# DEVELOPMENT OF AN APPROPRIATE RESOURCE INFORMATION SYSTEM TO SUPPORT AGRICULTURAL MANAGEMENT AT FARM ENTERPRISE LEVEL

## A prototype design for a decision support system in Moghan Agro-Industrial Complex, Iran

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Promotor: Dr. Ir. M. Molenaar
Hoogleraar landmeetkunde en teledetectie

Co-promotor: Dr. Ir. H. Van Keulen
Professor of Agroecology and Modelling
International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede

Mohammad Ali Sharifi

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# PROPOSITIONS

1- In the current practice of agricultural management systems, many technical data are collected that are not integrated into the management decisions.

2- A major contribution towards sustainable agricultural development can be expected from an appropriate resource information system that supports proper planning, monitoring and evaluation functions. *(This thesis)*

3- Planning is a dynamic process; its dynamics can be realized through a proper monitoring and evaluation system.

4- Integration of GIS and modelling capabilities to explain and simulate different phases of decision making in agricultural environments offers a real possibility to improve resource management and planning for sustainable agricultural development.*(This thesis)*

5- With increasing capacity and availability of computer processing techniques, it is feasible to develop and apply comprehensive land use planning methods which include crop growth simulation models, large-scale mathematical programming models and geographic information analysis. *(This thesis)*

6- Land use planning has agronomic, economic, social and political dimensions. It is a multiple decision problem with conflicting objectives. It requires methodologically sound decision support systems for the integrated analysis of inter- and multi-disciplinary phenomena.

7- Among normative models of decision making, linear programming models allow proper integration of knowledge from various disciplines and provide a rather natural framework for farm planning. *(This thesis)*

8- At the moment, crop growth simulation models are the best tools to quantify the relative productivity of different lands, long-term yield variability, and the relative importance of the growth factors, as a basis for land use planning.

9- For quantitative analysis of spatial data, new methods for preparation of thematic maps, on the basis of remote sensing techniques and direct use of all point observations and a proper spatial interpolation method in a GIS are needed.

10- The advent of GIS has created a great potential for the management and analysis of spatial information and communication of the results of analyses to decision makers. To date the information management and presentation features of GIS have received heavy emphasis.

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11- The purpose of technological development is to provide an abundance of goods and services for the betterment of mankind. Corporate control of technological development is preventing this, and is increasing rather than decreasing the differences between the rich and the poor. It is the duty of the intellectual community to guard science and technology against this corporate domination.

12- Different cultural and economic conditions require different technological approaches; thus, direct transfer of western technology is not the ultimate solution to all problems of the developing countries.

13- Technological development in third world countries cannot be generated or stimulated by only diffusing capital, hardware, software and operational training. This should be supplemented by educational programmes that allow upgrading/adaptation of the technology to the local conditions.

14- The educational programme of each society follows its development objectives. In many instances, training of elites from third world countries according to the educational programme of western society is non-functional, because their societal objectives are completely different.

15- Aid programmes for the development of third world countries are most effective if they are directed towards educational/training programmes which are adapted to the problems and needs of developing countries.

16- ITC should stay.

M.A.SHARIFI

# Abstract

Sharifi, M.A., 1992. Development of an appropriate resource information system to support agricultural management at farm enterprise level (ARIS). Ph.D. Thesis, Wageningen Agricultural University, The Netherlands. 217 pp., 42 figs, 23 tables.

This thesis describes development of and experimentation with a prototype of an appropriate resource information system that improves decision making processes in farm management. The system includes a geographic information system with a powerful process model that forms a decision support system for land use planning, monitoring and evaluation at farm enterprise level. The land use planning sub-system uses a new concept and supports planning at tactical and operational levels. It consists of a crop growth simulation model that accurately estimates the productivity of each feasible land use, a linear programming model that integrates the physical and socio-economic information and designs the best suitable plan that maximizes the profit of the system under a given set of constraints (tactical plan), and a spatial decision model that translates the tactical plan into an actual operational plan. The system illustrates the importance of process models in the integration of information from various disciplines and sources into management decisions, and the application of geographic information systems in support of multiple objective decision problems.

Keywords: Land use planning, monitoring and evaluation, information system development, decision making process, decision support systems,crop growth simulation, linear programming, multiple decision problem

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# Preface

The concept behind this dissertation developed during the time that I was an advisor to the management of Moghan Agro-Industrial Complex in Iran. The complex is engaged in a variety of agro-industrial activities and is one of the largest of its kind in the world. During that period, I found that a considerable quantity of technical information that was collected almost on a routine basis, documented in various reports and maps, and retained in the documentation centre, was rarely used in management decisions. Careful study revealed that the existing information was not properly utilized because its integration required a team of highly qualified experts in related fields, such as economics, agronomy, soil science, agro-climatology, and information science, which was practically impossible to realize at remote locations.

Further examination of the problem revealed methodological and operational shortcomings in the existing land use planning methods. My multidisciplinary educational and experimental background, combined with the importance of the subject, initiated the formulation and implementation of the present study. Much effort has been invested into this study, and I sincerely hope that the result will make a tangible contribution to better management of the scarce agricultural resources world-wide, in particular in the third world that needs it most.

This study would never have materialized without the contribution of many people to whom I have the pleasure of expressing my appreciation and gratitude. I am deeply grateful to Prof. Dr.Ir. K.J. Beek for encouraging the idea, providing the opportunity for undertaking the research and for his keen interest and critical comments at various stages of its development. I am greatly indebted to Prof. Dr.Ir. H. Van Keulen for his scientific backing, guidance, generous sharing of knowledge and experience, positive attitude, constructive comments, careful study and critical reviews of successive drafts and revisions of the manuscript. I gratefully acknowledge his contribution and have very much appreciated our many interesting discussions.

I am also very much grateful to my promoter, Prof. Dr. Ir. M. Molenaar, for leading the study and also for his critical comments and encouragement at various stages of the research. I owe a great deal to Prof. Dr.Ir. H. Luning who was very helpful in providing support inside ITC, in critical reviews of successive drafts and supporting the integration of the socio-economic information into the system. Many thanks are due to Bert Riekerk who efficiently organized the logistics of the research and was always available for strong moral support. I would also like to express my thanks and gratitude to ITC for providing funds and support, to implement this research.

Ann Stewart edited the thesis. I want to express my appreciation and gratitude for her kind attention, generous and careful work. I am also very grateful to Rob Lucas who donated much time and energy to the design of the cover.

This study would not have been possible without the full cooperation of many people within the Iranian Research Organization for Science and Technology and the management of the Moghan Agro-Industrial Complex. I am greatly indebted to the many individuals in these organizations who, in one way or another, contributed to the study by providing data and facilities in the course of the study, especially during the fieldwork. In particular, I would like to mention Dr. A. Motamedi, the scientific deputy of the Iranian Ministry of Higher Education and president of the Iranian Research Organization for Science and Technology, and engineer A. Khamnavi, the general manager of Moghan Agro-Industrial Complex. I greatly appreciate their help and support.

Finally, a special note of thanks and gratitude to all of my family members, especially Mehri, Yasaman and Sarvenaz for their love, moral support and understanding which were a great inspiration for me to continue and finish the study.

Mohammad Ali Sharifi, January 1992, Enschede

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# CHAPTER 1

## INTRODUCTION

Agricultural systems are dynamic, in the sense that they are in a constant state of change and evolution; events that occur at the present time affect the way in which the system performs both economically and biologically in the future. The dynamics of systems vary according to their type. The economics of agricultural systems are always dynamic, with future possibilities being affected by many different events that influence the biological and economic efficiency of the farm. Agriculture is practised in the form of production, enterprise or farming systems, and the objectives pursued are generally governed by economic considerations. Thus, agricultural systems have to be analyzed from an economic point of view, although financial return is not the only criterion.

Typically, farm management has at its disposal a supply of labour, capital items and land with different qualities and characteristics. Each piece of land can be allocated to the production of several crops under different management levels. Each input can be allocated among production possibilities in many ways, each having a different economic return. The number of possible alternative plans is very large because of the great variability in biological properties of different crops, the diversity in resource potential, and the wide range of feasible production alternatives.

In this complex agricultural environment, managers are frequently faced with such decisions as what commodities to produce, on which tract of land, by what method, in which time period and in what quantities. When decisions have to be made, access to accurate and timely information is essential for rational answers. In the farm environment, decisions are usually made subject to the prevailing farm physical, technical and financial constraints, and often in the face of considerable uncertainty about the planning period ahead. Uncertainty may be related to yield expectations, costs, availability of fixed resources, and to the total supply of resources. In farm planning with multiple and often conflicting demands on the development and use of a resource, and including complex processes, it is almost mandatory that a decision maker has the tools to analyze a variety of information in such a way that the consequences of a series of strategies or options can be examined.

Development of such tool requires a thorough understanding of the system, its constituent processes and their impact on system behaviour. Understanding of an agricultural system requires the integrated analysis of important biological, managerial and economic processes of the system, and, for implementation, finally an integrated model that combines all these interrelated processes.

According to Fayol (1949), management comprises planning, organizing, commanding, coordinating, controlling and evaluating. Because of the inherent complexities and dynamics of an agricultural system, the most crucial of these basic elements are planning, monitoring, controlling and evaluating. Successful implementation of these management elements requires a powerful resource information system that can integrate and analyze the important physical, social and economic components of the agricultural system to support decision making processes.

Such an information system should include planning models to translate the farm goals into operational objectives and, subsequently, these objectives into tactical and operational plans through an organizational hierarchy of planning activities. It should also provide facilities to use the formal plan as a basis for monitoring and controlling the activities and evaluating the results.

## 1.1 Methodological and operational constraints

Various tools and techniques with different orientations (agro-technical and socio-economic) have been developed to support farm management in the decision making process. The advent of geographic information systems (GISs) has created the capability to bring various forms of information from many different sources together and relate them on a common spatial basis. This has created a great potential for the management and analysis of spatial information and communication of the results of analysis to decision makers in a proper format (McAbee, 1991). To date, the information management, presentation and graphics capabilities of GISs have received heavy emphasis. According to Goodchild (1991a, 1991b), "despite widespread recognition that analysis is central to the purpose of GIS, very little progress has been made at incorporating the existing analysis techniques into the current products". In the same way, Nijkamp and Scholten (1991) claimed that the GIS analysis methods are still at an early stage of development and are used mostly as a supplement to existing analysis techniques. This is also true in the field of farm management and land use planning.

The introduction of information systems in general and GIS in particular is not just a matter of terminology; they have conceptual, methodological and structural effects on the organization (Molenaar, 1989, 1991). Their introduction fundamentally changes the way an organization can and will use data; they affect both the power structure in the organization and the mechanics of its work. Centralization of computer databases, such as in a GIS, tends to increase the power of the bureaucrats, administrators, technical experts and computer-literate groups who use them, at the expense of those who lack experience or access to these systems. Computer-based analyses can be used to mystify as easily as they can be used to clarify (Aronoff, 1989).

In the realm of agricultural planning, formal techniques of land use planning have been critically reviewed by, for example, Van Diepen et al. (1991) and Fresco et al. (1990). From these reviews the following main problem areas can be identified:

- Estimation of the biophysical potential of the land.
- Integration of biophysical, social and economic data.
- Operational and implementational aspects of the methods used.
- Integration of the existing information and knowledge into management decisions.

Because of the diversity and complexity of the processes involved in agricultural systems (ecologic, agronomic, social and economic), comprehensive techniques require considerable amount of data from various related disciplines. In actual farm management practice, implementation of these methods requires many data collected in a systematic or task-wise fashion. Fresco et al. (1990) and Van Diepen et al. (1991) discussed some of the operational and methodological constraints that prevent full integration of existing and collected data into management decisions. From those discussions and personal experience, the following problem areas were identified:

- Complexity of the system and decision environment.
- Requirements for high-quality experts (usually in teams).
- Different formats: data are collected by different departments and disciplines using different techniques.
- Lack of tools for analysis and integration.
- Lack of consistency between the available data and the data required.
- Operational constraints: in an agricultural environment, data collection manual organization and processing are inefficient, if not impossible.

These constraints constitute severe limitations for the use and integration of farm data into the management decisions to the extent that planning, monitoring and evaluation activities are frequently neglected, carried out and ignored, or implemented passively. The use of management support systems can remove some of these constraints and enhance the quality of planning, monitoring and evaluation functions, which are significant activities of management.

To improve this situation, methodological research, development of operational procedures and use of dynamic crop growth simulations have been recommended (Van Diepen et al., 1991). With the increasing availability of computer power, the problem of such quantitative analyses has shifted from the mechanics of the solution process to the design of the appropriate structure of the problem. As a result, the application of comprehensive techniques which include crop growth simulation models, large-scale mathematical programming models and the integration of all required processes in a GIS to form a powerful resource information system is becoming more feasible.

According to Moore et al. (1991), in recent years there have been many attempts to develop integrated biophysical and socio-economic models, but few examples of fully integrated models exist. Some of the most interesting research being carried out today is aimed at developing integrated models, databases and information systems to drive them, and decision support systems that permit their use by politicians, policy makers and managers who often lack detailed (or any) knowledge of the model being used. Most agricultural-system models have been either simulation models or optimization models (Hart, 1984). Baker and Hanson (1991) report on the conceptualization of a unique system (ARMS) which integrates the two classes of models.

## 1.2 Purpose of the study

This thesis describes an "appropriate resource information system" (ARIS) and its constituent processes that have been designed as a management support system for land use planning, monitoring and evaluation activities of an arable farming enterprise. The purpose of this system is to remove some of the existing methodological and operational constraints in land use planning, and in the integration of various sources of physical and socio-economic information into the management decisions. It consists of a GIS with a powerful process model that includes a new interactive, integrated land use planning model for supporting sustainable agricultural development at farm enterprise level.

One of the major components of land use planning is "resource analysis", which aims at understanding the basic characteristics of the existing resources and the processes through which they are allocated and utilized (Mitchel, 1979). The land use planning model therefore has the capability to carry out resource analysis and accurately estimate the productivity of land for any feasible type of land use (biophysical land evaluation) at different levels of inputs, and to combine that information with relevant socio-economic data for the design of the most suitable land use plan, taking into account the production policy and all resource and management constraints of the farm enterprise. By varying the constraints, costs and fixed resources, various scenarios can be generated and the effects of alternative decisions can be analyzed. To arrive at the actual operational plan, an allocation model, designed to support the spatial decision making process, translates the tactical plan into the actual operational plan.

Data collection and analysis with regard to state of implementation and performance of the plan constitute control, monitoring and evaluation processes, which are used to measure progress, identify deviations from plans, indicate corrective actions and evaluate management performance. Proper organization of these data, are used to update the relevant databases which will be used for planning, monitoring and evaluation processes. Monitoring and evaluation, normally implemented in three steps, include (1) establishing standards of operation, (2) measuring performance against the standards, and (3) adjusting deviations of the plans from the standards.

To carry out these tasks, the information system should have the necessary capabilities to provide support for determining the standards (decision support and structure decision system), for measuring performance, and for indicating corrective actions (structured decision and transaction processing system).

The Moghan Agro-Industrial Complex (MAIC) in Iran (see Chapter 3) was used as a pilot area to develop, test and evaluate the system. MAIC is located in the Dashte-Moghan area in the northeast corner of the province of East Azarbijan. The complex is engaged in diversified crop and fruit production, dairy farming, meat production, fruit processing and other agriculturally based industries. Arable farming comprises more than 22,000 hectares of irrigated and rainfed wheat, barley, alfalfa, sugar beet and maize for seed, grain and forage. MAIC is a government- owned corporation and runs under central management.

## 1.3 System development approach

There are a number of different approaches to the development of decision support systems. According to Davis and Olson (1985), there is general agreement that decision support systems are developed most successfully by an iterative, prototyping approach. It is an especially appropriate method when the complete requirements are difficult to identify in advance, or when the requirements may change significantly during development. Since this was the situation in this study, a prototyping approach was used for the design and development of ARIS. In the course of the study, an initial prototype of the resource information system was designed and built to support resource analysis, planning, monitoring and evaluation of MAIC.

Information system development requires an information model of the enterprise. An information model consists of three sub-models, i.e., the "data model", the "process model", and the "data processing model" (Benyon, 1990). The data model determines the structure of the information model and consists of data and their relationships. The process model, which includes all decision models and processing functions relevant to the organization, is the basis for the transformation of data into information, and therefore comprises the dynamic part that is the most important component of the information model. The data processing model establishes the relationships between the system's structure and dynamics.

According to Benyon (1990), Goodchild, (1991a) and Nijkamp and Scholten (1991), most of the research effort in information system development has gone into developing conceptual data models, and there is a wealth of literature on the subject. However, it is increasingly realized that the data model in itself is insufficient as an information model, and the process model should be taken into account, because it represents the dynamic part of the information system and integrates/transforms various data into useful information. Emphasis in this study has therefore been placed on the development of a proper process model and its integration into an information system to support rational decision making processes. This included the following:

- Information system development.
- Development of a powerful process model which includes an integrated land use planning model that can support resource analysis, planning, monitoring and evaluation of an arable farming enterprise.
- Experimentation with a prototype of the system implemented at the Moghan Agro-Industrial Complex to assess the quality of the information system and its effectiveness in supporting management functions. This consists mainly of calibration, validation and experimentation with the land use planning model.

The first two stages, which include analysis, design, and realization of a prototype system, have been implemented in the course of system development.

*Information system development*

ARIS includes spatial data handling, transaction processing, structured decisions and a decision support system. The system represents a new technology which should benefit operationally from the state-of-the-art in the related fields. Most of the existing information system development methods were created to support transaction and structured decision systems. They direct most of their effort to data modelling, and normally do not include development of sophisticated process models; some do not reflect present state-of-the-art technology in the definition of the required processes.

The method used for the development of ARIS, in which the process model forms the core of the information system, was based largely on the "ISAC" method proposed by Lunderberg et al. (1978), and where appropriate, uses were made from approaches developed by Hice et al. (1974), Wetherbe and Davis (1985), Jenkins (1983) and Benyon (1990). ISAC divided the analysis and design of the information system into two main groups of activities: problem-oriented work and data oriented-work (see section 2.3). In the present study, although a prototype system has been realized, the data-oriented work is not elaborated in detail. Most of the effort has gone into the description of the problem-oriented work and the development of the conceptual information model.

### *Development of an integrated land use planning model*

Land use planning has different dimensions, e.g., agronomic, social, economic, ecologic and political, and deals with multi purpose use of land, trade-offs between different functions of the land, conflicting interests between different classes of land users, and between collective and individual goals and needs (Van Keulen et al., 1987). As such, land use planning is a multi-objective problem.

As a specific form of planning activity, land use planning must comply with the basic definition and concepts of planning. Planning is defined as a dynamic process that reviews the social, economic, ecologic, physical and technologic development in the past and inventories of present knowledge, know-how, resources, social and economic opportunities and constraints, to provide a framework (plan) for future operational activities and decision making. In land use planning, the plan should be based on sustainable land use and reflect the expectations about the environment, about the capabilities of the organization, and decisions and bargains on such matters as allocation of resources and direction of efforts. The quantified expectations about the environment (planning data) are fed into the planning model (Davis and Olson, 1985).

In this study, an attempt is made to develop an operational integrated land use planning model and integrate it in a GIS to support decision makers in the assessment and evaluation of alternative land use plans. The model adequately incorporates the relevant aspects of theory and information on agronomic, soil, meteorological, economic and information systems, and is sufficiently straight-forward to be computationally feasible in support of land use planning at farm enterprise level. The planning model comprises a number of interrelated sub-models derived from various disciplines, inter alia spatial economics, environmental planning and ecology. The most relevant sub-models are:

- A biophysical land evaluation sub-model, which can accurately estimate the productivity of land for any type of possible land use. This sub-model contains a summary crop growth simulation model.

- A tactical planning sub-model, which integrates the biophysical and socio-economic information in a linear programming model to arrive at the most suitable land use plan in view of the physical suitability of the land and the management policy and constraints of the enterprise.

- An operational planning sub-model to support the spatial decision making process that translates the tactical plan into the actual operational plan. This model allocates a specific crop to each and every tract of land on the basis of demand, the biophysical suitability of the land, crop rotation requirements, irrigation losses and transportation costs for each particular crop product.

- A series of functions to allow derivation of the supporting plans required for the implementation of the operational plan.

***Experimentation with the prototype system in Moghan Agro-Industrial Complex***
Experimentation is essential to evaluate the output and behaviour of the various parts of the system, and includes calibration and validation processes. The monitoring and evaluation sub-system other than the crop growth simulation model, includes straightforward and simple processes, which do not require validation. However, the land use planning sub-system, comprising models of very complex processes of a dynamic system, does need calibration and validation. Experimentation with the system thus concentrated on the land use planning sub-system.

Experimentation focused on the whole planning procedure for a unit of the enterprise, covering an area of more than 2000 hectares of arable land. The biophysical land evaluation model was calibrated and validated using existing field data or data collected during the research on the major crops cultivated in the section. These results and the relevant socio-economic data of the enterprise were introduced into the tactical planning model to produce different scenarios. One scenario was selected and used for derivation of the actual operational and supporting plans.

