingly recognised role of non-agricultural income in farm household decision making. However, another limitation of the proposed methodology is also recognised: its operationalisation requires a very large amount of data at farm level. Data needed may not be available in many developing countries and they may lack the necessary resources to collect them. Nevertheless, the approach can be implemented with less data, and can be used to indicate information gaps that can be filled gradually.

9.4 Validity and usefulness of the methodology

The usefulness of the methodology developed in this study, and the relevance of its results has been evaluated on the basis of its application in a real case study. To assess the quality of the methodology, the generated results have been compared to those obtained from other approaches . The comparison has been made in terms of the magnitude of the aggregation errors associated with different land use modelling approaches. To quantify the aggregation errors, three alternative approaches of modelling land use in Amol Township have been developed, each with a different spatial unit as basis for the analysis. The three approaches include: a sub-regional model based on farm type land units (model 1), a sub-regional model based on farm types (model 2) and a sub-regional model in which the sub-region is modelled as a single farm (model 3). In terms of production techniques, the models could only select current land use systems. In all cases, the objective function is maximisation[8] of net benefits under 1994 input and output prices. Similar assumptions have been used in all specifications.

In the literature, the model based on the most disaggregated units is generally used as a standard, against which the performance of other models can be judged (see, for example, Jansen and Stoorvogel, 1998). This procedure is based on the implicit (biased) assumption that the lower the level of aggregation, the smaller the error. However, that is not necessarily true. In this study, the available data on the current situation are sufficiently detailed to be used as a yardstick against which the estimates obtained in the three models can be judged.

Three sub-regional models, corresponding to the different approaches have been constructed. Estimates obtained from these models are then compared with the actual situation. The percentage deviation of the estimates of the models from the actual situation is defined as aggregation error. This aggregation error is quantified for each of the three approaches in terms of land use, input use, and crop production, as presented in Table 9.1

[8] The objective function values obtained in the three models are *MRrials* 69017, *MRrials* 85383, and *MRrials* 100931 in model 1, model2, and model3 respectively.

Table 9.1 Quantification of aggregation errors using different modelling approaches

	Actual	Estimates by the various modelling approaches			Aggregation errors in the various modelling approaches		
		Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Fertiliser input use							
- urea (tons)	11334	11886	13424	14764	4.9%	18.4%	30.3%
- diamoniumphosphate (tons)	7950	8125	9386	9913	2.2%	18.1%	24.7%
Production							
- tarom (tons)	79695	77068	71814	56724	-3.3%	-9.9%	-28.8%
-amol3 (tons)	73316	77833	97039	127660	6.2%	32.4%	74.1%
Land use							
-tarom (ha)	20700	19999	15791	14102	-3.4%	-23.7%	-31.9%
-amol3 (ha)	12490	12829	16953	19559	2.7%	35.7%	56.6%

Table 9.1 shows a wide range in magnitude of the aggregation error in the estimates obtained by the three models. Model 1 shows the lowest aggregation errors, model 3 the highest. The aggregation error in model 3 is considerable, with, for instance, an estimated production of improved rice (amol3) exceeding actual production by more than 74%. The aggregation errors in model 1 are indeed small compared to those in both model 2 and model 3. Aggregation errors in model 2 are, on average, 58% of those in model 3, while those in model 1 are, on average, 20% and 10% of those in model 2 and model 3, respectively.

In conclusion, the proposed methodology proves to considerably reduce the aggregation errors when compared to the existing modelling approaches in land use planning and policy analysis and is therefore expected to make a significantly positive contribution to improved quality of agricultural planning and policy analysis. Some degree of aggregation is, of course, inevitable to facilitate modelling and to restrict the costs of the analysis to 'reasonable' levels. Implementation of the proposed methodology requires a large database and the gains in precision of the analysis must be balanced against the higher costs of developing and implementing the methodology.