## 1.4 Organization of the thesis

The methods used for the development of the information system and the integrated land use planning model are described in Chapter 2. The change analysis, including the overall study of the current situation in the pilot area and definition of the development measures for improvement, is discussed in Chapter 3. The activity study that includes identification of the existing problems, information requirements and overall system design is described in Chapter 4. The information analysis that includes definition of the outputs, major processing functions and input information requirements of the system is described in Chapter 5. Chapter 6 is devoted to the data system design, which includes design of the data model, process model, data processing model, equipment adaptation and realization of an initial prototype. Experimentation with the prototype is explained in Chapter 7. Finally, summary, major advantages of the system and recommendations for further studies are presented in Chapter 8.

# CHAPTER 2

## DEVELOPMENT METHOD

The goal of this study was to develop an appropriate resource information system (ARIS) to support resource analysis, planning, monitoring and evaluation of an arable farming enterprise.

A farming enterprise is a complex system. Managing that complexity requires a model, a simplified representation of the system, that contains all essential elements in view of its objectives. For the purpose of information system development, three models are required, i.e., a model of the structure of the enterprise, a model of the dynamics of the enterprise, and a model of relationships between structure and dynamics. Benyon (1990) called this combination an information model. The structure model consisting of data and their relationships is called a "data model"; the dynamics model composed of all the processes is a "process model"; and the model of the relationships between structure and dynamics is a "data processing model". A process model includes all decision models and processing functions relevant to the organization; it is the basis for the transformation of data into information, information system supports, and therefore comprises the most important component of the information model.

Although most database research effort has gone into developing conceptual data models (Benyon, 1990), database theorists realize that the data model in itself is insufficient as an information model, and the process model that integrates/ transforms various data into useful information should be taken into account. This is more evident in the current geographic information systems that are developed in support of natural resource management (Goodchild, 1991; Nijkamp and Scholten, 1991).

In this study, emphasis was put on the development of a proper process model, and its integration into an information system to provide required information for rational decision making in the management process of an agricultural enterprise. This included the following main activities:

- Information system development, including selection, modification and application of an information system development procedure which can be used to (i) identify the existing problems, (ii) identify the information requirements for better management, (iii) design and develop a prototype of an appropriate resource information system to support agricultural management at farm enterprise level.

- Development of a powerful process model which includes an integrated land use planning model that can support resource analysis, planning, monitoring and evaluation of an arable farming enterprise. The model integrates/ transforms data from various disciplines and sources to produce decision-related information in support of sustainable agricultural development. The integrated land use planning model comprises various sub-models that provide facilities to analyze resources, identify potentials and constraints of the agricultural environment and support land use planning at tactical and operational levels.

## 2.1 ARIS system approach

ARIS is a decision support system (DSS) for agricultural development at farm enterprise level. Such a decision support system should allow the decision maker to retrieve data, use appropriate decision models, generate alternative decisions, and test the feasibility and impact of alternative decisions in the course of the decision making process.

A decision making process, as defined by Simon (1960), comprises the following three phases:

- Intelligence phase: the environment is examined to identify problem situations or opportunity situations.
- Design phase: the possible courses of action are initiated, developed and analyzed. This involves application of decision models that compare alternatives, generate solutions, test solutions for feasibility, and analyze different alternatives.
- Choice phase: one of the alternatives, i.e., a specific course of action, is selected.

In the course of the intelligence and design phases, problems are found and formulated, and alternative solutions are developed (Pounds, 1969; Davis and Olson, 1985). Figure 1 shows a flow chart of the decision making process.

There is a flow of activities from intelligence to design to choice, but at any phase there may be a return to a preceding phase. For example, the decision maker in the choice phase may reject all alternatives and return to the design phase for the generation of additional alternatives.

The result of each phase has to be transferred quickly to the decision maker in a manageable, communicable form to control and verify the process. Presentation of the result is therefore very important. Thus an intermediate step containing the proper presentation of the results is added to each phase of the decision making process.

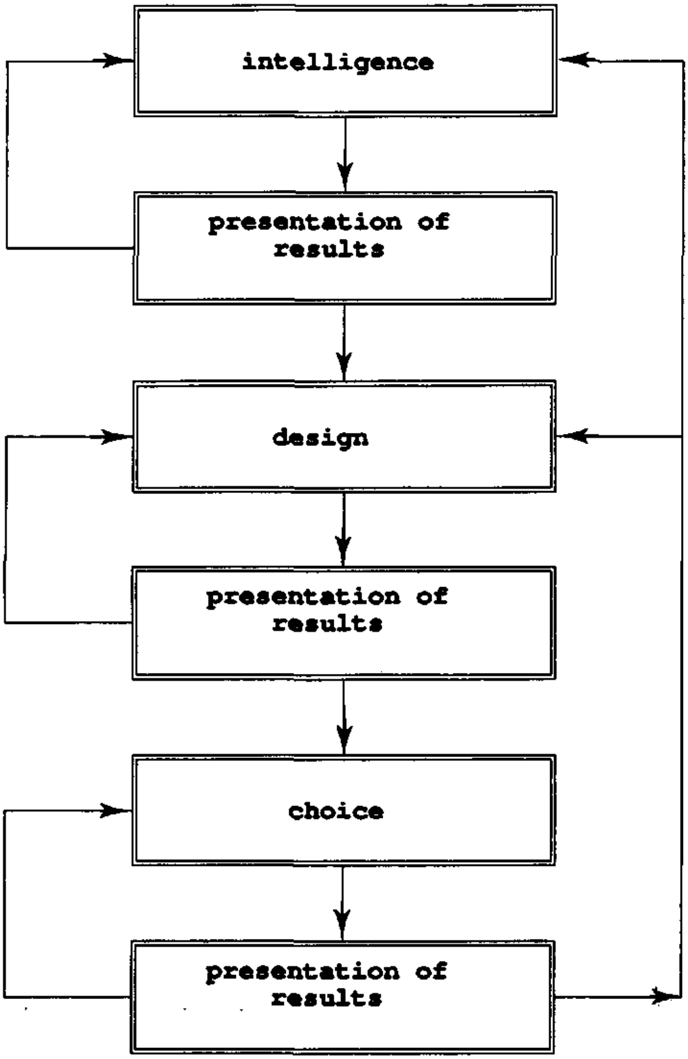


**Figure 1. Flow chart of the decision making process**

Spatial representation is a natural way of approaching any spatial problem. Research on mental imagery indicates that images are used to remember facts about objects and events (Kosslyn, 1983), and it is estimated that 50 percent of the brain's neurons are associated with vision (McCormic, 1987). Image presentation can help communicate large amounts of information quickly, a very important and powerful characteristic. The capacity of the brain to comprehend and take in information is estimated to be about 2 gigabits per second (Mundie, 1989). The visualization of results provided by GIS technology is thus one of the most comprehensive forms of presentation and communication.

To support planning, monitoring and evaluation, the information system should have sufficient capabilities to support all phases of the decision making process. To support the intelligence phase, potentials and constraints of the agricultural environment should be identified, and different types of reports that compare expectations with current and projected performance should be generated. This includes the following types of capabilities:

- Simulation model to examine the agricultural system environment to assist the user in understanding the main constituent processes of the system and identifying different opportunities and constraints.
- Generation of summary reports of the current performance of the "system".
- Generation of comparative reports of performance with the potential, plans, averages and historical data.
- Generation of predictive reports that forecast production and production requirements based on the plan.

Following the intelligence phase, which results in problem identification and opportunity recognition, is the design phase, which involves developing and analyzing possible courses of action. Supports during the design phase should include the following:

- Support in understanding the problem. This includes the application of models that simulate the current situation.
- Support in generating the solution. This can be achieved by manipulation of the proper model or by information retrieval capacity.
- Support for testing the feasibility of the solution. The analysis may be performed judgmentally against broad measures or using a model which simulates the case.

In ARIS, the required capabilities to support decision making processes are built into the different sub-systems. They consist of:

- Data analysis capability to improve the user's understanding of the problem. This allows manipulation of data by either analysis tailored to a specific task or general analysis operations.
- Analysis information to assist the user to understand the problem and generate solutions. This gives access to a series of databases and small models.
- Optimization model to help in understanding the problem and generate solutions. This

simulates the problem and provides guidelines for action by generating optimal solutions consistent with a series of constraints.
- Simulation model to help in understanding the problem, generate solutions and test feasibility. Here normally a descriptive model is used to describe the behaviour of the system under different circumstances.
- Allocation model which assigns existing resources to different activities on the basis of predefined criteria.

Following the design phase, which results in a series of alternative solutions, is the choice phase. Support for this phase is knowledge of the predicted outcomes of different alternatives and the impacts of various decisions. These types of support are provided by various models and processing facilities described above.

The required capacities for the decision making process are distributed over different modules of ARIS, on the basis of their nature and functions:

- The planning sub-system has access to a series of databases and makes use of the required capacities of all phases, i.e., simulation, optimization, allocation and prediction.
- The monitoring and evaluation sub-system can access a series of databases and makes use of the capabilities required for the intelligence phase, data analysis and information analysis.

## 2.2 ARIS development approach

There are different approaches in the development of decision support systems. According to Davis and Olson (1985), there is a general agreement that decision support systems are developed most successfully by an iterative, prototyping approach. Prototyping was described by Jenkins (1983) as "an evolutionary design method for achieving experimental assurance in development of information system applications". Because it is an especially appropriate method when all requirements are difficult to specify in advance, or when the requirements may change significantly during development, the prototyping approach was taken for the design and development of ARIS.

Prototyping an applications system is basically a four-step process:

- Identifying the user's basic information requirements; in this stage the required data elements are defined and their availability is determined.
- Develop the initial prototype system that responds only to the user's basic information requirements. Here the emphasis is placed on the speed of building and efficiency of

functions rather than the efficiency of the programs.
- Use of the prototype system to refine the user's requirements.
- Revise and enhance the prototype system.

An initial prototype of the information system was designed and built in the course of this study.

## 2.3 Information system development approach

Janssen and Nijkamp (1988) defined information as a collection of organized data (for example by means of statistical techniques, modelling or transformation) to provide structure and systematic insight into a phenomenon. Along these lines, they defined an information system as any kind of systematic and coherent analysis or decision support system for planners and policy makers, to contribute to solving, organizing or rationalizing complex choice and decision problems. In this study, an attempt was made to develop the information system in this context.

Information system development consists of analysis, design and realization. These activities are followed by implementation and follow-up (upgrading) of the information system. There are a number of methods for analysis and design leading to a design specification of the information system. Each method has a specific primary orientation with emphasis on different stages of the process.

ARIS use the capabilities for spatial data handling, transaction processing, structured decision, and decision support systems in the complex and dynamic environment of an agricultural system. The information system, with its process models, will be a new technology to be developed and introduced in the farming environment. The system should benefit operationally from state-of-the-art technology in related fields. Most existing information system development methods, support transaction processing and structured decision systems. They direct most of their effort to data modelling, and normally do not include development of sophisticated process models; some do not include state-of-the-art technology in defining the required processes.

For this study, in which the process model forms the core of the information system, a special method was used, based largely on the method proposed by Lundeberg et al. (1978), the "information system work and analysis of changes" (ISAC) group. Where appropriate, it also used the procedures and logic of the "system development methodology" (SDM) developed by Hice et al. (1974), the system development approach developed by Wetherbe and Davis (1985),the prototyping approach of Jenkins (1983) and information modelling of Benyon (1990).

According to ISAC method, the analysis comprises two parts. The first, which precedes information system development, is to study the organization and identify feasible types of development measures (changes or improvements) that should be incorporated in the activities of the organization to solve existing problems and fulfil needs.

If the first part of the analysis indicates that development of an information system can provide positive contributions to the activities of the organization, then the second part of the analysis is carried out on the information processing parts of the activities to identify, classify and delineate information sub-systems, and finally design the overall structure of the information system.

ISAC distinguished two main groups of activities in the analysis and design of the information system: (i) problem-oriented work directed towards the logical structure, and (ii) data-oriented work that forms the basis for the physical structure of the system.

Problem-oriented work refers to those activities whose purpose is to specify what the information system should do from the user's point of view. Data-oriented work refers to the activities whose purpose is to design technical solutions that meet the logical specifications. These are developed through implementation of the following methods.

### 2.3.1 Change analysis

Change analysis comprised assessment of the existing situation of Moghan Agro-Industrial Complex (MAIC) to identify the problems and requirements and, consequently, the proper development measures aimed at improvements. The final product of this activity is the identification of the appropriate measures, which for MAIC will be the development of an appropriate resource information system to support planning, monitoring and evaluation of the enterprise.

### 2.3.2 Activity studies

Activity studies delimited (defined) the function of the resource information system in the activities of MAIC. Information requirements were identified in such a way that they can contribute to solving the problems of different interest groups within the enterprise. This was achieved by detailed analysis and design of activities related to the planning, monitoring and evaluation processes, based on identification of problems and definition of the information requirements for each activity to improve the situation. The end products of this activity were the information requirements and the overall design of the system structure.

Information systems have value only if they contribute to improving the situation for people in the organization, i.e., they derive their value from their contribution to solving the problems of different interest groups involved (Lundeberg et al., 1978). Information systems should be developed if they can in some way facilitate or improve some activities, or meet the requirements and needs of the organization they serve. Correct and complete identification and definition of the information requirements are therefore the key ingredients of successful information system development.

Information requirements are defined using the following main approaches:

- Data analysis approach in which the information requirements are identified through analysis of the inputs and outputs of the existing system. This approach is most suitable when the system performs fairly standard operations and the related activities in the organization are satisfactory, or at least not subject to drastic change.
- Object analysis approach in which the information requirements are identified through analysis of characteristics of the utilizing system. In fact, the requirements for information originate from the activities of the object system. This approach is the most logical and appropriate for deriving information requirements, especially when the utilizing system is changing or the proposed system substantially deviates from the current system (Davis and Olson, 1985).

In MAIC, according to the preliminary evaluation (section 3.4), the existing procedures and methods for planning, monitoring and evaluating were not efficient and therefore not acceptable. In this case, the first step was the design (specification) of the required activities for a proper planning, monitoring and evaluation system on the basis of new developments and state-of-the-art technologies in the relevant disciplines.

This started with analyzing the relevant activities of the enterprise, using the object analysis approach, to identify their problems and the information requirements for their improvement. At a subsequent stage, the required information was used for the identification of required activities and various sub-systems; by integrating the various sub-systems, the overall structure of the system (ARIS) was designed.

To analyze the current situation, identify existing problems and derive the information needs for planning, monitoring and evaluation in MAIC, the Wetherbe and Davis (1983) approach was used. This method, which uses interviews with key management personnel, includes the following:

(1) Study the functions, mandate and organizational structure of the complex and define the underlying organizational sub-systems with respect to the ARIS objectives. Each organizational sub-system was considered as one major activity of the organization with respect to the objectives of ARIS. To clarify

responsibilities and identify the managers to be interviewed (identifying the interest groups), a sub-system manager matrix was developed.

(2) Define and evaluate information requirements for each organizational sub-system by interviewing each manager to define his information requirements. Since this is not satisfactory most of the time because of human limitations, the structure of the questions, as proposed by Davis and Olson (1985), was used to help the managers in conceptualizing their information requirements. This structure reflects three ways of thinking about information requirements (i.e., business system planning (1981), the critical success factors approach of Rockart (1979), and the end-means analysis approach of Wetherbe and Davis) and increases the probability of obtaining a complete set of information requirements. These questions included:

- Define the mandate and purpose of organization's existence.
- Define the existing relationships among different organizational sub-systems.
- What problems do you have and what information is needed for solving them? What decisions do you make and what information do you need for decision making?
- What factors are critical to the success of your activities and what information do you need to cope with them successfully?
- What are the outputs from your activities and what information do you need to measure effectiveness in achieving the outputs? What resources are used to produce the outputs and what information is needed to measure efficiency in terms of resource use.

(3) Analyze the information collected through the above steps (interviews) to identify and classify the problem areas and the information requirements. Information requirements are established at three hierarchical levels:

- The organizational information requirement.
- The information requirements for each application.
- The information requirements for each database.

Identification of the information requirements is a key activity in planning organizational information systems, in implementing information systems and in building databases. The organizational information requirements are used for planning the information system, identifying applications and planning the information architecture. More detailed information requirements are needed for design of applications and databases (Davis and Olson, 1985).

The information requirements at the organizational level were determined by the strategies, goals, objectives and procedures in any of the individual organizational units and the analyses of current problems and activities. The information requirements were then categorized and used to create an information sub-system matrix, showing the required categories of information for each sub-system and helping in the design of the information system.

(4) Design of overall system structure: information systems provide information services to facilitate operation of the object system to those who utilize the information. Requirements for the information system are thus derived from the activities of the object system. Therefore, information systems are designed on the basis of information requirements of the various activities executed in the organization. Information systems developed for systems with a poor activity design may accelerate the operations, but will not affect the quality of the operations, and therefore the first step in most system development methods is activity design.

Based on the results of the analysis of the current situation, definition of the problem areas and their information requirements for improvement, the overall structure of the system was designed to match the requirements. The designed system should have sufficient capability to provide all information requirements.

### 2.3.3 Information analysis

Information analysis defines the actual content of the information system. On the basis of the information requirements of each sub-system and study of existing methods and system environments, the outputs, major processing functions and inputs of the system were defined. The processing functions were combined into the main modules of the system and, for simplicity, only these modules are described. Both process analysis and precedence analysis were used to define the output and input information requirements. The main processing functions were defined by analysis of the existing methods and selecting the one most appropriate to the system environment.

Information systems comprise three views: external, conceptual and internal. The conceptual view represents the information content of the information system that must accommodate all external, or user, views. Information analysis defines the conceptual view of the system and describes what the future information system should contain and what it should be able to do.

Using the information requirements of each sub-system and a study of existing methods and system environments, the outputs, types of major processing function, major processing functions and inputs of each sub-system were defined. This was done on the basis of:

- "Precedence and component analysis" (Lundeberg et al., 1978) which describes the objectives and information requirements of each sub-system in terms of new information sets.
- Process analysis which identifies processing and input requirements of each sub-system.
- Property analysis which describes the qualitative and quantitative properties of each information subset.

Several strategies have been proposed for determining input (information) requirements (Davis and Olson, 1985) from object system analysis. The process-based method is one of the comprehensive approaches to the synthesis of information system requirements. The idea underlying this approach is that processes are the basis for information system support. Processes, which include groups of decisions and activities required to manage the resources of an organization, are assumed to be relatively constant over time, hence the requirements derived from the process reflect the non-transient needs of the organization (BSP, 1981).

In developing ARIS, which includes fairly constant types of process, the "precedence, process and component analysis" approach was used to determine the information requirements, processing functions and input requirements of all sub-systems. In this approach the information requirements of the sub-systems are derived in a top-down fashion by starting with objectives and then defining the necessary processes. Subsequently, the processes are used as the basis for data collection and analysis. In this way, logically related categories of data are identified and related to a process.

Every item of the information requirements at the organizational level (section 4.2.1) is treated as an objective to be satisfied by an operational sub-system. By collecting and analyzing the various methods, procedures and techniques that can be used to arrive at any of the objectives, the appropriate data analysis and processing functions were identified. Processing functions were considered appropriate if they can be implemented in the enterprise environment.

The input requirements of the system were defined on the basis of the input requirements of the selected processing functions. To assure the applicability of the system in the enterprise environment, the input requirements were further analyzed with respect to their availability, accessibility, and reliability, and the applicability of processing functions in the enterprise environment.

By further analyzing the data requirements for each processing function, the user oriented data model (infological) of the system was developed, which organizes all data items required by the processing functions. Furthermore, considering the enterprise rules and by using functional and organizational dependency diagrams, the input data items were analyzed to design the preliminary data collection forms. This procedure is presented schematically in figure 2.

### 2.3.3.1 Definition of system output requirements

The precedence analysis procedure was used to determine the major output requirements of each sub-system, starting at the objective and determining the information which has to precede it.
The information requirements at the organizational level serve as the objectives at the application level. Each objective (requirement) was further analyzed with respect to the problem areas and objectives of the sub-systems to define the information sets required to attain the objective. These information sets are referred to as the output data element.

Determination of the output requirements consisted of the following steps:

- Formulate a preliminary output description for each element of the information requirements defined in the activity study.
- Identify all output data elements that are needed to meet the information requirements at each specified organizational level (entity set at organizational level).
- Analyze data to classify related output data elements into logical data groups and sub-systems (preliminary formatting of the outputs).

As a result of this analysis, the output requirements of all sub-systems were defined and grouped in preliminary output
reports. To finalize the output requirements of the system, the format and content of these reports were discussed with the various user groups and analyzed with respect to the technologic constraints, availability, reliability and accessibility of data and their applications in supporting management decisions.

### 2.3.3.2 Definition of the major processing functions

Much basic research has been carried out on the development of methods, models, functions and decision rules for farm management decision support. Each problem can be tackled in different ways, each emphasizing a particular aspect of the problem, or the same problem in different task environments. Thus, for every problem, there may be a variety of solutions, of which only some are appropriate to the situation. Hence design of the process model that includes the appropriate processing functions is very important.

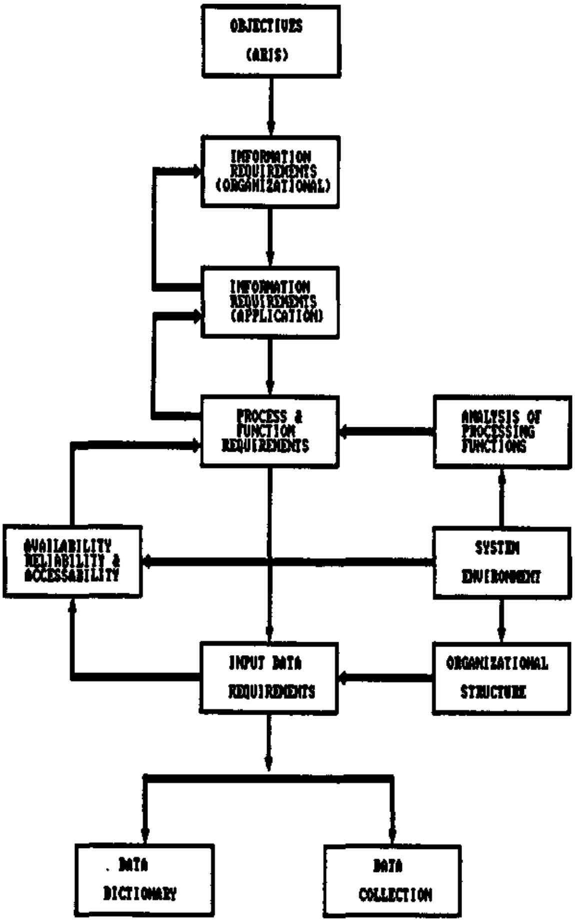


**Figure 2. Schematic view of the process analysis procedure**

Information systems are judged on the basis of their contribution to improving decision making processes (Janssen and Nijkamp, 1988). That contribution is based on decision models consisting of processing functions. Processing functions, comprising the dynamic part of the information system, therefore form its most important part.

The processing functions of each sub-system were defined using the following procedure:

- Analyzing the system environment with respect to the organizational culture, power distribution, and formal and informal organizational learning to establish a framework for selecting or developing the processes.
- Analyzing existing methods on the basis of this framework and selecting or developing the approach or types of processing function appropriate to the situation (Hice et al., 1974). The type of information required in each sub-system can be derived using various approaches and methods, each having its own methodological and operational advantages and disadvantages. The proper types of processing functions and models appropriate to each sub-system were identified by considering the results of the analysis of the system environment and using the following procedure:
  - Collecting information on existing methods, procedures and processing routines which can be used to derive the required output information set from each sub-system.
  - Analyzing the existing methods, procedures and processing routines to select the most appropriate for deriving each output information set. The analysis comprised consideration of the reliability of the result, availability, reliability and accessibility of the required input data and overall applicability of the method in the MAIC environment.
- Defining the required processing functions and models, and organizing them in the model base.

#### 2.3.3.3 Definition of input requirements

Based on the output information requirements and analysis of the process model, the input data requirements of the information system were identified, analyzed and used to design the infological data model (user oriented) of each sub-system, which describes the content and structure of the required information sets. This included the following:

- Analyzing all output information requirements with respect to the processing functions to identify the data elements that are essential for the derivation of the required information.
- Determining the content and structure of each information set, including a description

of message type, its value, identification term and property terms (Lundeberg et al., 1978).
- Determining relevant quantitative and qualitative property values of the information sets.
- Analyzing data requirements with respect to the organizational structure of the enterprise to design the data collection procedure and input forms.
- Providing a preliminary description of each data element (definition of attributes and compilation of data dictionary).

As a result of these activities, the information sets, their constituent data items and their relationships were identified and used to design the data collection procedure and forms.

### 2.3.4 Data system design

Data system design is the first part of data-oriented work in information system development. It provides hardware/software- independent data system solutions to the information system, specified in the information analysis phase. Subsequently, the proper hardware/software configuration that can accommodate the system functions, and at the same time is appropriate to the system environment, is selected and used for equipment adaptation of the designed data system. This concludes the analysis and design phases of the information system, which resultes in the development of a model and specifications (blueprints) of the desired information system.

#### 2.3.4.1 Data model

The data model defines the structure of the stored data that will be accessed by the processes. The resulting data structure describes the data types and the relationships of spatial and non-spatial data.

ARIS includes many spatial analysis features, the related thematic and management data and quite a number of processing algorithms. Each geographic feature was identified and described by their geometric and thematic characteristics, where geometric refers to geographic position and spatial relationships (topology), and the thematic characteristics assign meaning to the data through a set of thematic attribute values (Molenaar, 1991). A proper data model for such a system should therefore provide the means to organize the spatial and non-spatial attribute data (efficient storage, retrieval and updating), and provide facilities for processing algorithms and analysis (Googchild, 1991b). The data model most widely accepted for handling non-spatial attribute data, especially in association with spatial data (GIS), is the relational data model (Aronoff, 1989). Hence the relational data model was selected and adapted for the flexible requirements of the GIS analysis environment.

Spatial data are inherently more complex to store and manipulate and they require a special data model to handel them. Aronoff (1989) discussed the limitations of general database management system for spatial data handling. Analysis of the required processing functions in ARIS (section 4.2.2) showed that, for analyses such as minimizing conveyance water loss in the irrigation network or minimizing transportation cost through the road network, spatial analysis capability is required. Spatial analysis is facilitated to a large extent by a topological data structure, hence a topological data model was selected for handling the spatial data in ARIS.

Various practical approaches have been developed to provide data management services for GISs. Aronoff (1989) grouped them in four categories, of which the hybrid system is the most popular. It uses a commercially available DBMS (mainly relational) for non-spatial attributes and separate software for spatial data, with access to the attribute data through the relational DBMS, (e.g. Arc/Info system of Environmental Systems Research Institute, ESRI) (Morehouse, 1985). Such an approach was taken to implement the data model for spatial and non-spatial data in ARIS. Finally, to organize all required applications programs (model base), file processing approaches were used. A general view of such a system is presented graphically in figure 3.

*Data model for attribute data*

Data modelling for attribute data using the relational approach consists of identifying the entities, providing normalized relations and defining the entity-relation model (Benyon, 1990). In ARIS this was achieved through the following:

- Identification of data elements: analyzing all output information requirements with respect to the processing functions to identify the essential data elements.
- Definition of entities and relations: grouping common related data elements into logical records, using functional dependencies. Logical records consist of a number of data elements that are associated with an entity or are considered together because of certain similarities.
- Entity-Relation models: defining the entity-relationship (E-R) model by associating links between two or more entities.
- Analyzing the relations (entity sets) using the normalization rule to eliminate redundancy and logical errors in the defined tables.
- Finalization of inputs-outputs: re-evaluating the content and format of the input forms and output reports, and making necessary modifications.

*Data model for spatial data*

Spatial data are modelled using a topological vector data approach. Here the terrain features were identified and described by their metric and thematic characteristics and

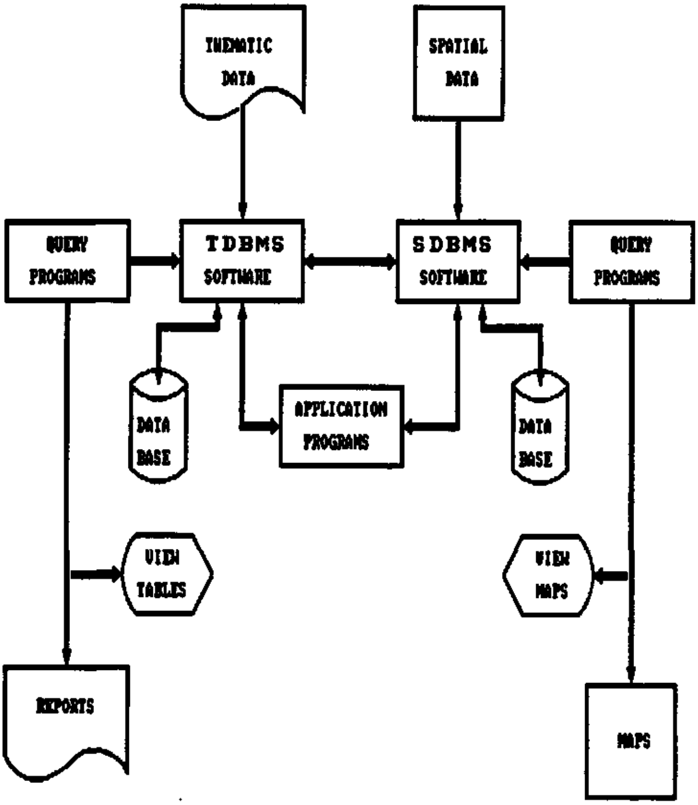


Figure 3. General view of hybrid system approach

stored in different files. Geometric and thematic data were linked through a feature identifier. Feature sets were defined via their geometric aspects by three feature types (point, line and area features), and via their thematic aspects by different feature classes (Molenaar, 1991).

Geometrically, all terrain features were represented by sets of geometric elements such as nodes and arcs with their topological relationships. Different types of thematic information represented in a single paper map (map layer), generally describing only one map feature, were treated as a basic unit of storage containing both locational data and thematic attributes of map features.

### 2.3.4.2 Process model

The process model defines the events and operations that must take place in the information system. The input data are transformed according to defined processes and manipulation techniques, and re-structured or related to other data. The process may therefore need to reference more than one data file (permanent data storage). The basic requirements of the process model are inputs, outputs, processes and stores of data. Since the output from one process may be input to another, the movement of data through processes is viewed as a "data flow" (Benyon, 1990).

The process model was developed by integrating the relevant processes and functions defined in the information analysis phase into the program structure. The program structure describes each program and consists of program delimitation and subsequently program design. During program design, the sequence, selection and type of mathematical operation of each function within the various processes were described.

Aronoff (1989) distinguished four basic categories of analytic functions in a GIS: (1) maintenance and analysis of spatial data, (2) maintenance and analysis of attribute data, (3) integrated analysis of spatial and attribute data, (4) output formatting of the results. In ARIS, processing function requirements were defined in such a way that the system follows the logic of decision making process in a farm enterprise environment; this has required substantial additional processing capabilities, i.e. applications software. This software, which was developed in a file processing environment and organized in the model base, is added to the Aronoff classification (as category 5).

For the purpose of data system design and development, the required functional analysis capabilities were grouped into two main classes:

- Required processing capabilities for the land use planning sub-system.
- Required processing capabilities for the monitoring and evaluation sub-system.

The land use planning sub-system requires all five different classes of analytic capabilities with output formatting; the monitoring and evaluation sub-system uses mainly the attribute data analysis capability and output formatting. This is graphically represented in figure 4.

### 2.3.4.3 Data processing model

The data processing model is the link between the data model and the process model. It tests the completeness and consistency of the dynamic (process) and the static (data) parts of the information system. This is usually developed by preparing an entity life history (ELH) and a transaction matrix (Benyon, 1990). The ELH is a structure diagram that depicts the events which effect the state of an entity (occurrence), from its creation to its removal from the system. They are very useful tools for exposing gaps between the process model and the data model. The transaction matrix is a tabular model that shows the entities needed for any particular process. It cross references the data and processes to uncover any discrepancies between the two models.

### 2.3.5 Equipment adaptation and realization of a prototype system

The purpose of equipment adaptation was to determine the specific hardware and software configuration on which the system should run, and to adapt the equipment-independent data system model to the selected configuration (Lundeberg et al., 1978). This concluded the analysis and design of the information system, which led to a number of different models of future information systems. Thereafter each of the modules of the information system was built, tested and integrated into the models, sub-systems and system respectively. The models and sub-systems were tested separately and in combination for consistency, and finally documented. Since the prototyping approach was used here (section 2.2), further adaptation and adjustment were not required, and an initial prototype of the system was built.

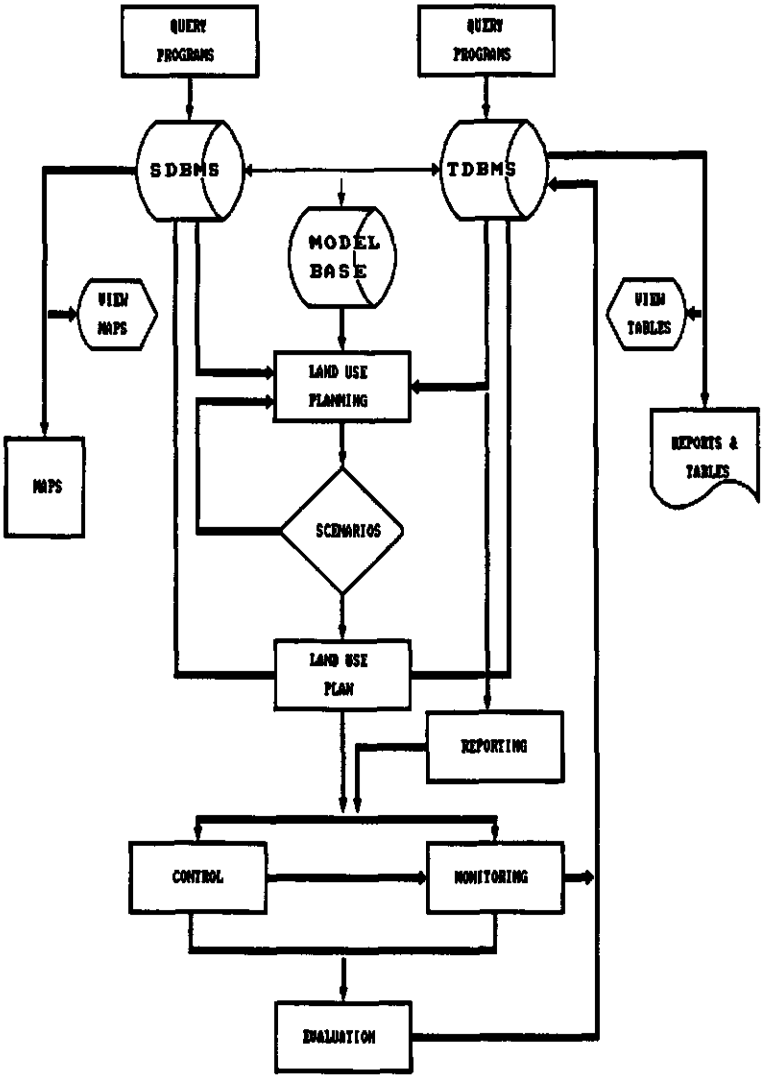


**Figure 4.** **Data flow between various components of ARIS**

## 2.4 Development of an integrated land use planning model

In recent years, planning methods have often relied on those evaluation research methods. Evaluation aims at assessing the degree of attainment of what was expected from planning and decision making by systematically structuring all relevant aspects of policy choices, for example the assessment of impacts of alternative options (Janssen and Nijkamp, 1988). The results of an evaluation procedure have to be communicated to policy-makers in a manageable and comprehensible form, particularly because evaluation problems are usually multi-dimensional (including unmeasurable or intangible aspects) (Janssen and Nijkamp, 1988).

The use of evaluation methods (such as cost-benefit analysis, multi-criteria analysis and multi-objective analysis) in planning has increased considerably. A general trend can be observed to move from prescriptive, "black box", one-step methods to interactive, open, iterative methods. The first approach results in an evaluation report, the second in a decision support system (DSS) that contains the same information as the evaluation report, but can be amended as desired. This approach is especially useful in situations where the various parties have not only different objectives and priorities but also different opinions about the problem content (Janssen, 1987).
If a decision problem is completely structured, that is if the problem content and priorities are agreed by all interested parties, there is no need for a decision support system. If, at the other extreme, no structure can be brought into the problem content and/or the problem solving procedure, decision support is impossible. It is only between these extremes that a DSS is relevant (Grinzberg and Stohr, 1982).

In land use planning, agreement on a planning method implies agreement on the types of prediction method, types of data, types of alternative and types of appraisal criteria to be considered. There may be no agreement, however, on the exact specifications of all alternatives, the benefits to be included, the level and effects of all constraints, etc. There may even be strong disagreement on the relative importance of the various decision variables at different times and places. A decision on the most suitable land use plan is thus a semi-structured problem that can greatly benefit from the decision support system approach.

### 2.4.1 Land use planning at farm enterprise level

Land use planning, as defined by Fresco et al. (1990), is a form of regional agricultural planning directed to the "best" use of land in view of accepted objectives and environmental and societal opportunities and constraints. Similarly, land use planning as defined by Dent (1988) "should provide capability to help decision makers to decide how to use land: by systematic evaluation of land, and alternative patterns of land use, choosing the best of which meets specific goals, and the drawing of policies and programs for the use of land".

In the context of planning, the same definition is extended to land use planning at farm enterprise level, with emphasis on its application at different levels of planning,i.e., strategic, tactical and operational. Development of a successful planning tool requires an understanding of the system's environment, planning components and their hierarchy at farm enterprise level.

### *Land use planning environment*

A farm enterprise has a supply of labour, capital items, land with different qualities and characteristics, and may have options for increasing its resource supplies. Each piece of land can be allocated to the production of several crops under various management levels. Each input can be allocated among different production possibilities, each with a specific economic return.

Available resources may vary in quality and quantity. Some land may be suitable for irrigation, while other parts allow only rainfed cropping and may therefore be less suitable or less productive for some crops. Some management practices may be more efficient than others, and supplies of land and labour may be critical because of the seasonality of farming activities.

The options for increasing the resource supplies may include acquisition of new land, hiring additional labour or investing in new machinery or infrastructure. On the other hand, production possibilities may be restricted by agro-technical considerations, such as crop rotation requirements, or by social and economic considerations such as the requirement for food self-sufficiency or the desire to avoid risks.

The number of possible alternative plans may become very large, because of the wide range in biological properties of different crops, diverse resource potentials, and the wide range of feasible production techniques.

### *Land use planning dimensions and components*

Land use planning has agronomic, social, economic and political dimensions and deals with multi-purpose uses of land, trade-offs between different functions of the land, and conflicting interests between the different categories of land users and between collective and individual goals and needs (Van Keulen et al., 1987). Hence land use planning is a multi-objective problem.

Land use planning, as a specific planning, must comply with the basic definitions and concepts of planning. Planning is defined as an ongoing organizational activity that provides the framework for operational activities and decision making (Davis and Olson, 1985). The plan should reflect expectations about the environment, the capacity of the system (organization), and the trade-offs on such matters as allocation of resources and direction of efforts. The quantified expectations about the enterprise environment (planning data) are fed into the planning model.

The planning model is used for structuring, manipulating and communicating future plans. It describes the process by which plans are developed from input data and internal computations (Davis and Olson, 1985). The output is the plan in a format suitable to the environment.

***Land use planning hierarchy***

Land use planning, like any other planning, takes place at different levels, i.e., strategic, tactical and operational.

- Strategic planning aims at determining the main strategies and policies and expressing these in general statements or concepts that guide or channel thinking and actions in the decision making process. Strategy denotes a general programme of action and deployment of emphasis and resources to attain comprehensive objectives (Koontz and O'Donnel, 1988). It is a non-programmable decision process that shows a unified direction and sets the general guidelines for the future of the enterprise. It refers to overall directions and provides a framework for planning and operation of the enterprise. Anthony (1965) defined "strategies" as resulting from the process of deciding on objectives of the organization, on changes in these objectives, on the required resource use to attain these objectives, and on the policies governing the acquisition, use and disposition of the resources.

  The major strategies and policies that give the primary shape to the enterprise in accomplishing its objectives are affected mostly by external conditions. These are usually imposed on the management of the enterprise and very often cannot be altered. They act as boundary conditions for the overall objectives and guidelines of land use planning, and are not derived from the routine planning process.

- Tactical planning refers to the physical implementation of strategic plans. It reflects all relevant agro-technical and social and economic conditions. In the present context, it is a land use plan prepared for one production cycle. It takes into consideration the guidelines set by strategic planning, the land capabilities, realistic resource and management-to-product relationships, and supply of scarce resources to determine the best land use plan which satisfies all constraints and provides the maximum contribution to the overall objectives of the enterprise.

  This level of planning is a semi-programmable decision making process. Its support system should logically follow the different steps in the decision making process, and include an appropriate planning model to integrate agro-ecologic and agro-economic information and to assess the implications of different resource endowments, different market conditions, application of existing, improved and new technologies and different management strategies.

The land use plan (cropping pattern) developed in the tactical planning process includes the total area required for each land utilization type (crop and management level), but it does not include spatial information for the allocation of a land use type to a specific tract of land. Land utilization type refers to a crop with a specific level of management, i.e., different management levels of the same crops represent different land utilization types.

- Operational planning is the actual implementation of the tactical plan and includes the allocation of specific crops to different tracts of land, and allocation of different tasks to different organizational units.

  This level of planning is also a semi-programmable decision making process. Support for this level requires a planning model that can assist in the allocation of the resources and tasks to different land utilization types and operational units, based on their suitabilities and the existing technical and managerial constraints.

### 2.4.2 ARIS land use planning approach

To support land use planning in agricultural environments, formal techniques of land evaluation (LE) and farming systems analysis (FSA) have been developed by multidisciplinary teams of specialists, largely independent of each other. These methods, which are very different in nature (agro-technical orientation in LE and social and economic orientation in FSA), are practised in the broad framework of land use planning, and both have their strengths and shortcomings.

Fresco et al. (1990) reviewed the current state of the art in both land evaluation and farming systems analysis, and discussed their relative strengths and weaknesses with respect to basic philosophy as well as their application. They concluded that neither methods alone can integrate all relevant features of the agricultural system in the land use planning process. To improve the land use planning methods, they developed and proposed a theoretical guideline to integrate land evaluation and farming systems analysis (LEFSA).

In current land evaluation practices, integration of information from biophysical, technologic, and social and economic disciplines still relies heavily on subjective judgements, and its operational use within land use planning is weakly articulated (Van

Diepen et al., 1991). There appears to be ample scope for improvement and replacement by objective, integrated operational models.