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Samenvatting

De groeiende aandacht voor bodembeheer, onder andere ingegeven door de waargenomen achteruitgang in bodemkwaliteit, heeft geleid tot het besef dat problemen die zich voordoen bij planning en beleidsformulering met betrekking tot landgebruik, niet door disciplinair onderzoek kunnen worden opgelost. Dat besef heeft geleid tot hernieuwde belangstelling voor geïntegreerde interdisciplinaire benaderingen. Er wordt betoogd dat toepassing van dergelijke geïntegreerde interdisciplinaire benaderingen met betrekking tot problemen rond landgebruiksplanning en beleidsformulering vooral wordt gehinderd door gebrek aan een adequate methode. Hoewel deze beperking in toenemende mate wordt (h)erkend in de verschillende disciplines, wordt er relatief weinig aandacht besteed aan de vraag hoe agro-ecologische en sociaal-economische aspecten van landgebruik kunnen worden geïntegreerd.

De studie die in dit proefschrift wordt beschreven levert een bijdrage aan ontwikkeling en operationalisering van een methode voor planning van en beleidsanalyse met betrekking tot landgebruik die de agro-ecologische en agro-economische informatie integreert op een zodanige manier dat beleidsopties voor landgebruik op sub-regionaal niveau kunnen worden geformuleerd en geevalueerd, met het doel beleidsmakers te ondersteunen.

De studie begint met een kritische evaluatie van de bestaande instrumenten voor landgebruiksplanning met speciale aandacht voor hun sterke en zwakke punten met betrekking tot integratie van bio-fysische en agro-economische aspecten. Dit leidt tot de vaststelling dat er behoefte is aan een alternatieve geïntegreerde methode, en tot identificatie van de moeilijkheden en uitdagingen die ontwikkeling van een dergelijke methode met zich mee brengt. De basisstructuur van een raamwerk voor een methode die bio-fysische en sociaal-economische aspecten van landgebruik integreert is ontwikkeld en wordt gepresenteerd.

De conceptuele basis voor het geïntegreerde raamwerk is afgeleid van de theorie van economische beleidsanalyse van de landbouwsector, de systeemanalytische benadering en de concepten van regionale landgebruiksplanning en beleidsanalyse. De structuur van het methodologische raamwerk bestaat uit een aantal aan elkaar gerelateerde blokken (sub-raamwerken). Ieder sub-raamwerk van de methode bevat een aantal stappen, en heeft een aantal instrumenten en/of methoden nodig voor operationalisering. De sub-raamwerken zijn verder ontwikkeld en geoperationaliseerd aan de hand van een case studie voor de Amol sub-regio in Iran.

Na identificering van de beperkingen van bestaande classificatiesystemen voor landbouwbedrijven is een alternatieve methode ontwikkeld. De voornaamste doelen van de bedrijfsclassificatie zijn het verminderen van de fouten die optreden als gevolg van aggregeren, en het integreren van de analyse op bedrijfsniveau met de analyse op geaggregeerd niveau. De ontwikkelde methode combineert verschillende manieren van clustering en benaderingsmethoden voor het groeperen van bedrijven op grond van operationele karakteristieken die de noodzakelijke voorwaarden voor een exacte aggregatie weerspiegelen. De methode bestaat uit een stap-voor-stap procedure door een set van mogelijke classificatiesystemen teneinde er één te identificeren die geschikt is voor het gestelde doel. De methode, zoals geïllustreerd voor Amol Township, maakt het mogelijk verschillende classificatiesystemen, die ieder resulteren in verschillende bedrijfstypen, te genereren en te testen.

In de studie wordt aangegeven dat 'land' ook een sterke economische component heeft, die niet wordt meegenomen in het concept van 'landeenheid (=land unit)', en er is daarom een meer geïntegreerde eenheid gedefinieerd. Voor dat doel is het concept 'bedrijfstype-landeenheid (farm type land unit, FTLU)' geïntroduceerd. Een FTLU wordt beschouwd als dat deel van het land van een bepaald bedrijfstype dat in een gegeven landeenheid ligt, of, in andere woorden, dat deel van een bepaalde landeenheid die bij een bepaald bedrijfstype hoort. Het concept FTLU is geoperationaliseerd door een (gedeeltelijke) link te maken tussen een Geografisch Informatiesysteem (GIS) en de classificatiemodellen. Deze link maakt het mogelijk bedrijfstypen in kaart te brengen en ze dan ruimtelijk te verbinden met landeenheden.