The pluriform nature of ecologic and economic processes can in general hardly be described by means of conventional approaches adopted in monodisciplinary analysis. Although a consistent and operational linkage of multi-dimensional aspects of a complex reality is fraught with difficulties, there is an increasing need for a sound, integrated method for analyzing inter- and monodisciplinary phenomena (Brouwer and Nijkamp, 1985).

The solutions to land use problems require the formulation of land use development objectives that can be used for the optimization of land use under competing demands. Failure of land evaluations to influence land use decisions is often related to the institutional context, such as a lack of capabilitity to support decision making processes in conflicting situations (Van Diepen et al., 1991).

The approaches to solving land use problems range from the application of pragmatic empirical rating systems to analytical mathematical models. Van Diepen et al. (1991) discussed different methods applied in land use planning and concluded that some of the subjective elements in land use planning can be replaced by existing operational tools, but that complete integration of all existing information into operational methods requires more methodological research and could benefit from the application of operations research and information theory.

In this study, attempts were made to develop an operational integrated land use planning model and to integrate it in a geographic information system (GIS) to support decision makers in the assessment and evaluation of alternative land use plans. The model incorporates adequately the relevant aspects of theory and information on agronomic, soil, meteorologic, economic and information systems, but is sufficiently straightforward to be computationally feasible in support of land use planning at farm enterprise level. The four principles suggested by Hillel (1986) i.e. parsimony, modesty, accuracy and testability, were used to guide model development. The planning model, which is based on sustainable land use systems, comprises a number of interrelated submodels which are derived from various disciplines, inter alia spatial economics, environmental planning and ecology. Here, sustainability for arable cropping systems implies an equilibrium in the nutrient balances of the macro-elements (N, P, and K), and retaining the existing levels of the ground water table. That means, in a long run, the total amounts of nutrients in the soil and the level of ground water table remain constant.

The system provides support for land use planning at different levels. It allows the decision maker to retrieve data, use appropriate planning models, generate plans, and test the feasibility of alternative plans in the course of the decision making process.

A planning support system, as a sub-set of the broad concept of decision support systems, should follow the same logic, and as a planning tool should contain planning data, planning models and provide planning results. In such systems, quantification of expectations about the environment, the planning model and the planning results correspond to the intelligence, design and choice phases of the decision making process, respectively.

The ARIS land use planning sub-system was designed to follow the logic of the decision making process for tactical and operational land use planning at farm enterprise level.

### *Intelligence phase*

Three methods are used to formulate and quantify expectations to be used for planning (Davis and Olson, 1985):

- Objective analysis of values and priorities: if quantitative values are available or can be generated through, for example, simulation models.
- Statistical methods: trends, projections, correlation analysis and sampling provide expectations based on statistical analysis of historical data.
- Judgement: subjective judgement is used to formulate expectations if no statistical or other quantitative data for forecasting are available.

Objective analysis and statistical methods were used in the intelligence phase to examine the agricultural system environment, understand the main constituent processes of the system and their impact on its behaviour, identify different opportunities (land use types) and their requirements, and the existing constraints limiting the productivity of each land use type and the overall productivity of the enterprise.

In agricultural systems, opportunities and problems may be related to agro-technical conditions (physical), or to agro-economic conditions (social and economic). The physical aspects refer to the assessment of the biophysical productivity of each tract of land for each prospective land use type, characterized by crop yield estimates derived from proper modelling of the main growth- controlling factors and processes. The agro-economic aspects refer to existing constraints on fixed resources, external and subjective constraints, the coefficients that reflect the demand of each unit of a land utilization type on each relevant resource, and the respective net price or gross margin of each crop (land utilization type).

The gross margin of each land utilization type at each tract of land (parcel) is related to the yield prediction under a given management system and input level. A management system includes a combination of practices, such as rotation, fertilizer application, irrigation, and an indication of farm management skills, food and income security, etc.

*Design phase*

This is the most important part of the decision making process in land use planning. It requires facilities to analyze the problems, generate solutions, and test the feasibility of the solutions, using planning models that generate alternative land use plans, including the associated results and requirements of the plan. A special model is used at each level of planning.

In tactical planning, a decision model is developed to integrate agro-economic and agro-technical information to arrive at economically optimum combinations of inputs for a farm with given land resources and production policies. Normative decision models, which assume a completely rational decision maker who will always choose the optimum alternative, can in a limited time generate a variety of alternative plans and provide the capability to test and thoroughly analyze their consequences (Davis, and Olson, 1985).

In operational planning, an allocation model is developed to translate the tactical plan into an operational plan. This model is a spatial decision making process (geo-referenced) and assigns a proper land utilization type to each parcel on the basis of its biophysical suitability, crop rotation requirements and specified technical and management criteria, and results in an actual land use plan that meets the objectives of the tactical plan.

*Choice phase*

During the choice phase, the planner ranks the alternative plans on the basis of their results and level of decision impacts, and makes a best choice. An important consideration in evaluating alternatives is the sensitivity of the solution to changes in the assumptions on which the decision is to be based or in the expected conditions.

# CHAPTER 3

## CHANGE ANALYSIS AND PROBLEM FORMULATION IN THE PILOT ORGANIZATION

Lack of good management is often caused by imperfections in the decision making process, which may be the result of such factors as stress, time constraints and the complexity to which the manager is exposed. Increased understanding of the system may facilitate the tasks of the manager. Better understanding requires information about the "task environment", i.e., an individual task seen within the context of the organization as a whole (Bokelmann, 1986). In an agricultural setting, the complexity of the task environment can be the main reason for the failure to achieve the expected results.

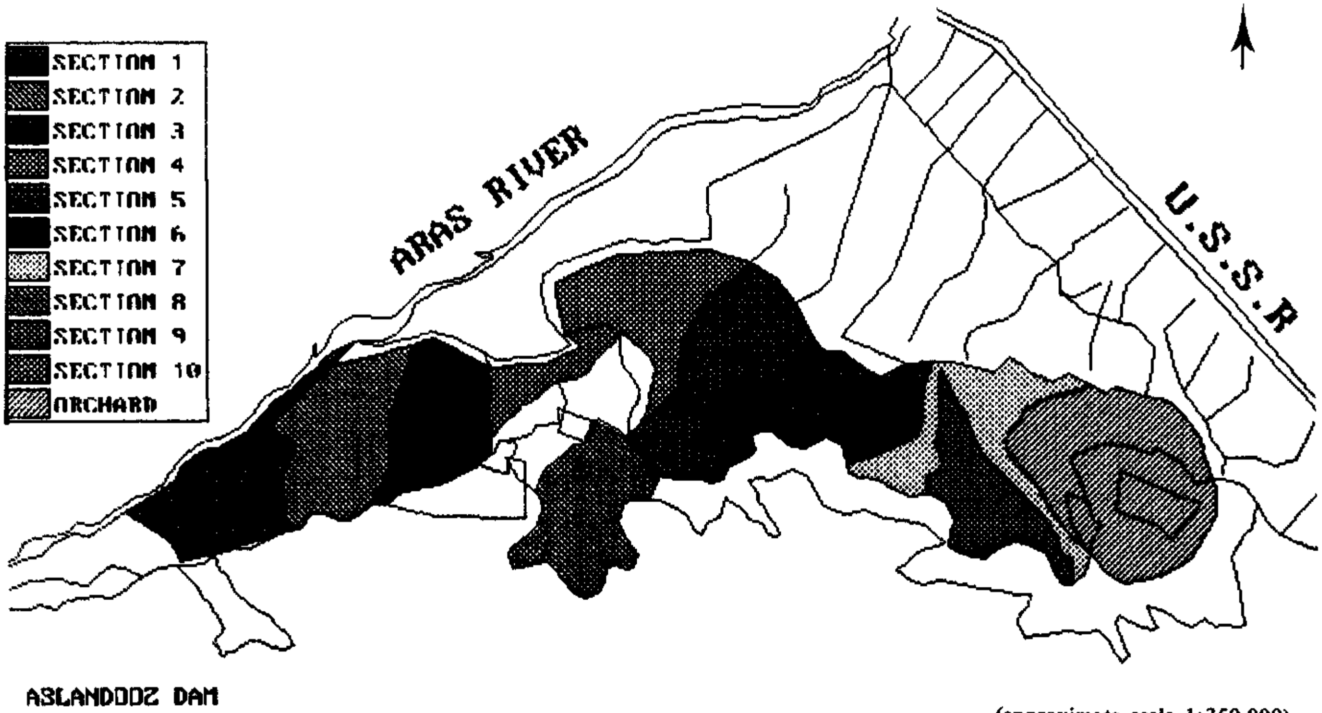
The purpose of change analysis is to examine the task environment in the organization and identify the problems and requirements for a system to support the decision making process. On the basis of the results of this analysis, an investigation is carried out to identify the feasible changes that can be introduced in the organization's activity to alleviate the existing problems and improve the quality of the decision making process. Finally the required changes are grouped and defined in terms of major activities.

### 3.1 Moghan Agro-Industrial Complex (MAIC)

In this study, Moghan Agro-Industrial Complex (MAIC) in Iran was used as pilot area to develop, test, evaluate and demonstrate an "appropriate resource information system" (ARIS) to support agricultural management at farm enterprise level.

MAIC was established with the aim of utilizing Iranian natural resources to increase agricultural production and rural employment and to reduce Iran's dependence on imported agricultural products. Before 1970, the area was used for extensive grazing; through a massive investment programme in infrastructure and land improvement, it has been transformed into the present agro-industrial complex under central management.

The complex is in the Dashte-Moghan region in the northeast corner of the province of East Azarbijan. The Dashte-Moghan triangle covers more than 90,000 hectares and is bordered on the northwest by the Arass river and on the northeast by the Iran/U.S.S.R frontier, as shown in figure 5. The complex includes more than 63,000 ha of fertile land; most of it is used for arable farming, livestock farming and horticulture.



(approximate scale 1:350,000)

Figure 5. Moghan Agro-Industrial Complex

It also comprises such agro-industrial activities as a sugar refinery, dairy processing plant, fruit processing plant, seed processing plant, animal feed mill, cotton mill and other agriculturally based industries. Arable farming comprises more than 22,000 ha of irrigated and rainfed wheat, barley, alfalfa, sugar beet, and maize for seed, grain and forage. Livestock farming includes fattening of sheep, cattle, camels, dairy farming and bee keeping. More than 2500 ha are used for horticulture including orchards of different varieties of apple, pear, peach, nectarine, cherry, hazelnut, walnut and pomegranate.

## 3.2 MAIC organizational structure

The organizational structure of the entire complex is shown in figure 6 and the structure of the arable farming sector is shown in further detail in figure 7. As shown in figure 7, for management purposes the sector has been divided into three regions, each region into three or four sections, and each section into three or four farms. Each farm is further divided into several sub-units (average 9 or 10) and each sub-unit into several (average five) parcels. Each parcel, which is thus the smallest production unit, is approximately 20 ha. The average number and size of each unit are listed in table 1.

| unit | average size (ha) | total number in enterprise |
|---|---|---|
| region | 7400 | 3 |
| section | 2200 | 10 |
| farm | 917 | 24 |
| sub-unit | 95 | 232 |
| parcel | 20 | 1100 |

**Table 1 Average size and number of units**

The organizational structure was designed in such a way that each section operates as an independent farm unit and has therefore been provided with a mechanization as well as a crop protection unit to carry out farm operations. Each section has its own personnel and agricultural equipment for all agricultural operations except harvesting.

The central mechanization unit is responsible for major repairs and maintenance of all farm equipment in the agricultural sector. Harvesting equipment is stored and maintained by this unit and is distributed during the harvesting period. The mechanization unit at section level is responsible for servicing and simple repairs of its own equipment.

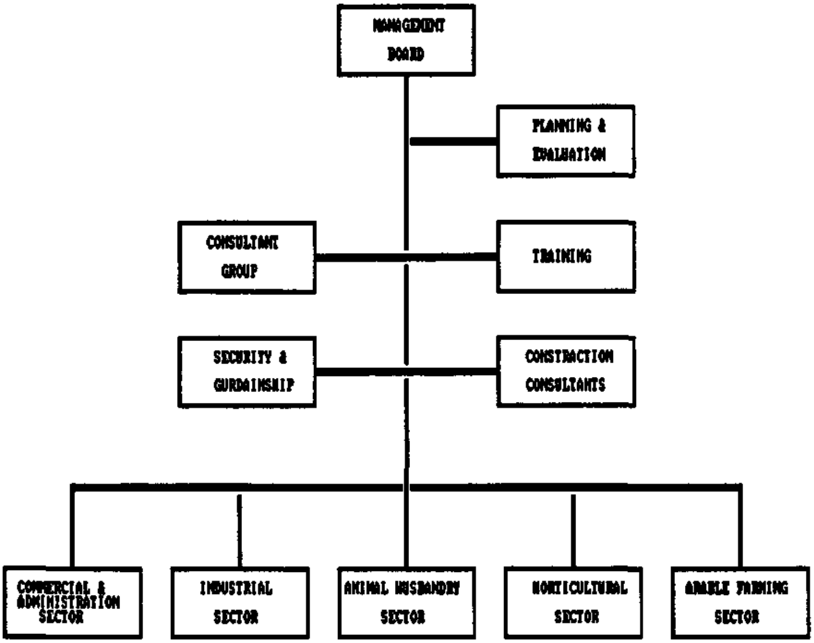


**Figure 6. Organizational structure of MAIC**

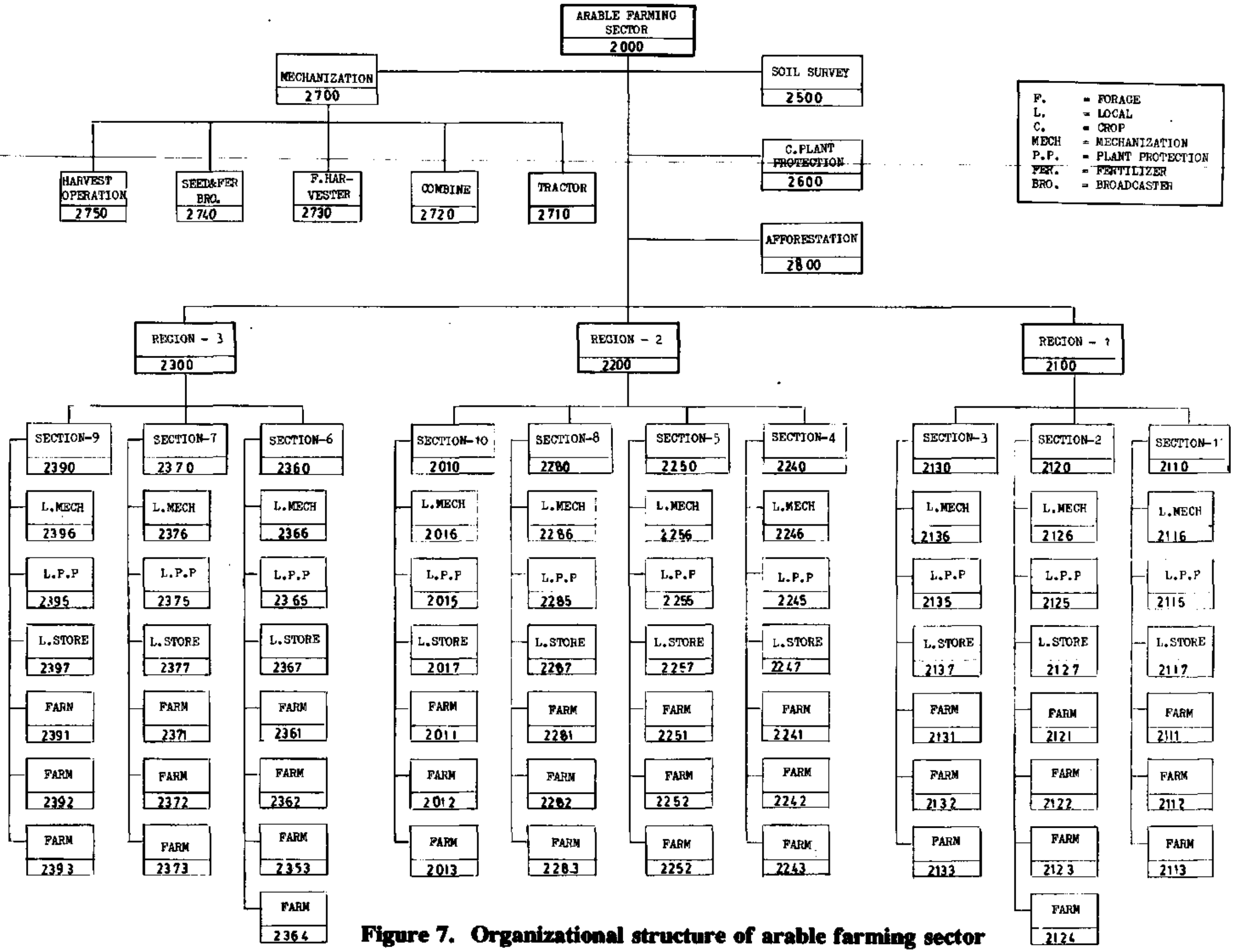


Figure 7. Organizational structure of arable farming sector

The central crop protection unit has responsibility for preparing the instructions and methods (including timing) for crop protection against pests, diseases, weeds and other harmful organisms. The plant protection unit at section level is responsible for implementing crop protection measures in its section.

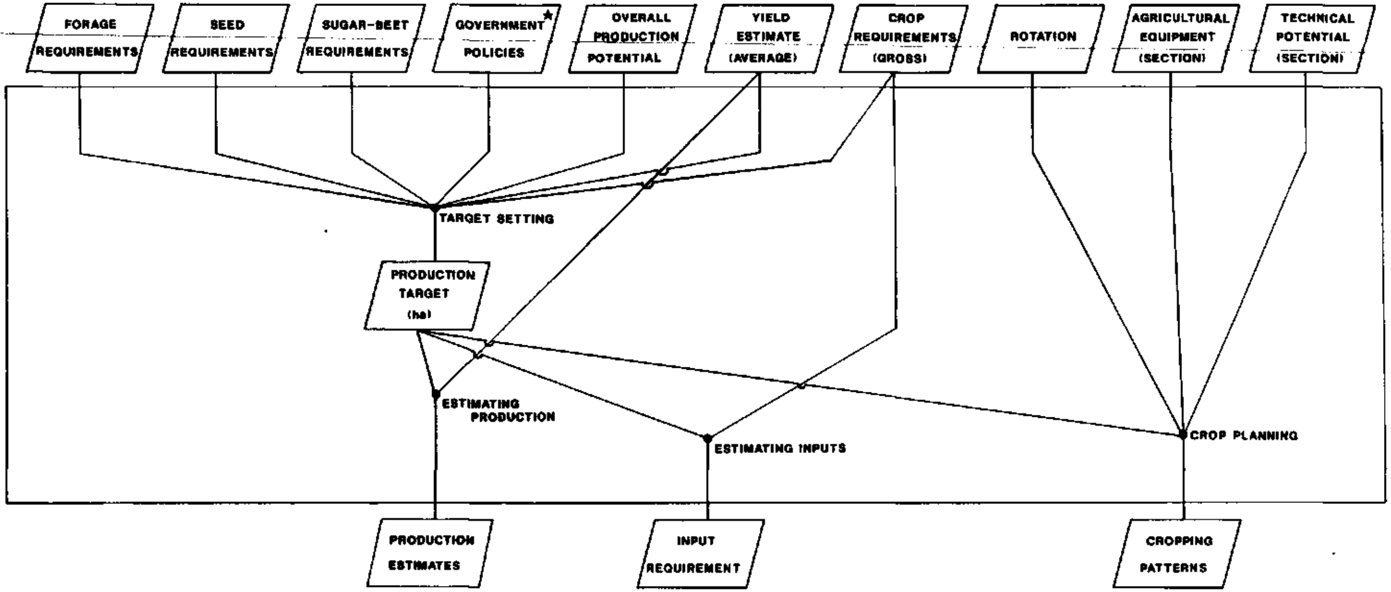
## 3.3 Current planning, monitoring and evaluation activities

At present, overall planning and evaluation are carried out centrally by the planning office of the complex (see figure 6), which determines production targets and total areas for each crop. This is based mainly on the requirements of the animal husbandry sector, the sugar beet refinery plant, seed requirements and various government policies. The management of the arable farming sector uses information on production targets, crop rotation and its technical capacity to design cropping patterns (for the various parcels, sections and regions) for each production year. Figure 8 provides a schematic representation of activities in the crop planning process.

In this process, decisions about the type and quantity of commodities to be produced, the techniques and methods to be used, the planning and timing of different operations and the required inputs (agricultural) are made on an ad-hoc basis guided by common sense. Hence such factors as land suitability, interdependence between crops, choice of production methods, water, labour and farm machinery limitations are not properly taken into account.

Evaluation generally consists of comparing the total annual production and area of each crop with the production and area of the same crop in preceding years. It is usually restricted to enterprise level, and sometimes for some crops to section level, but it never goes into more detail and crop performance at lower levels is never evaluated. Cost/benefit analyses are seldom carried out at production unit (parcel) level. Monitoring is a simple aggregation of weekly reports from the various sections. These reports contain information on the total number of different farm operations carried out each week in each section. The monitoring and evaluation are shown schematically in figure 9.

Because of the lack of relevant information and the absence of proper analysis of activities, the current monitoring and evaluation activities have scarcely any operational value within the enterprise. Analysis of the current situation in MAIC showed that the management devotes most of its attention to the implementation of farm operations and puts very little effort into planning, monitoring and evaluation of the farm activities.



(★ refers to policy related to the crop production)

Figure 8. Overview of current planning activity

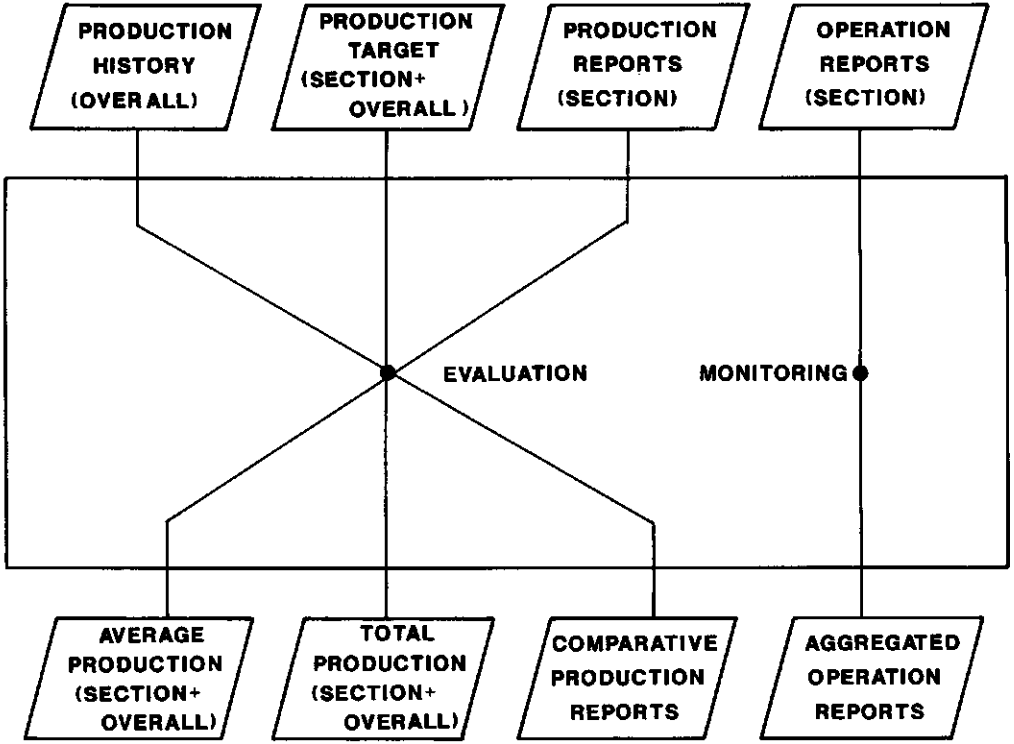


Figure 9. Overview of current monitoring and evaluation activities

## 3.4 Evaluation of the current situation and choice of development measures

MAIC, as a typical farm management unit, has a supply of labour, capital items and land with different qualities. Available resources may vary in quality and quantity; water supply is limited and may not be sufficient to fully irrigate all crops. Some land is irrigable, while other land can be cultivated only under rainfed conditions and is therefore less suitable or less productive for some crops. In different regions and sections of the enterprise, some management measures are more effective than others, and supplies of land, labour and agricultural machinery are often very critical because of the seasonality of farming activities.

The enterprise has various options for increasing its resource supplies. These include hiring seasonal or daily labour, or investing in new machines or infrastructure. On the other hand, the production potentials are restricted by technical constraints, such as crop rotation requirements, or by the desire of the enterprise to be self-sufficient in seeds and the requirements of other sectors of the enterprise, or by a desire to minimize risks. The number of possible alternative plans is almost infinite because of the variation in the biological properties of different crops, the diverse resource potential and the wide range of technically feasible production alternatives.

In such a complex environment, each year a land use plan should be designed and used as a guideline for farm operation, control, monitoring and evaluation. Such a plan should specify the best land use policy in view of the social and economic goals and technical constraints of the enterprise.

Almost all technical aspects of the enterprise have been studied in detail by different consulting organizations; this is expected to continue for some time in the future. As a result of these activities, which started before the establishment of the enterprise, a wealth of technical information on various aspects of the enterprise has been collected and documented in reports and maps. Unfortunately, most of the information resulting from these efforts and investments is not utilized properly, simply because it is not integrated in the management process. This is attributed to the complexity and variability of the information (in time and space), on one hand, and lack of proper tools for its integration, on the other.

MAIC, as any irrigated farming scheme in the arid or semi-arid region, is faced with soil degradation due to an inefficient irrigation system. According to Yekom (1984) in the 1967-1983 period, the water table rose at a rate of 0.3 to 0.75 m a year and reached the land surface at some places where not long before it had been 12 m deep. This has caused waterlogging, salinization and eventually degradation of the land to the extent that some areas have already been abandoned. Lack of proper organization, expertise, standards, data collection and information analysis capabilities, poor information flow between various divisions of the enterprise, and the high costs and considerable time required for planning, monitoring and evaluation have placed a severe limitation on these activities within the enterprise.

Analysis of the current planning, monitoring and evaluation activities showed that the existing information and procedures at all levels of management do not make an adequate contribution to the overall objectives of the organization. Among other things, this is attributed to the lack of proper management support systems capable of providing the required information to support decisions related to planning, monitoring and evaluation in the arable farming sector.

In the complex agricultural environment, the management is frequently faced with difficult choices, and access to accurate and timely information may provide rational answers. In the field of crop management, a decision making process usually starts when there is an unacceptable difference between standards and actual performance; the decision making process is therefore necessarily linked with the monitoring and control system (Bokelmann, 1986). In land use planning with multiple and often conflicting demands on the development and use of a resource, it is almost mandatory that decision makers have access to a tool to analyze a variety of information in such a way that the consequences of a series of strategies or options can be simulated.

Because planning, monitoring and evaluation are basic elements of management, the use of decision support systems to remove information-related constraints will improve the performance of the planning, monitoring and evaluation processes and therefore improve the efficiency of management. Hence many of the current problems and difficulties could be solved by introducing a proper information system to support decision making processes. This has been discussed and agreed by the management, and it is thus well prepared for changes to improve the present situation. In this context, the final choice of development measures, aimed at improving the decision making process, is to develop an appropriate resource information system to support planning, monitoring and evaluation activities.

"Appropriate", a relative term, in this context requires knowledge about the specific problems and needs and criteria to define requisite information and the form in which it should be presented. At MAIC, the main problem (with respect to information) is failure to incorporate the collected and existing wealth of technical information into management decisions. This is due mainly to the following constraints:

- Complexity of the system and the decision environment (task environment); agricultural systems include many complex processes that are in the domain of different disciplines, while our understanding of their basic principles is only

fragmentary.
- Requirements for high-quality experts (usually working in team) in each domain for interpretation of the technical data and their integration in management decisions. These experts are scarce, and moreover, difficult to integrate into teams.
- The data are collected by different departments and disciplines using different technologies and techniques. These data are normally tailored to the departmental needs and stored using different structures and formats. They are widely dispersed and therefore not easy to access and integrate.
- Lack of tools for the analysis and integration of the existing information into management decisions.
- Lack of consistency between the available data and the data required by the proper method for analyzing and integrating the information in management decisions.
- Manual organization and application of existing information is tedious, difficult, time-consuming and inefficient (an operational constraint).

All of these constraints put a severe limitation on the use of existing information. On the basis of the definitions given for information and information systems, and the identified problems, in this study the following characteristics were defined as requisites for the information system to be "appropriate":

- Analytic capabilities for resource analysis and integration of technical and managerial information to support management decisions (appropriate in terms of application).
- Minimum dependence on high-quality experts for its operation (appropriate in terms of operation).
- Minimum dependence on sophisticated hardware and software, so that the system can work in the farm environment (appropriate in terms of hardware and software).
- Relatively easy maintenance and follow-up procedures (appropriate in terms of maintenance).

## 3.5 Main objectives of ARIS (development measure)

The main objective of ARIS is to improve the decision making capacity in Moghan Agro-Industrial Complex through development of an appropriate resource information system. The system should provide proper information to support planning, monitoring, evaluation, operations, and related decision making processes for sustainable agricultural production.

In the course of system development, the state of the art in relevant disciplines was reviewed to select and apply the appropriate technologies and develop the required decision models. The system contains the necessary analytic capabilities for resource analysis and to integrate the relevant aspects of crops, soils, water, climate, agricultural inputs and machinery information into the planning and management processes of the enterprise. It provides support in the decision making processes by incorporating relevant decision models.

The system is based on the available information resources for a first estimate, and its quality and performance should be improved in the course of normal operation by making use of feed-back processes.

In more specific terms, the system should have the capabilities to meet the following main objectives:

- Resource analysis and land suitability assessment (biophysical) for sustained land use, based on different crops for each production unit. The resource analysis and suitability assessment for irrigated and rainfed crop production should be based on the results of the biophysical land evaluation model which provides quantitative estimates of potential yields (i.e., determined by genetic plant properties, radiation and temperature), water-limited yields (determined by moisture availability as dictated by precipitation pattern and soil physical properties) and nutrient-limited yields (determined by crop nutrient requirements and soil chemical properties). In addition, it should provide quantitative information on irrigation requirements and nutrient requirements to move from one yield level to a subsequently higher level.

- Land use planning and policy formulation, based on biophysical land suitability, water availability, availability of agricultural inputs, machinery, labour, production policy and other social and economic considerations of the enterprise. On the basis of proper optimization algorithms and using information on available production techniques, production systems, reclamation level, biophysical production potentials, availability of various resources and crop requirements, various feasible cropping patterns under different constraints and policies (target/objective) can be determined, and the most suitable one selected.

- Monitoring and evaluation of farm activities to improve overall farm performance through identification of constraints, and using feed-back and feed-forward processes.

- Facilities to provide proper outputs to facilitate the presentation (transfer) of results to the policy makers in a manageable and communicable form.

A schematic presentation of the system is given in figure 10.

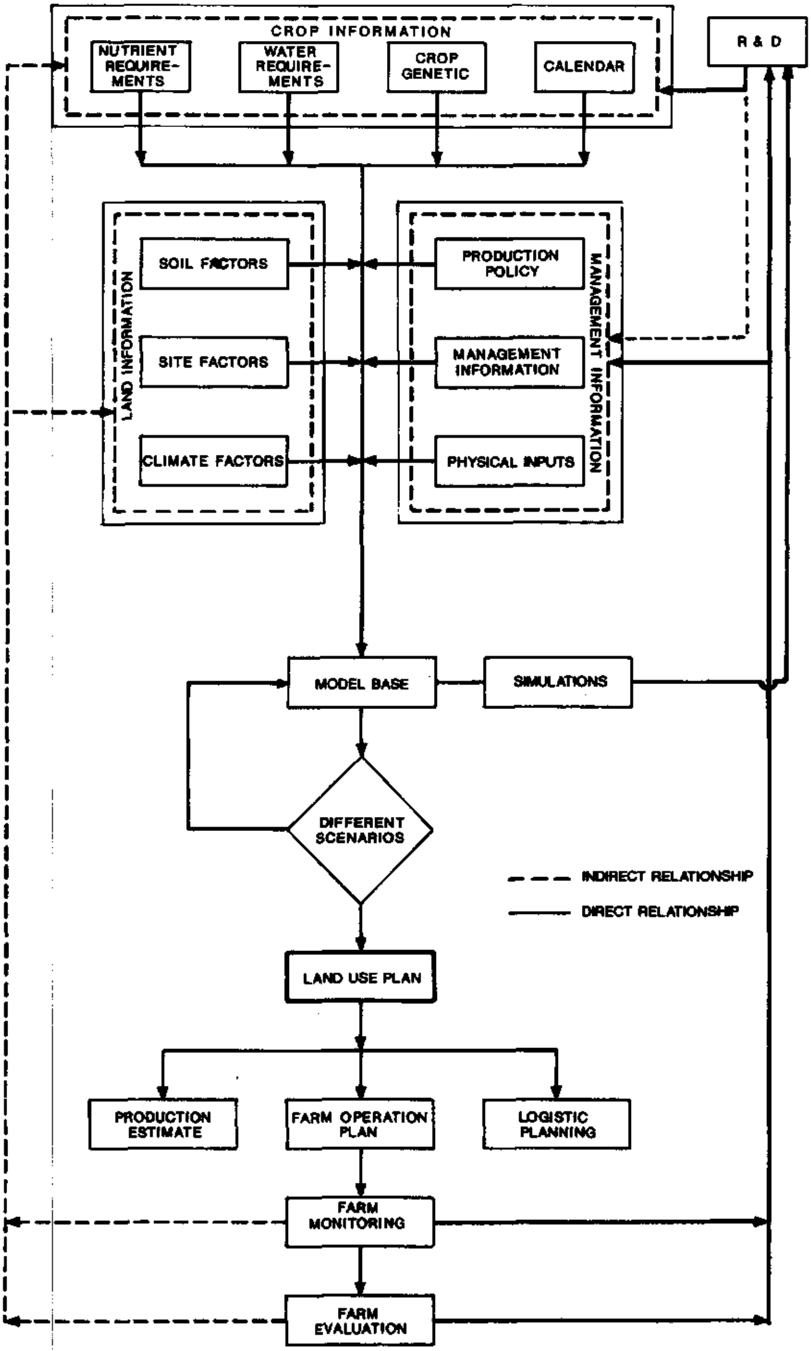


**Figure 10. Schematic view of ARIS**

# CHAPTER 4

## INFORMATION REQUIREMENTS AND DESIGN OF THE OVERALL SYSTEM STRUCTURE

**(activity studies)**

In the course of the activity study, the mandate, functions and organizational structure of MAIC were studied with respect to the objectives of ARIS to identify the existing problems and the information requirements. The information requirements were used to identify the required activities and various sub-systems and, finally the overall structure of the system was designed by integrating the different sub-systems .

### 4.1 Analysis of current situation and problems at organizational level

Using the Wetherbe and Davis (1983) approach characterized in Chapter 2, the current situation in MAIC was analyzed, the existing problems were identified, and the information needs for planning, monitoring and evaluation were derived. This approach, which uses interviews with key management personnel, includes the following:

1 - Study the functions, mandate and organizational structure of the complex and define the underlying organizational sub-systems with respect to the ARIS objectives.

Following an iterative process, the organizational sub-systems involved in planning, monitoring and evaluation in MAIC were defined as follows:

- Planning
  - Land evaluation
  - Tactical land use planning
  - Operational land use planning (land/crop allocation)
  - Derivation of supporting plans

- Implementation
  - Farm operation
  - Mechanized operation
  - Plant protection
  - Material handling
  - Purchases and sales
  - Accounting

  - Personnel and payroll

- Monitoring
  - Quantitative monitoring
    - Reporting
    - Control
  - Qualitative monitoring

- Evaluation

To clarify responsibilities and identify the managers (interest group) to be interviewed, a sub-system manager matrix was developed as shown in table 2.

2 - Define and evaluate information requirements for each organizational sub-system by interviewing each manager and using the structured questions defined in Chapter 2.

3 - Analyze the information collected through these steps (interviews) to identify and classify the problem areas and the information requirements at the organizational level. The results of categorizing the problems were:

- Problems related to the planning activities:

  - Management of the enterprise has not valued available information sufficiently as a vital corporate resource. This must change, and optimum use must be made of the existing information to maximize return on the investments made for collecting it.
  - Land use planning is not based on land suitability assessment for different crops. No formal procedure is used to relate crop requirements to land quality characteristics.
  - The existing technical information on the current state of natural resources and the management capacities are not used in the land use planning process.
  - The capacity of the irrigation network is not properly taken into account in the planning process.
  - Climatic information on the region is not properly used in the planning process.
  - The capacity of available mechanized equipment is not known and therefore is not used in the planning process.
  - Distribution of agricultural equipment among different management units is not based on technical needs.
  - Logistics requirements of the plan are not properly identified and planned.

|  | SUB-SYSTEMS |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MANAGER | Planning | Land evaluation | Tactical plan | Operational plan | Supportive plan | Implementation | Farm management | Mechanization | Plant protection | Inventory | Commercial | Accounting | Personnel | Monitoring | Quantitative monitoring | Reporting | Control | Qualitative monitoring | Evaluation |
| MANAGEMENT BOARD | X |  | X |  |  |  |  |  |  |  |  | X | X | X | X |  | X | X | X |
| PLANNING & EVALUATION | X | X | X | X | X | X | X | X | X | X | X |  |  | X | X | X | X | X | X |
| CONSULTANT GROUP | X | X | X | X | X | X | X | X |  |  |  |  |  | X | X | X | X | X | X |
| COMMERCIAL DEP. | X |  | X |  | X |  |  | X | X | X |  | X |  |  |  | X | X |  | X |
| ACCOUNTING | X |  | X |  | X |  | X | X | X | X | X |  | X | X | X | X | X |  | X |
| INVENTORY | X |  | X |  | X |  | X | X | X |  | X | X | X | X | X | X | X |  |  |
| AGRICULTURAL MAN. | X | X | X | X | X | X | X | X | X | X |  | X | X | X | X | X | X | X | X |
| CEN. MECHANIZATION | X |  | X | X | X | X | X | X | X | X | X |  | X | X | X | X | X |  | X |
| CEN. PLANT PROTECTION | X |  | X | X | X | X | X | X | X | X | X |  | X | X | X | X | X |  | X |
| SECTION MANAGER | X | X | X | X | X | X | X | X | X | X | X |  | X | X | X | X | X |  |  |
| LOC. MECHANIZATION | X |  | X | X | X | X | X | X |  | X |  |  | X | X | X | X | X |  |  |
| LOC. PLANT PROTECTION | X |  | X | X | X | X | X | X | X | X |  |  | X | X | X | X | X |  |  |
| LOCAL INVENTORY | X |  | X | X | X | X | X | X | X | X | X |  | X | X | X | X | X |  |  |
| SOIL SURVEY | X | X | X | X | X |  |  |  |  |  |  |  | X | X |  |  |  |  |  |

Table 2. Subsystem manager matrix

- The production estimates that are used for planning purposes in the commercial department of the enterprise are unreliable.

  - Reliable historical databases for planning and evaluation are lacking (data and proper organization of data).
  - The potential production of any crop in any production unit is unknown; therefore actual yields cannot be judged by any yardstick. This implies that proper standards for evaluating performance are lacking and, hence, that feed-back and feed-forward operations are impossible (this also holds for monitoring and evaluation).

- Problems related to the implementation of the production plan:

  - The wage-payment system that is supposed to be related to the production level in each management unit is not working properly.
  - The inadequate management and supervision system does not provide incentives for increasing productivity.
  - Availability of agricultural equipment does not match the needs.
  - The flow of information among managerial units is inadequate.
  - Because of a lack of technical expertise and inefficient information transfer, crop management is inadequate throughout planting, growing and harvesting stages.
  - The timeliness and quality of agricultural operations is not optimal.

- Problems related to monitoring, control and evaluation.

  - There are no standards to judge or define system performance; hence monitoring, control and evaluation of the activities within various management units are highly inadequate.
  - Information on the degree to which the targets in any production and management unit have been achieved is not available.
  - Information on timeliness and quality of operations is not available.
  - Land degradation is visible in some parts of the enterprise, but its spatial extent is not known.
  - The efficiency of the irrigation network is decreasing (salinization, heterogeneity and physical degradation are apparent).
  - Distribution and application of agricultural inputs are not under proper control.
  - Yields per production unit (parcel) are unknown.
  - Efficiency (cost/ha) of production per parcel cannot be estimated.
  - Utilization efficiency of agricultural machinery is not recorded.

## 4.2 Definition of information requirements

The information requirements are determined by the strategies, goals, objectives and procedures in any of the individual organizational units and the analyses of current problems and activities. In the following section, the organizational information requirements are elucidated and categorized on the basis of analysis of the current situation, results of interviews and the existing problems.

### 4.2.1 Definition of information requirements at the organizational level

Information requirements at the organizational or enterprise level are key elements in developing the overall information system structure and in specifying databases and applications. Analysis of the activities and requirements of the various organizational sub-systems led to the following categories of information requirements.

**A - Decision support information requirements**

The basic decision support information requirements were defined on the basis of the objectives of ARIS, the mandate of the enterprise and discussion on the identified problem areas with various interest groups within the enterprise. These information requirements were derived from the following:

- Resource analysis that resulted in definition of the fundamental characteristics of the available resources and understanding of the processes through which they are allocated and utilized.
- Formulating alternative land use plans, based on biophysical suitability of the land, technical feasibility, social and economic information and availability of various resources under different constraints and objectives.
- Establishing standards to gauge/measure the performance of different activities.
- Monitoring the performance of farm technology to identify the constraints and permit introduction of measures to alleviate them.
- Monitoring ongoing farm operations in relation to the planning, and establishing their efficiency as a basis for improved farm management.
- Determining total production and yield of each crop at each production unit and management level.
- Determining reliable estimates of total production costs and costs per hectare of each crop at each production unit and management level.
- Determining the available farm machinery capacity, degree of utilization and utilization efficiency.
- Determining farm machinery repair and maintenance efficiency.
- Determining timeliness of farm operations.

- Monitoring agricultural inputs at each production unit for each management level.
- Monitoring total labour input and labour efficiency for each operation at each production unit and management level.
- Identifying the production constraints and agricultural research priorities to focus on development of the required technology.