Een geïntegreerde benadering voor het definiëren en beschrijven van landgebruikssystemen, en het kwantificeren van hun input- en outputcoëfficiënten wordt gepresenteerd. De gegeven benadering beschouwt landgebruikssystemen als integrale systemen, gekarakteriseerd door zowel bio-fysische als sociaal-economische karakteristieken. Het concept van een Geïntegreerd Landgebruikssysteem (Integrated Land Use System, ILUS) behelst een specifieke manier om een landgebruikssysteem te beschrijven. Iedere ILUS bestaat uit een unieke combinatie van een bedrijfstype-landeenheid, een landgebruikstype (LUT) en een productietechniek. ILUSs worden beschreven in termen van de volgorde van werkzaamheden ('operation sequences'). Die beschrijving dient vervolgens als de basis voor berekening van de benodigde input- en outputcoëfficiënten. Iedere specifieke volgorde van werkzaamheden binnen een ILUS kan worden geïnterpreteerd als een specifieke (landgebruiks)activiteit. Iedere activiteit wordt gedefinieerd en beschreven in termen van input- en outputcoëfficiënten, die in kwantitatieve termen de relaties beschrijven tussen de voor productie benodigde inzet van middelen en de producten, zowel gewenste als ongewenste.

De informatie met betrekking tot bio-fysische en sociaal-economische componenten van landgebruikssystemen wordt dan samengebracht in een geïntegreerd model voor landgebruiksplanning en beleidsanalyse (Integrated Land Use Planning and Policy Analysis, ILUPPA). ILUPPA is een wiskundig programmeringsmodel in termen van de oplossingstechniek, maar het kan het best omschreven worden als een simulatiemodel van het gedrag. Het model probeert te beschrijven hoe boeren zullen reageren op bepaalde soorten beleidsmaatregelen, die mogelijk invloed kunnen uitoefenen op hun beslissingen met betrekking tot landgebruik. ILUPPA genereert verschillende beleidsopties met betrekking tot landgebruik, door het definiëren en beschrijven van verschillende beleidsscenario's, die corresponderen met verschillende beleidsmaatregelen.

Omdat het model bedoeld is om beleidsopties voor duurzaam landgebruik te genereren, zijn verschillende landgebruiksscenario's gedefinieerd, die corresponderen met verschillende beleidsmaatregelen. Op grond van deze scenario's genereert het model een aantal alternatieve haalbare landgebruikspatronen, gekarakteriseerd door de gebruikte ILUSs met hun bijbehorende input- en outputcoëfficiënten. Vervolgens is een multi-criteria evaluatiemethode toegepast om de rangorde van de set van alternatieve landgebruikspatronen te bepalen, om zodoende beleidsmakers te helpen bij het selecteren van het 'beste' of het meest gewenste landgebruikspatroon, of om het vinden van een consensus te vergemakkelijken. Om rekening te houden met de vele en mogelijk conflicterende opvattingen, worden verschillende voorkeuren of prioriteiten in de evaluatie betrokken.

De volgorde van de verschillende beleidsscenario's, zoals bepaald door verschillende beleidsperspectieven, wordt gepresenteerd. De resultaten laten zien dat, voor de specifieke situatie van Amol Township, en voor de aangenomen beleidsopvatting, niet-financiële beleidsinstrumenten het meest effectief zijn voor het verwezenlijken van gewenste veranderingen en het realiseren van beleidsdoelstellingen; wanneer milieubescherming een hoge prioriteit heeft, wordt de huidige situatie, zoals beschreven in de basisrun, als de meest ongunstige gerangschikt, en is het 'ruilverkavelings-scenario' een goed compromis voor de verschillende opvattingen.

Op grond van de resultaten mag worden geconcludeerd dat de voorgestelde methode leidt tot aanzienlijke vermindering van de aggregatiefouten, in vergelijking tot bestaande modelbenaderingen voor landgebruiksplanning en beleidsanalyse, en de verwachting is gerechtvaardigd dat deze methode een belangrijke bijdrage kan leveren aan het verbeteren van de kwaliteit van landbouwplanning en beleidsanalyse. Een zekere mate van aggregatie is altijd noodzakelijk, om modelanalyse mogelijk te maken en om de kosten van de analyse binnen de perken te houden. Toepassing van de voorgestelde methode vraagt echter een zeer uitgebreide database en de winst in nauwkeurigheid moet wel worden afgewogen tegen de hogere kosten van ontwikkeling en toepassing van deze methode.