### B - Basic information requirements

To generate the required decision support information, the following categories of information are required:

- Land information requirements
  - Basic and reliable quantitative information on relevant land qualities and their characteristics
  - Basic and reliable information on climatic characteristics
  - Quantitative information on irrigation network capacity and water availability

- Information requirements on cropping history and production
  - Historical information on land utilization for each production unit
  - Information on total area under supervision of each management division and the area of each crop at each management level

- Crop information requirements (crop behaviour)
  - Crop physiological and phenological properties
  - Crop nutrient requirements
  - Crop calendar and production information
  - Crop rotation

- Information requirements on agricultural equipment
  - Capacity of agricultural machinery and implements at each management level
  - Utilization rate of agricultural machinery at each management unit
    - Efficiency of utilization
    - Performance of the workshops for maintenance and repairs

- Information requirements on agricultural operations
  - Farm operation and harvesting information for each production unit and management level
  - Material input requirements and use for each parcel and management level
  - Timeliness and quality of operation

|  | ORGANIZATIONAL SUB-SYSTEM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INFORMATION CATEGORY | Planning | Land evaluation | Tactical planning | Operational planning | Supportive planning | Farm operation | Mechanization | Plant protection | Inventory | Purchase & sales | Accounting | Personnel & payroll | Reporting | Monitoring | Quantitative monitoring | Evaluation |
| Crop information | 2/2 | 2/3 | 2/3 | 2/3 |  | 2/3 | 3/2 | 3/3 | 2/2 |  | 1/1 |  | 1/2 | 1/3 | 1/3 | 1/3 |
| Crop operation | 1/2 | 2/3 | 2/3 | 2/3 | 2/3 | 2/3 | 2/3 | 2/3 | 2/2 | 1/1 | 1/2 | 1/3 | 1/2 | 1/3 | 1/2 | 1/3 |
| Agric. Machinery | 1/3 |  | 1/3 | 1/3 | 1/3 | 1/3 | 2/3 | 2/3 | 2/2 | 1/1 | 1/2 | 1/3 | 1/2 | 1/2 | 1/2 | 1/3 |
| Agric. Inputs | 2/3 | 2/3 | 2/3 | 2/3 | 2/3 | 2/3 | 2/3 | 2/3 | 2/3 | 1/3 | 1/3 |  | 1/2 | 1/2 | 1/3 | 1/3 |
| Acreage & Rotation | 3/3 | 3/3 | 3/3 | 3/3 | 2/3 | 1/3 | 1/3 | 1/2 |  |  | 1/3 | 1/3 | 1/3 | 1/3 | 1/3 | 1/3 |
| Cost Accounting | 1/3 | 1/3 | 1/3 | 1/3 | 1/3 | 1/2 | 1/3 | 1/2 | 1/3 | 1/3 | 1/3 | 1/3 | 1/3 | 1/3 |  | 1/3 |
| Land information | 1/3 | 1/3 | 1/3 | 2/3 | 1/3 | 1/3 | 1/3 | 1/3 |  |  |  |  |  | 1/3 | 1/3 | 1/3 |

Availability Code (A)
1 = Low
2 = Medium
3 = High

Degree of importance (B)
1 = Low
2 = Medium
3 = High

**Table 3.** **Availability and degree of importance of various information categories per organizational sub-system (A/B)**

- Information requirement on agricultural inputs
  - Fertilizer, insecticides, herbicides, fungicides and other chemicals
  - Seeds at each production unit

- Information requirements on costs of different inputs
  - Various materials and chemicals
  - Labour
  - Mechanized operations

Table 3 shows the information categories per organizational sub-system. In this matrix, rough indications are given of the degree of importance and the availability of information.

## 4.3 Overall system structure

Based on the results of the analysis of the current situation in MAIC, definition of the problem areas and their information requirements for improvement, a planning, monitoring and evaluation system was designed to match these requirements. The designed system is able to meet all information requirements, and therefore has a capability to analyze resources, provide support for decision making problems and integrate the available information into the agricultural planning and management of the enterprise.

Development and implementation of such a system included the following:

- Data collection, and organization of the required spatial data in proper spatial databases
- Data collection and organization of the required thematic data in proper databases
- Selection and implementation of processing functions
- Implementation of planning functions
- Reporting
- Control
- Monitoring
- Evaluation

These activities were grouped in five main processes on the basis of the type of processing, "formalizability", "automatability" and the volume of the transactions. The major functions (processes), inputs and outputs of the system are illustrated in figure 11. The legend is given in figure 12.

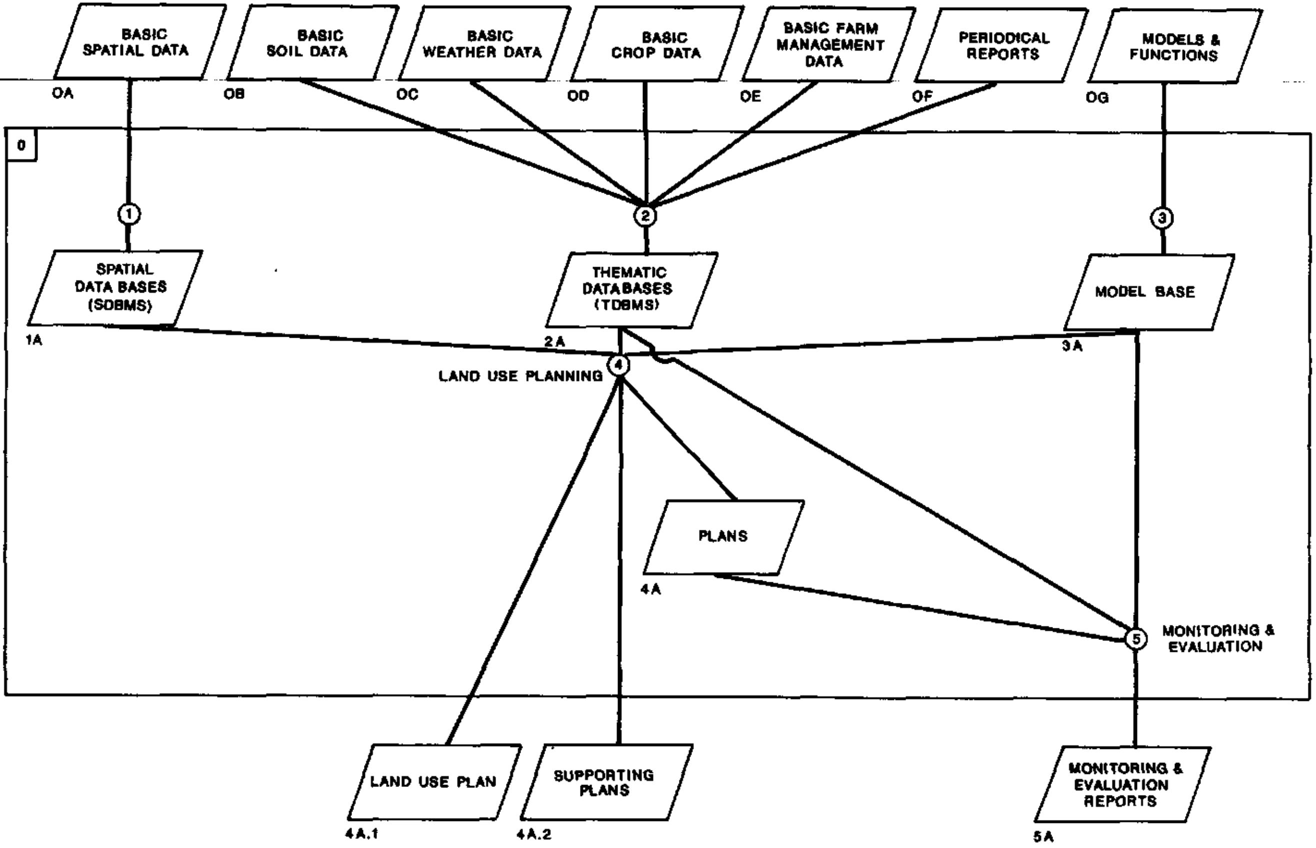


Figure 11. Global representation of ARIS (zero chart)

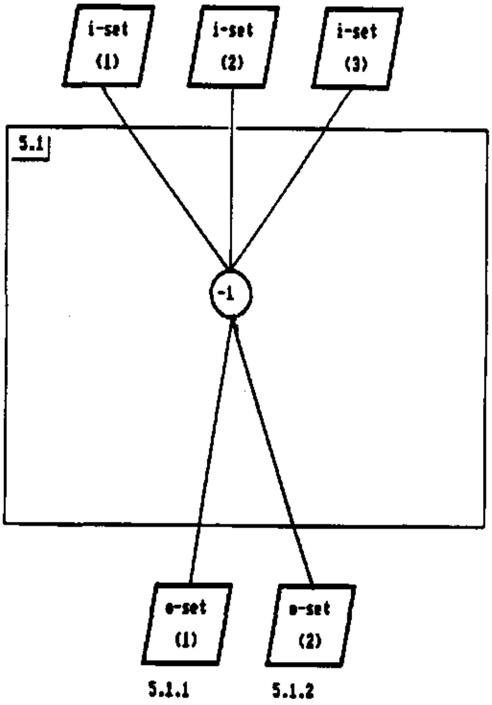


**Figure 12. Legend of the graphic symbols used for system development**

*This type of representation, illustrates how the processes transform information from one or more input information sets (I-sets) into one or more output I-sets. The I-sets are represented by boxes and the processes by circles. Each process is described and represented in a chart which is numbered according to the process numbers .*

*The system boundaries are represented by two horizontal lines, with system inputs above the upper system boundary and outputs below the lower system boundary. The upper left hand corner of each chart carries the number of the process it describes, with the overall structure of the system by convention carrying the number zero. Processes are numbered sequentially in the zero chart.*

*I-sets are numbered according to the process which produces them, followed by a number (i.e. process 1 produces I-set 1.A1,1.A2..). In more detailed charts they are decomposed using a sequence number (i.e. process 1 is decomposed into 1.1 ,1.2, 1.3,...), and for convenience in presentation, a dash may be used to replace the main reference code (van Laan and Berkhout, 1988; Lundeberg et al., 1978).*

At the first process level, the raw spatial and attribute data are stored in the spatial and thematic databases, (processes 1 and 2). The structure of these data (the data model) must be such that the required information can be made available to the "process model". At the same level, all required functions and models are organized in the model base (process 3) so that all required events and operations can be simulated in the system's "process model" (see Benyon, 1990).

At the second level, the models and functions from the model base are combined with the relevant data from the spatial and thematic databases for land use planning. This process includes proper facilities to accurately estimate the productivity of the land for any kind of feasible use (biophysical land evaluation) at different input levels. This information is combined with relevant management data in a planning model to design the most suitable plan with respect to the production policy, the available resources and management constraints of the farm enterprise. At a later stage, the tactical plan is transformed into the actual operational plan using an appropriate spatial decision model.At the third level, the plan of action is used as the standard in combination with the periodic reports and the relevant functions of the model base for monitoring and evaluation.

The first three processes are the supporting processes and the last two (4 and 5) are the functional processes of ARIS. In this document, only the process model (process 3) and the functional processes will be elaborated in detail. The main processes are referred to as sub-systems.

### 4.3.1 Spatial database management sub-system (SDBMS)

This sub-system provides the capacity to describe the location of map features and the topological relationships among map elements. It contains facilities to input, store, retrieve, process, update and output all related spatial data, such as various soil and topographic maps, irrigation and road networks, etc.

### 4.3.2 Thematic database management sub-system (TDBMS)

This sub-system handles thematic data that identify and describe map features and social and economic conditions. It contains data processing capacity to input, store, process, retrieve, import, export, output and update different technical and economic attribute data, such as climate, soil and farm data of each management unit (figure 11), and provide data for planning, monitoring and evaluation at different levels of aggregation. Thematic data are organized in tabular form and manipulated with a relational database management system (TDBMS).

### 4.3.3 Model base sub-system

This sub-system provides functions and processing facilities for all operations that must take place in ARIS to improve and support the decision making process in planning, monitoring and evaluation. It includes all physical and mathematical models and functions that are required for different processes of land use planning, monitoring and evaluation sub-systems. They are grouped in various process models on the basis of the functions and backgrounds of the processes and organized in a model base sub-system. Thus each process in every functional sub-system corresponds to a process model.

These process models, which simulate different aspects of the complex agricultural system at specific times and places, are different in nature and are derived from various disciplines. While the biophysical land evaluation model includes variables that reflect the association and diversity of ecosystems, the tactical planning model includes physical, social and economic variables. The first uses crop growth simulation based on the interaction of site characteristics, such as soil and climate, with crop properties; the latter, applying mathematical programming techniques, integrates the biophysical and social and economic variables.

### 4.3.4 Land use planning sub-system

A decision support system for planning at farm enterprise level should comply with the land use planning definition and provide support for understanding the agricultural system environment, and for tactical and operational planning. Such a system has been designed, as presented in figure 13 in which the inputs, outputs and main processes are schematically presented. The processes are referred to as models.

This sub-system consists of facilities to analyze the agricultural system environment, and quantify its effects on the agricultural production potentials, in support of tactical and operational planning and generation of supportive plans.

The land use planning sub-system is the core of ARIS. It contains an integrated land use planning model (Sharifi and van Keulen, 1991) that integrates all relevant information--on crop, soil, water, climate, agricultural machinery, agricultural inputs and other resource endowments, production policies and constraints-- to generate the optimum feasible cropping pattern. This pattern is subsequently transformed into an operational plan; this plan then forms the basis for deriving all supporting plans, such as production estimates of the various agricultural commodities and the logistics requirements for implementation of the plan.

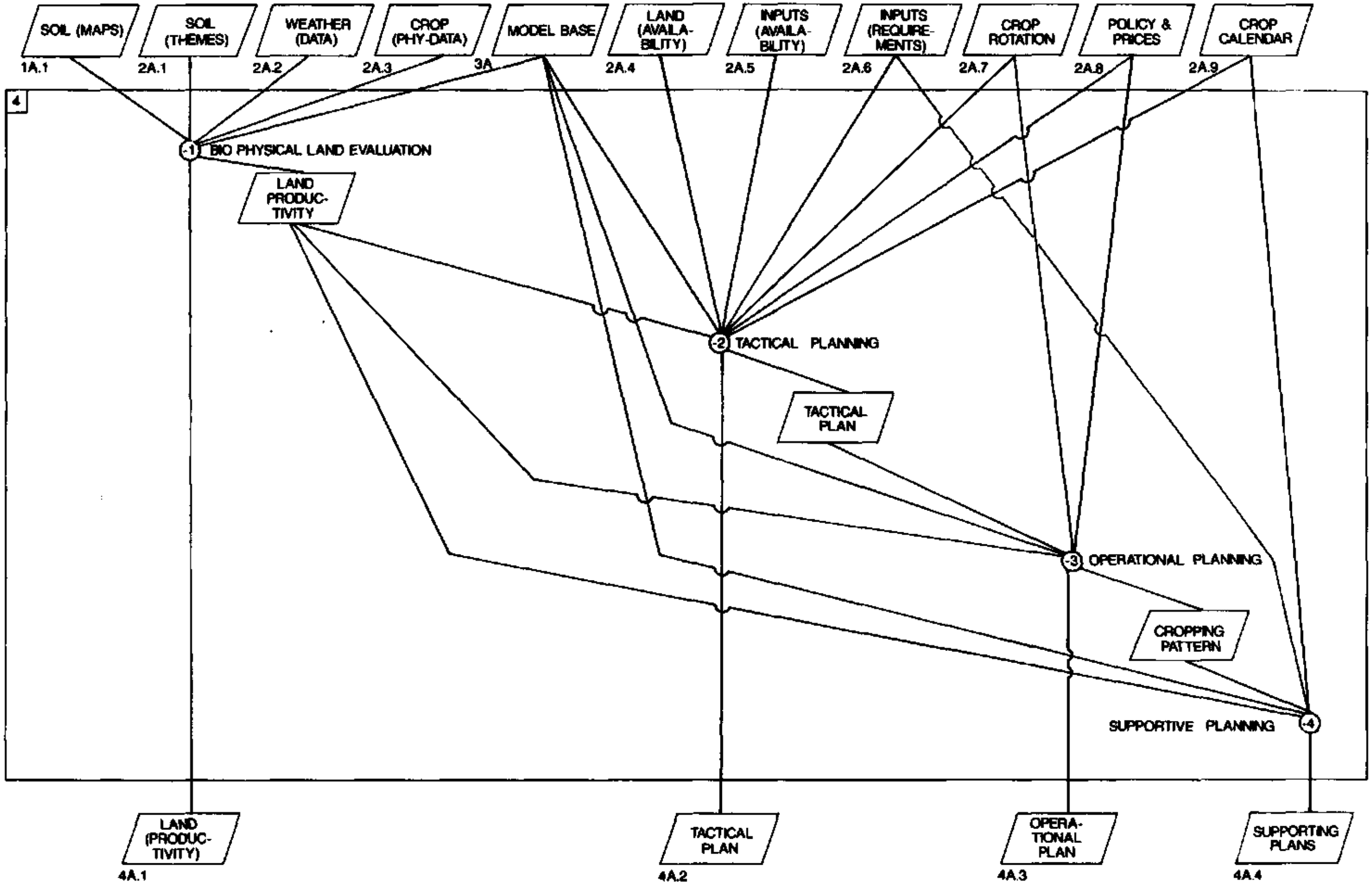


Figure 13. Global presentation of land use planning sub-system

### Process 4.1 Biophysical land evaluation

The biophysical land evaluation model is used for resource analysis and quantification of expectations about the physical capacities of the agricultural environment. In this model, the relevant crop-environment interactions are described quantitatively in a set of simulation modules representing current understanding of the constituent processes of the system and their impact on system behaviour. It also aims at assessing limits to agro-ecological productivity, environmental tolerance or technical feasibility. This model is used to identify promising alternative production practices in the enterprise environment, and to establish reliable input/output response relationships between water and macro-nutrient requirements of each crop and its production potential.

The biophysical land evaluation model yields the productivity of a crop with explicitly defined properties in a well-defined aerial environment on a particular tract of land, characterized by its location, physical and chemical properties and its topographic features at different reclamation levels. The aerial environment is characterized by the relevant climatic or weather characteristics. The model also provides reliable estimates of crop water and macro-nutrient requirements at different levels of reclamation. By integrating the input costs and gross returns of each unit of land, a suitability index was established to characterize the performance of each specific land utilization type.The estimated productivity or suitability indices were used in a quantified land evaluation procedure to evaluate relative differences between parcels or regions, and the relative importance of the growth factors (water and nutrients) as a basis for establishing planning priorities.

### Process 4.2 Tactical planning

Tactical planning is the process of generating an optimum land use plan based on suitability assessment and input requirements (estimated during the biophysical land evaluation), social and economic conditions and management policies of the enterprise. Land use planning has agronomic, social, economic and political dimensions, and it deals with multi-purpose uses of land, trade-offs between different functions of the land, and conflicting interests between different categories of land users and between collective and individual goals and needs (Van Keulen et al., 1987).

Tactical planning provides the capability to integrate the productivity of the land for any type of feasible land use (biophysical land evaluation), at different levels of input, with relevant social and economic data to formulate the most suitable tactical plan for a given combination of production policy, available resource base and management constraints at the farm enterprise. By varying the constraints, costs or fixed resources, different scenarios can be generated and the effects of alternative decisions analyzed.

**Process 4.3 Operational planning**
Operational planning is the process of determining an optimal land use plan which satisfies the tactical plan, biophysical conditions and the management priorities of the enterprise. It is supported by a spatial decision model and geographic information system capabilities to assign each production unit (parcel) to a specific land utilization type, considering the various priority parameters.

**Process 4.4 Support planning**
Supporting plans (planning queries) are a series of auxiliaries to the basic operational land use plan, such as farm operation plan, total production estimates, logistics requirements and plan, etc. This process is supported by a series of simple models, data and information analysis capabilities.

### 4.3.5 Monitoring and evaluation sub-system

Monitoring and evaluation are two of the basic elements of management which should be implemented as the plan becomes operational. They imply continuous measurement of accomplishments and comparison with the predefined plans, and possible correction of deviations to assure the attainment of objectives.

Here, the operational plan and all auxiliary supporting plans are used as a target for assessing progress and efficiencies. The cost performance of each operation and production efficiency at each management level are evaluated and used for negative and positive feedbacks.

This sub-system includes processing capabilities to allow manipulation of data for analyses aiming at specific tasks or for general purpose analyses. It provides access to a series of databases and small models to produce the required information. All data collected for monitoring and evaluation are stored in the respective databases to update the existing data which are used later for different management processes. The system thus starts with available data sets, some of which, at the first stage, may be estimates and therefore not very reliable; in the course of routine operation of the system, they are updated and improved.

The input, output and processes of this sub-system are presented schematically in figure 14.

**Process 5.1 Reporting**
In the reporting process, sets of pre-defined reports on the status of the most important operations in terms of the plan are selected, prepared and presented. They are simple and user-friendly types of reports with the following characteristics:

- Contain the minimum information necessary for the management to take timely and appropriate actions on critical events
- Alert the management to supporting element needs
- Provide each level of management with the relevant information
- Provide more generalized, well-selected information on the most important indicators of progress and performance going from lower to higher levels of management
- Indicate clearly the current status of operations both favourable and unfavourable

### Process 5.2 Control

In the control process, the performance of each operation is established and compared with some pre-defined standard (basic and supportive plans) to evaluate the degree of achievement and provide information on difficulties and successes.

### Process 5.3 Monitoring

The monitoring process works at a higher level of aggregation than the two preceding processes in this sub-system. It uses the information provided by the reporting and control processes to evaluate the actual situation in terms of the desired plan of action, and to identify the degree of progress and the most significant problems and successes.

The problems identified by the monitoring process should be used as feed-back for corrections; successes should provide feed-forward to disseminate information about successes to promote progress (Mollett, 1990).

### Process 5.4 Evaluation

The evaluation process is an on-going (built-in) evaluation process that analyzes the information provided by the monitoring process to identify failures and achievements and their causes (Mollett, 1990). This information is used to implement the appropriate corrections, and to improve planning and implementation of future operations.

By recognizing the achievements and analyzing their causes, successful experiences, new ideas and innovations can be developed or expanded in future planning and operations.

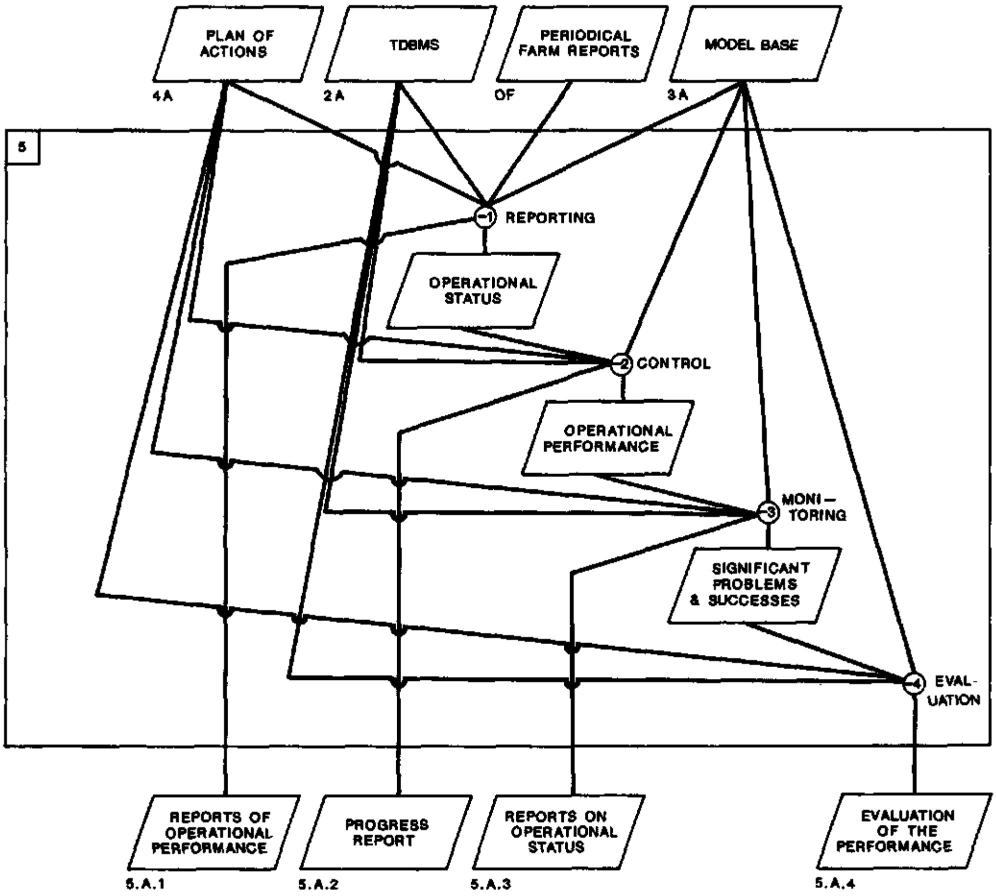


**Figure 14. Global presentation of monitoring and evaluation sub-system**

# CHAPTER 5

## INFORMATION ANALYSIS AND DEFINITION OF OUTPUTS, MAJOR PROCESSING FUNCTIONS, AND INPUTS OF THE SYSTEM

On the basis of the information requirements of each sub-system, study of existing methods and the system environment, the outputs, types of major processing function, major processing functions and inputs of each of the sub-systems were defined. The procedures were discribed in Chapter 2.

### 5.1 Definition of system output requirements

The precedence analysis procedure was used to determine the major output requirements of each sub-system, starting with the objectives and determining the information which has to precede them (Chapter 2).

The decision support information requirements and the basic information requirements at the organizational level served as the objectives at the application level. Each objective (requirement) was further analyzed with respect to the problem areas (section 4.3) and objectives of the sub-systems to define the information sets which are required to attain them. These information sets are referred to as the output data element.

As a result of this analysis, the output requirements of all sub-systems were defined and grouped in preliminary output reports. To finalize the output requirements of the system, the format and content of these reports were discussed with the various user groups and analyzed with respect to the technologic constraints, availability, reliability and accessibility of data and their applications in supporting management decisions. The output data items of each sub-system and detail information and format of the output reports are included in the documentation of the computer system. The major output elements of each functional sub-systems are described here.

### 5.1.1 Output requirements of the land use planning sub-system

A - General description of the major output elements of the biophysical land evaluation

- Potential yield and production of each relevant crop under the prevailing conditions of temperature and radiation.

- Yield and production of each relevant crop for each parcel as determined by water and/or macro-nutrient availability under natural conditions.
- Irrigation requirement per month of each crop at each parcel
- Macro-nutrient requirements for realization of the potential production.
- Biophysical suitability assessment of each parcel for each prospective crop.

B - General description of the major output elements of the tactical planning.

- Alternative cropping patterns resulting from maximizing total gross margin of the enterprise, subject to various management and physical constraints, e.g., production policy, resource availabilities, biophysical suitabilities.
- Estimates of the expected benefits of each plan (total gross margin) and the economic value of each resource and crop in the plan (shadow prices and reduced costs, see sections 5.2.3.1.2 & 7.2.3).
- Estimates of the input requirements of each plan.

C - General description of major output elements of the operational planning (allocation model).

- The annual cropping pattern derived from optimum allocation of a crop to a tract of land, based on biophysical suitability of the land, crop rotation, demands for the crop defined by the tactical planning model, and other management policies.

D - General description of major output elements of the supportive plans:

- Operation requirements for cultivating any crop.
- Crop operation plan for each parcel and management division.
- Total operation requirement for any cropping pattern in any specified period.
- Total, monthly and seasonal labour requirements for implementation of the plan.
- Total, monthly and seasonal requirements of the plan for all physical inputs, including seeds, agricultural machinery, chemicals, irrigation water and other supplies such as oil, gas, etc.
- Total land requirement (from different categories) for implementation of the plan.
- Production costs per hectare of each crop at each production unit and management level.
- Total production and yield of each crop at each production unit and management level.
- Production estimate for any specified cropping pattern.
- Total area per crop acreage at each management level.

### 5.1.2 Output requirements of the monitoring and evaluation sub-system

A - General description of major output elements for the reporting process.

- Farm operation progress report per specified period at each management level.
- Farm material utilization level per specified period at each management level.
- Delay in farm operations at each management level.
- Labour and contractor price information.
- Information on utilization and maintenance of agricultural equipment
- Information on harvest operations per specified period at each management level.
- Crop production at each parcel.

B - General description of major output elements for the control process.

- Problems encountered in farm operations.
- Delays in farm operations.
- Condition and utilization of agricultural equipment.
- Deviations from crop calendar.
- Deviations of actual input levels from their respective norms.
- Check for the availability of the required material and agricultural equipment.
- Production costs per hectare of each crop at each production unit.
- Utilization efficiency of land, agricultural inputs and agricultural equipment.
- Farm machinery capacity available, degree of utilization and utilization efficiency at each management level.
- Cropping history of each parcel.

C - General description of major output elements for the monitoring process.

In the monitoring process that works at a higher level of aggregation than the control process, reports on the actual situation are produced for comparison with the plan of action to establish the current status of operations and the most outstanding problems and achievements.

D - General description of major output elements for the evaluation process.

- Land utilization efficiency in terms of average, highest and lowest yields.
- Production constraints (to derive research priorities).
- Efficiency of farm operations at different parcels and different management levels.
- Utilization efficiency of agricultural equipment.
- Efficiency of workshop in repairing agricultural equipment.
- Achievements and failure of crop production at different management levels.
- Quality of land utilization (quality of management).

- Comparative performance of cropping systems in each management unit in relation to the potential, actual and average yield in the past years.

## 5.2 Definition of the major processing functions

The processing functions of each sub-system were defined using the procedures discussed in chapter 2. This include analysis of the system environment and analysis of existing method with respect to the results of the environment analysis to select or develop the proper type of processing functions appropriate to the situation. Finally the actual processing function was defined in such a way that it could be developed during the data system design phase.

### 5.2.1 Analysis of system environment

Planning, reporting, control, monitoring and evaluation processes essentially provide access to a series of databases and use processing capacities to provide support for decision making processes. The processing capacities can vary in level of sophistication and ambition from simple data manipulation to very complex models. The selected level of ambition and sophistication is determined by the system environment and system requirements. System environment plays a dominant role in defining the processing capacity, and that itself is very much affected by organizational culture, power structure and organizational learning (skills).

Each organization has its culture and a specific pattern of power distribution which reinforces values, norms and beliefs about the organization (Davis and Olson, 1985). Organizational learning refers to the process by which an organization identifies action-outcome relationships, stores experience in organizational personnel by teaching new employees, and stores the experiences in procedures, forms, systems, rules, etc. Goals, objectives, strategies and processing functions of an information system should suit the culture, power distribution, organizational learning, and capacity of the organization to avoid high resistance and risk of failure.

Analysis of the system environment in MAIC showed the following:

- Organizational learning in terms of experience and procedures with respect to the complexity and extent of activities is very limited, because the organization is relatively young. This means that procedures and methods for planning, reporting, control, monitoring and evaluation of all types of activity are not well established and this has resulted in an organizational culture that creates the problem areas discussed in section 4.2.

- The number of qualified personnel is very small compared with the numbers required. In some areas, such as electronic data processing, they are very scarce, if present at all.
- Because of the heavy investment in study of the infrastructure of the enterprise, a considerable amount of basic information on natural resources of the area is available.
- Organizational power is not uniformly distributed within the organization, and the administrative sector has the most power.

This analysis led to the following considerations in selecting processing functions:

- Use centralized planning, monitoring and evaluation activities to improve distribution and utilization of resources and identify the problem areas and achievements. This may lead to increased productivity and remove some of the constraints.
- For reporting, control, monitoring and evaluation, collecting too much detailed information should be avoided, and emphasis should be placed on easily aquirable data, collected regularly (preferably on a daily basis). This will decrease possible manipulation of data by personnel.
- On matters such as cost accounting, for which the required data are not available and comprehensive data collection procedures are very difficult to establish, a simple model producing acceptable results is being considered.
- Select a method to improve the flow of technical information between high-level technical personnel (consultant to the general manager) and low-level technicians to provide specialist knowledge on each crop to the farm manager, who has a very great technical responsibility but lacks the required knowledge.
- Select comprehensive models on technical issues with inputs that are available or can be easily collected.
- Apply all possible techniques that can assist technical personnel of the enterprise in improving cropping practices.

All these considerations were taken into account in defining the output and processing capabilities of each sub-system.

### 5.2.2 Type of processing functions

The type of information required in each sub-system can be derived using various approaches and methods, each having its own methodological and operational advantages and disadvantages. In this sub-section the proper type of processing functions and models appropriate to each of the functional sub-systems are identified by considering the results of the analysis of system environment and using the procedure discussed in Chapter 2.

The ARIS system approach in land use planning, monitoring and evaluation were discussed in Chapter 2; and their general structure were disscussed in Chapter 4. The type of processing functions required for each of the functional sub-systems is discussed here.

### 5.2.2.1 Type of processing functions for land use planning sub-system

Land use planning comprised of:
(1) biophysical land evaluation process,
(2) tactical planning process,
(3) operational planning process,
(4) supportive planning process.

According to the method described in Chapter 2, the type of processing function for each of these processes was determined and represented by a model. The general type of these models are described below.

### 5.2.2.1.1 Type of processing functions in biophysical land evaluation

The purpose of land evaluation is to predict the performance of specific land use systems as determined by the constraining influence of land conditions (Beek, 1978). The predicted performance of the land is expressed in productivity or suitability classes. The method of assembling or generating information on land productivity varies among evaluation systems.

Biot (1988) discussed the different kinds of productivity indices currently used for land evaluation. Three main categories were identified: measured, simulated and rating systems.

- Measured crop yields: determined from systematic experiments and/or extensive surveys.
- Simulated crop yields: calculated using crop growth models based on the principles outlined by De Wit (1985) and Van Keulen and Wolf (1986).
- Land qualities and characteristics: a number of productivity indices have been proposed on the basis of land characteristics and/or qualities. This approach primarily establishes and utilizes a relationship between crop yield and productivity indices.
  - Soil depth or depth of topsoil was used by Elwell and Stocking (1984), and Todorovic et al.(1987).
  - Biot et al. (1984) used a rating technique to assess the productivity of the land with regard to tropical crops based on the method suggested by Sys (1980).
  - Various rating systems were developed by Kiniry et al. (1983), Craft et al. (1985),

Busacaa et al. (1985), Miller and Singer (1985) in the context of erosion/productivity research.
- Available water storage capacity was proposed by Biot (1988).

Crop yield estimates, differentiated by physical conditions and management system, are one of the major concerns in land evaluation (Van Diepen et al., 1991). In the context of land evaluation, yield estimates serve as a basis for comparing the productivity of different kinds of land. In a biophysical land evaluation model, primarily the biologic productiviy, as defined by ecologic and technologic constraints, is used to predict the performance of a specific land use system.

The methods of assembling or generating information on yields also vary among evaluation systems. Van Diepen et al. (1991) categorised the major approaches to yield estimation in three main groups:

- Systematization of observed yield levels, including methods for estimating innate soil productivity, soil potential rating, and matching concept. Gersmehl and Brown (1986) indicated the regional disparities in the innate soil productivity index and its anticipated changes due to management improvements. The focal point in matching procedures is that data from different sources are combined and compared to define suitability or productivity classes. In all of these procedures, the functional relationships between the land and its use are based on subjective judgements of the land evaluator.

- Statistical analyses of observed yield levels, including linear and multiple regression analyses, and a parametric approach. Stochastic (demonstrative) models, containing statistical relations between some relevant and perceptible attributes of the system, lead indirectly to the required results. The functioning of the system in terms of flows of energy, mass and information is considered a "black box"; only the output of the model is similar to that of the real system (Berkhout, 1986). In particular, statistical procedures are not suitable for dealing with positive and negative feedbacks between dynamic factors.

  A regression model is one form of a demonstrative model. It describes a relation between yield and one or more environmental variables. No matter how many factors are included to establish a multiple regression between the agricultural system and its environment, it provides a gross estimate and cannot be generalized and used for other areas (i.e; it is site-specific), (Penning de Vries, 1983).

  Regression models can be good predictive tools if the mechanisms underlying the response of yield to environmental variables are unknown.

- In deterministic (explanatory) models, causal relationships among the variables are formulated and quantified, based on understanding of the underlying processes of the system. Such models are applicable under a wide range of conditions after sound calibration and validation procedures ( Van Keulen, 1976). Such models simulate crop behaviour as controlled by the environment and calculate the yield response to environmental factors. In a dynamic deterministic model, the state of the system at any specific time can be defined quantitatively and the rate of change of the system can be expressed in mathematical terms. Based on their development stage, three types of dynamic model can be distinguished (Penning de Vries, 1983):

  - Preliminary models with structure and data that reflect current scientific knowledge of the processes; they cannot be used for extrapolation and prediction because insight at the explanatory level is still vague and imprecise.
  - Comprehensive models that simulate the behaviour of the system, based on a thorough understanding of the essential elements of the system.
  - Summary models are abstracts of comprehensive models; essential aspects are formulated in less detail for simplicity, accessibility and applicability.

Preliminary models are used mainly to increase insight into the behaviour of the system and to test alternative hypotheses, while comprehensive and summary models are used for operational purposes.
All types of dynamic models may work better than a regression model (Penning de Vries, 1983). The major advantages of this approach are its sound theoretical basis and the possibility of predicting yield of any crop at any location. However, the more detailed the dynamic model, the more information is required for initialization and definition of functional relationships. If such information is not available, regression models may be a better option.

The FAO framework for land evaluation (Beek, 1978) is still one of the basic documents in land evaluation and the most widely quoted reference. It uses the matching concept for comparison of land use requirements and land qualities to derive suitability classes. Land use requirements are expressed in terms of land qualities and rated on the basis of empirical and experimental data, i.e., "factor rating" (FAO, 1983).

Review of the relevant literature describing the theoretical basis of and practical experience with the framework shows methodological and operational shortcomings that could be alleviated by implementing the results of land evaluation research achieved during the last decade (Van Diepen et al., 1991; Fresco et al., 1990).

Over the last two decades, the system-analytical approach to crop ecology has led to the development of many crop growth simulation models for quantitative estimates of the growth and production of the main agricultural crops, under a wide range of weather and soil conditions (De Wit and Van Keulen, 1987). Such models have been developedon the basis of insight into the fundamental relationships between crop performance andsoil and weather conditions, and describe crop response to water and macro-nutrient availability to calculate the main resource requirements for realization of the production potential. The conceptual framework of such a model was described by Van Keulen and Wolf (1986). With the increasing availability of computing capacity and the advance of geographic information systems, application of dynamic simulation models in land evaluation is becoming more feasible.

On the basis of this analysis, a biophysical land evaluation model was formulated as presented schematically in figure 15. In this approach, a summary crop growth simulation model is used to describe the relationship between crop characteristics, land quality level and yield. Land quality level is determined by soil properties, prevailing weather conditions and level of reclamation. The model can be used as a tool for analyzing the growth andproduction of field crops under a wide range of weather and soil conditions. Such an analysis shows, first to what extent crop production is limited by the availability of light, moisture and macro-nutrients and, second, what improvements are possible. The yield level is considered concurrently as a dependent variable, determined by crop characteristics and land quality level, and an independent variable dictating the input requirements for its realization.

Hence in this procedure the simulation model is used to derive crop water requirements, nutrient requirements and yields at different levels of reclamation. It serves as a powerful tool in quantified land evaluation.

### 5.2.2.1.2 Type of processing functions for tactical planning

Tactical planning requires a planning model that

(1) integrates the biophysical potential of the land with social and economic conditions and management policies of the enterprise to formulate a land use plan and calculate the achievements and requirements of all feasible plans, and
(2) selects the most suitable plan from the various alternatives for a given combination of production policy, available resources and management constraints.

Assuming that all alternative plans and their outcomes are known, or can be known, the problem in tactical land use planning is to select the optimal alternative for a given objective and set of constraints.

Janssen and Nijkamp (1988) distinguished three categories of conceptual models for decision making:

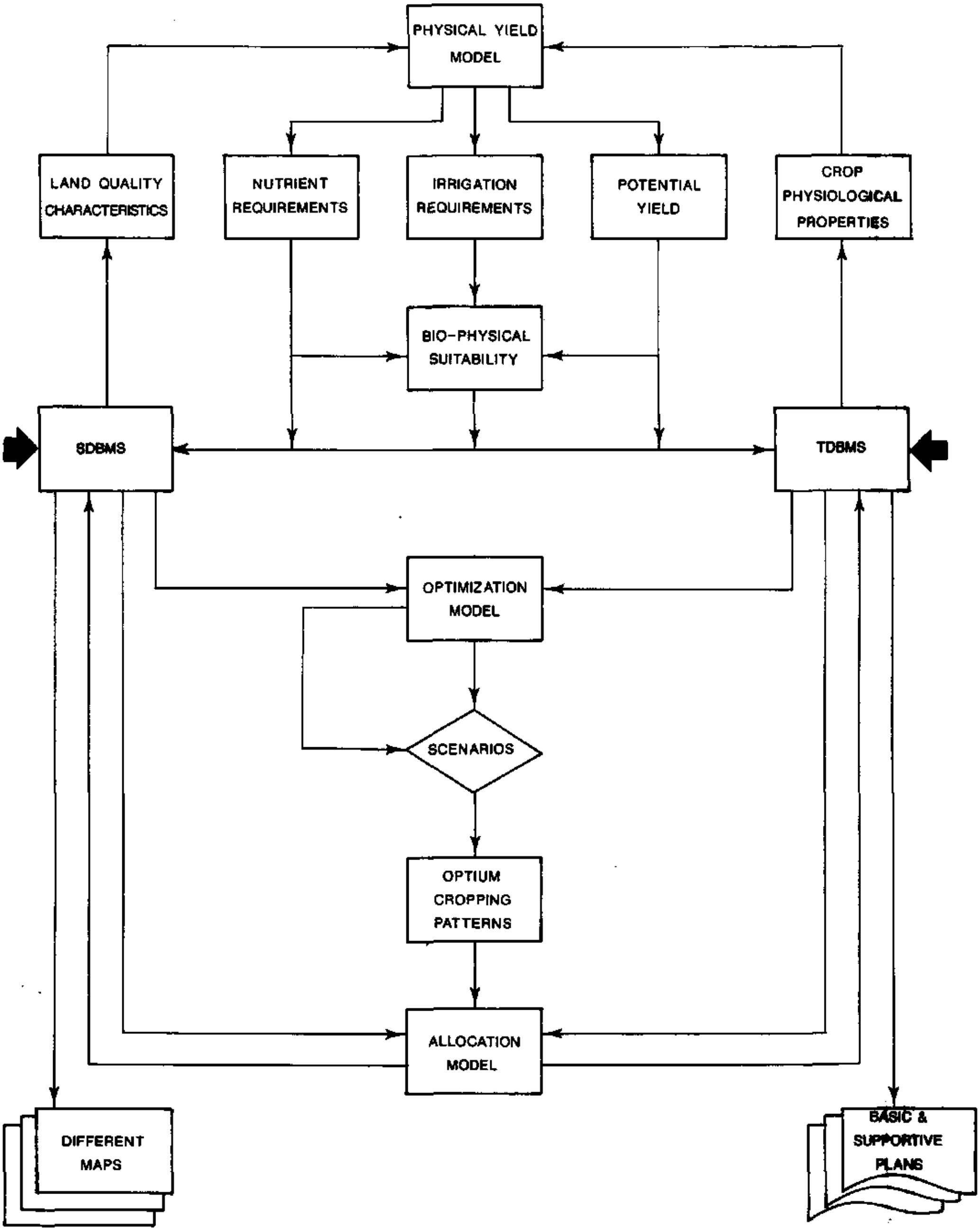


**Figure 15.** **Conceptual flow of information and relations between different models in the land use planning sub-system**

- Models of optimizing behaviour
- Models of satisficing behaviour
- Models of justifycing behaviour.

Most formal evaluation techniques focus on the first and to a lesser extent on the second category. The last is often used to justify policy decisions, even if the actual decisions are not in agreement with "optimizing" or "satisficing" principles. The models of optimizing behaviour are normative: while their purpose is to arrive at an optimum solution among available alternatives, they simulate the problem area. The others are descriptive: while their purpose is to describe the relationships between elements of decision problems, they are used to select the alternative that satisfies the existing conditions (Koontz and Donnell, 1988).

At the farm enterprise level, where the decision maker is interested in the possible consequences of various decision rules in association with the related existing constraints, a normative model for decision making was appropriate (Hazell and Norton, 1986). A normative decision model is therefore applied to support the tactical planning process and derive a proper decision rule to select the best allocation of scarce resources of the enterprise. Among normative models, linear programming is one of the most powerful tools for analysis of resource allocation choices at the farm and sectoral level (Hazell and Norton, 1986).

Farmers, agronomists and other agricultural specialists describe farm activities in terms of inputs and outputs per annual crop cycle, with input-output coefficients expressed per hectare of land. In farm analysis, input costs are disaggregated into labour, machinery services, fertilizer, etc., per land unit. They also often express the agricultural problems in terms of inequality constraints, such as upper bounds on seasonal resource availability; they are accustumed to the existence of slack resources in some seasons, while the same resources are fully utilized in other seasons (Hazell and Norton, 1986). This way of thinking fits naturally into linear programming models, which therefore provide a rather natural framework for farm planning.

Linear programming allows integration of knowledge from various disciplines and provides facilities to analyze the impact of the various factors in land use planning at farm enterprise level.

- Different production technologies for producing the various crops can be incorporated by treating each alternative technology as a separate activity (rainfed versus irrigated crops).
- Activities can be disaggregated to a level where each field operation represents a separate activity. Such a narrow definition of activities is sometimes useful in models in which the focus of analysis is on the power, machinery, labour arrangement, or the

amount of field work that can be accomplished during a critical period (Beneke and Winterboer, 1973).

- Different production techniques, i.e., various combinations of inputs within each production technology, can be incorporated, using factor substitution, e.g., alternative mechanization options and choices among different fertilizers in meeting nutrient requirements, or input/output response relation techniques, e.g., different amounts of fertilizer or irrigation application (Hazell and Norton, 1986).
- Buying options can be incorporated to allow increased supply of particular resources if they add to the total value of the programme. This provides the option for management to increase the resource supplies to meet their demands.
- Crop rotation constraints can be formulated and introduced to limit the area allocated to each crop.
- Multiple products and inter-cropping can be incorporated by introduction of a single activity that uses a fixed mix of resources, and produces two or more outputs in fixed proportions.
- Intermediate products can be defined in the model to allow use of products within the farm enterprise, and to ensure that the internal demand for these products is met.
- Quality differences in resources can be incorporated
  by treating each quality class of a resource with its own set of technical coefficients and right-hand side.
- Seasonality in the use of resources can be incorporated, which is important because farming activities are characterized by distinct seasonal patterns in resource use and availability, such that land, labour and other fixed factors may be fully utilized or available only part of the year.
- Capital accounting can be incorporated if it is desirable to estimate the capital demand to carry on the plan, or if capital is not a limiting factor because other constraints are more limiting, or if the enterprise is willing and able to continue investment as long as that will add to the value of the programme (an objective function) (Beneke and Winterboer, 1973).
- Multi-period linear programming provides options to estimate capital accumulation, or determine an optimal growth strategy, taking into account the initial and long-term investment levels and the optimal adjustment path to be pursued for optimizing the objectives (Hazell and Norton, 1986).
- At the farm level, the linear programming model is used to analyze the implications of differences in resource endowment, market conditions, or the introduction of improved or new techniques. This type of information is generated by the model via variations in parameter values, with a new solution obtained for each set of parameter values.
- Policy formulation is not programmable, but policy analysis can be supported using linear programming planning models. In this process, the policy issues, which may be rather broad, are translated into specific analytical questions that can be addressed by the model to simulate the response to possible policy changes. The output of this

process are the overall objectives and the different policies affecting the land use plan.

- A new investment policy can be formulated by evaluating comparative advantages, assessing the employment effects of different policies, generating input demand functions, and evaluating various scenarios. By analysis of supply response functions of the system, such as associated response of inputs (labour, agro-chemicals, etc.), many policy-oriented questions can be answered.
- Multi-objective decision problems can be supported by using composite (Field, 1973; Dane et al., 1977; Shakya, and Leuschner, 1990), compromise (Brouwer et al., 1985) and interactive multiple goal (Van Keulen 1990; Spronk and Veeneklaas, 1983) programming techniques. All of these techniques are based on linear programming.

The assumptions underlying linear programming models are stringent (Hazell, and Norton, 1986), but fortunately many ingenious methods for increasing their flexibility have been developed without violating the assumptions, e.g., non-linearity between inputs and outputs can be approximated by defining several different activities for the production of an individual crop or livestock product (piecewise linear approximation of non-linear relations). Introduction of non-linear methods, multiple period features, and a structure that makes it possible to consider risk in the selection of production activities have widened the scope for application of linear programming techniques in farm planning (Hazell and Norton, 1986).

One of the critical steps in developing linear programming models is the estimation of input product relationships. Making reliable estimates for these types of data is difficult, especially in agricultural environments which include many complex ecologic processes. By incorporating the biophysical land evaluation module for establishing realistic input/output response relations between yield and major factors of the agricultural environment, this constraint is relaxed to a large extent. Thus the applicability of linear programming techniques in land use planning is enhanced.

In intensive agricultural production systems, we can assume that there is only one outcome for each alternative plan on which complete and accurate knowledge is available or can be generated. This assumption will simplify the land use planning decision problem and make it possible to apply methods of decision making under certainty.

Hence a linear programming model (decision making under certainty) that integrates agro-technical and agro-economic information of the farm is used as a planning tool for tactical planning to arrive at feasible land use alternatives that meet the production targets and satisfy the technical and social and economic constraints of the enterprise.

In this model, the production of each crop under a well-defined level of management, or a combination of crops in a particular rotation, or any operation in crop husbandry can be considered an activity. Each activity is characterized by its relevant input and output coefficients that are derived from a well-defined way of executing or implementing the activity. Cropping activities are characterized by coefficients that define the yield of both marketable products and crop residues, the material inputs required to realize that yield, such as fertilizer, herbicides and water, the labour requirements, etc., if necessary, specified as a function of time.

#### 5.2.2.1.3 Type of processing functions for operational planning

Operational planning deals with the translation of the tactical plan into an operational plan. In land use planning, it refers to the derivation of a land use plan through the allocation of prospective crops to the existing suitable parcels. Allocation is the process of finding an optimal land use plan which satisfies the tactical plan, the biophysical suitabilities, and management priorities and constraints, such as:

- Optimizing allocation of crops to parcels based on biophysical/physical suitabilities
- Minimizing conveyance irrigation losses
- Minimizing transportation costs
- Considering crop rotation
- Meeting the demands for the various crop products.

In the given situation of crop allocation under multiple objectives and no clearly-defined weights for the various objectives, the problem cannot be supported directly by a normative decision model. That assumes a completely rational decision maker who is fully aware of all alternatives and will always choose the optimal alternative (decision making under certainty or risk), and that is not the case here. Such a problem requires a descriptive model that explains how decision making can take place (Davis and Olson, 1985). This approach, which was first proposed by Simon (1960), considers the decision as taking place in a complex and partially unknown environment, by a decision maker who is not completely rational (bounded rationality), but rather displays rationality only within limits imposed by background, perception of alternatives, ability to handle a decision model, etc.

In this approach, the criterion for decision making is satisficing, and decision makers have limited cognitive ability to perceive alternatives and/or consequences. Decision makers therefore limit the search for alternatives and accept the first alternative which satisfies the problem constraints, rather than continuing to search until the optimal alternative is found (Davis and Olson, 1985).

To support the decision making process in operational planning, a special type of model is required to formulate the crop allocation problem (descriptive) in the form of an optimization model (normative). That would simplify the problem and allow the decision maker to select an optimal solution under the given assumptions.

Each crop allocation objective can be treated as a special case of the general problem of finding the minimum cost flow through a network. The concept of the minimum cost flow problem, first described by Hitchcock (1941), has been used to formulate a variety of problems, such as transportation, transhipment, assignment and the shortest path problem (Williams, 1985). A comprehensive review of application of the minimum cost network flow problem was given by Bradley (1975).

To help in understanding and formulating the operational planning problem, the general form of the transportation problem is briefly explained here. Assume that a number of suppliers (S1, S2,...,Sm) are to provide a number of customers (T1,T2,...,Tn) with a commodity. The transportation problem is how to meet each customer's requirement, while not exceeding the capacity of any supplier, at minimum cost. Costs are known for supplying one unit of the commodity by each Si to each Tj. In distribution problems, these costs are often related to the distance between Si and Tj. It is assumed that the capacity of each supplier and the requirement of each customer are known.

In the above transportation problem, we change

(1) the supplier to the storage location of each crop (repository for the yield of each crop) with the capacity equal to the area of each crop to be cultivated (derived from tactical planning),
(2) the customers to the parcels with a demand equal to the area of each parcel,
(3) the unit cost for supplying each customer from each supplier to some sort of road impedance, proportional to the distance between each parcel and the storage location through the road network. Then allocating a crop to each parcel in such a way that transportation costs are minimized can be regarded as the minimum cost flow through a road network.

The same formulation can be applied to the allocation on the basis of minimizing the conveyance irrigation losses. Allocation on the basis of the biophysical suitability criterion (alone) can be regarded as a sort of assignment problem and handled accordingly (Wiliams, 1985). The first two allocation criteria, apart from their operational problems, do not consider the biophysical suitabilities of the land, which are important factors in crop allocation. The last one does not consider the transportation costs and conveyance losses, but each handles one objective at a time and leads to a solution by applying mathematical programming techniques.

Many farm linear programming models have been developed to explicitly include crop rotation considerations. Methodological suggestions were made by many authors, such as Beneke and Winterboer (1973); Burt (1982); Lazarus and Swanson (1983); Musser et al. (1985). Talaat and McCarl (1986), reviewing the background of rotation modelling, concluded that virtually all of the suggested methods use explicit sequential methods which limit the choice of rotations to the combinations that the modeller develops. The reasons for such a limitation are model size and data availability. To improve the situation, they presented an approach for development of a continuously repeatable "optimum" crop rotation. This approach allows the model to determine freely the optimal long-term rotation. But all of these models explicitly consider crop rotation as the only objective.

The crop allocation problem is a multi-objective problem, and as such almost always involves trade-offs between objectives. As Wiliams (1985) suggested, there are basicaly two classes of solution techniques for these types of problem. The first approach is to bring all objectives under a common denominator and treat them as one (benefit - cost formulation); the second is to solve the model a number of times for each objective in turn. In the latter case, comparison of the results may suggest a satisfactory solution. Interchange of objectives and constraints in mathematical programming models are leading to a method of handling multiple objective problems, called "interactive multiple goal linear programming". Formulating the crop allocation problem using this approach is very difficult, especially because of the differences in the types of objective and the computational tasks involved in interchanging objectives with the constraints.

Another way of tackling multiple objectives is to define a new objective function as a suitable linear combination of all objective functions (Ijiri, 1965; Lee, 1972; Williams, 1985). Specifying a composite objective function is a major difficulty, because weights have to be assigned a priori to the individual objectives. Establishing proper weights for a composite objective function is one of the hurdles in using multiple objective programming, and a variety of techniques have been used to define appropriate weight factors(Shakya et al., 1989; Shakya and Leuschner, 1990). Cohon and Marks (1975) identified three classes of solution techniques for multiple-criterion problems: those which generate solutions without preference information, then select the preferred strategy; those which rely on prime articulation of preference and select the preferred strategy directly; and iterative techniques which rely on progressive articulation of preferences. They noted the computational difficulties of large problems with the first and third techniques, and recommended the second class of techniques which assigns directly proper weights to the different objectives. They also noted the difficulty of defining a preference set, the lack of explicit trade-offs, and the possibility of unknowingly selecting an inferior solution as the preferred strategy.

Various formal techniques exist to form composite objectives, such as goal programming (Ijiri, 1965; Field, 1973; Hammer and Zoutendijk, 1974), and compromise programming (Brouwer and Nijkamp, 1985). Wiliams (1985) suggested that there is no one obvious way of dealing with multiple objectives through mathematical programming. The most suitable approach depends on the particular conditions of the study.

An advantage of the compromise and composite programming procedures is that the phenomena (objectives) are related to each other in a rather straightforward way. However, a disadvantage of it is that no distinction is made for differences in nature because the variables with different units of measurement are transformed into dimensionless figures (Brouwer and Nijkamp, 1985); sometimes variables are not even converted, but are directly aggregated (Hazell and Norton, 1986). In both cases no meaningful interpretation can be given of the objective function value or the shadow prices of the different decision variables related to the various objectives (Field, 1973).

In large-scale farming enterprises (such as MAIC), which include several hundreds of parcels, many crops and several storage locations for each crop, implementation of such methods are subject to computational and operational difficulties. The computational problems refer to the formulation of the problem which should include integer programming (assignment) and thus all problems inherent to this type of formulation. The operational difficulties refer to the preparation of the right data. This includes (1) identification of the shortest path between each parcel and each storage location through the existing road network, which requires a shortest-route model (Wagner, 1975), and (2) calculation of the transportation costs (impedance) for each crop. The same holds for calculation of the conveyance irrigation losses between the source (start of the irrigation network) and each sink (field inlet), using the existing irrigation network.

Based on these considerations, in the process of operational planning a model with a composite objective function that combines weighted multiple objectives into a single objective function was formulated to handle the crop allocation problem. To overcome (some of) the problems of implementing the composite programming approach, an attempt was made to benefit from advances in computer technology and geographic information systems to remove the computational and operational constraints.

#### 5.2.2.1.4 Type of processing functions for supportive planning

Derived or supporting plans are a series of plans that support the implementation of the basic plan. They are structured, programmable decision rules, derived through the application of accounting models. They are prespecified (programmed decision) rules, decision procedures which are reflected in rule books, decision tables and regulations. They are used for the derivation of the supporting plans, such as farm operation plan, production plan, and logistics requirements of the basic plan, etc.

### 5.2.2.2 Type of processing functions for the monitoring and evaluation sub-system

Monitoring and evaluation activities require assessment of accomplishments and comparison with predefined standards to initiate corrective actions. Performance is expressed as current levels of input, activity, or output in comparison with preset standards. This sub-system therefore requires capabilities to provide the following types of information:

- Identification of achievements.
- Establishment of standards.
- Comparison of the achievements against standards to generate evaluation reports which give information about performance.
- Use the performance information to control future actions.

In ARIS, monitoring and evaluation are performed at operational and management levels.

Operational control is the process of ensuring that operational activities are carried out effectively on the basis of pre-established procedures and decision rules. The operational decisions and resulting actions cover a short time period (one day to a week). Here individual transactions are important; the system must therefore be able to respond to individual and aggregated transactions. The types of processing support for operational control are:

- Transaction processing capabilities
- Report processing
- Inquiry processing
- Database containing internal data generated from transaction processing.

Management control is the process of monitoring and evaluating at higher level. It includes measurement of the achievements, comparison of achievement with predefined standards, decisions on control actions, formulation of new decision rules to be applied by operational personnel and allocation of resources. These require a capability to provide the following information:

- Planned or standard performance
- Deviations from planned performance
- Possible reasons for deviations
- Analysis of possible decisions or courses of action
- Databases containing operation and planning data, and standards that define management expectations of performance.

Analysis of possible decisions and of reasons for deviations from planned performance are not structured problems and require an interactive dialogue between the user and the system. The other information is derived from structured problems and requires variance reporting and query programs to assist in responding to the inquiries.

Processing functions in the monitoring and evaluation sub-system consist mainly of a capacity to access series of databases and use data analysis and analysis of information capabilities to derive or access standards and produce summary, comparative and other types of required reports.

This includes the following:

- Simulation capability to derive the norm and standards of production at each parcel and management level. This is the same type of simulation that is used for biophysical land evaluation.
- Procedures for generating summary reports and analysing data.
- Analysis of information, which includes data analysis capacities and application of series of small decision models.

### 5.2.3 Definition of the major processing functions (data processing model)

The overall structure of each sub-system is explained in section 4.3, and the types of processing functions for each process are given in subsection 5.2.2. In this subsection, the selected approach to generating the information requirements of each sub-system is further analyzed to define all required processing functions.

In each model of every sub-system, the related processing functions are grouped in modules. The detailed definitions of the main modules are described in the model base sub-system (process model). The functional description of each module, together with the processes that uses them to derive the output requirements of the models, is given when the respective models are explained (data processing model).

#### 5.2.3.1 Definition of processing functions in the land use planning sub-system (process 4)

The land use planning sub-system is a dynamic decision support system for land use planning. Decision support systems (DSS) allow the decision maker to retrieve data, use proper planning models, generate plans, and test alternative plans in the course of the decision making process.

The land use planning sub-system consists of facilities to examine the agricultural system environment, quantify its natural agricultural potentials, and support tactical planning and operational planning and generate supporting plans.

In this approach, a biophysical land evaluation model accurately estimates the productivity of the land for any type of feasible land use at different levels of inputs. An optimization model combines physical information with relevant social and economic information to design the most suitable land use plan as dictated by the production policy and all resource and management constraints of the farm enterprise. By varying the constraints, costs, and fixed resources in a tactical planning model, a variety of scenarios can be generated and the effects of alternative decisions can be analyzed. An allocation model translates the tactical plan into the actual operational plan, and supports the spatial decision making process. Finally, supporting plans are derived using the supportive planning functions.

#### 5.2.3.1.1 Definition of the biophysical land evaluation model (process 4.1)

Land evaluation is the process of assessing land performance when used for specific purposes at different management levels (FAO, 1983). Similarly, in this study biophysical land evaluation refers to the assessment of the biophysical performance of land when used for arable farming at different levels of inputs. Crop performance is the result of the crop-soil-wheather interactions, of which weather parameters have a non-linear relationship with production and change during a growing period from year to year. The use of average values for weather parameters therefore leads to erroneous results (Van Keulen, 1988). This can be avoided by first calculating the production for a large number of years using actual weather data and subsequently averaging the results. This method requires many more calculations than the method of averaging first and calculating later, but it is highly preferable provided that the required data are available.

In the biophysical land evaluation process, the production efficiency of each prospective crop on each tract of land at different levels of inputs is estimated using the following procedure:

- If daily weather data are available for several years, the production of each crop on each tract of land is simulated using the weather data of each year and at different levels of inputs (i.e., fully irrigated and fertilized, fully irrigated not fertilized, rainfed and fertilized, rainfed and not fertilized). The mean value of production and crop requirements over the years is taken as an estimate of production efficiency of a crop on a specific tract of land.
- If only average monthly climatic data are available, the average monthly rainfall is

distributed over a defined number of randomly chosen rainy days and used with the other average weather parameters in the simulation. The "random" distribution of rain and the production of each crop on a specified soil are calculated 20 times. The mean of the 20 simulation runs is then considered as an estimate of the crop production efficiency (Ayyad and Van Keulen, 1987).

- The model assumes good management, and on that basis calculates the potential production of each crop. Since this may not be realistic for most applications, an option is considered to correct the production efficiency for the management efficiencies (efficiency of "1" for perfect management, and "0" for a worse situation). This coefficient is assumed to be the same during the various stages of crop development and is applied to the daily production of the crop.
- In each case, if the production efficiency (estimated by yield) is equal to or exceeds a minimum value specified by the planner, the yield, calculated monthly water requirements and macro-nutrient requirements (N, P, K) are incorporated in the crop-soil-climate-yield table (CSCTAB, table 4).
- By sorting the yield column in CSCTAB, the biophysical suitability of each land unit for each land utilization type is determined. By adding a column containing reliable estimates of gross margin for each production activity and sorting the table according to that criterion, the productivity and profitability of different land use types on different land units is displayed (i.e., land evaluation).

The biophysical land evaluation model consists of several modules describing:

- Crop growth and yield formation
- Soil water balance and irrigation requirements
- Soil fertility status and crop nutrient requirements

In the module on crop growth and yield formation, information on crop physiologic and phenologic properties is combined with information on the environment in which the crop is grown to derive yield estimates for all relevant combinations of crop, weather and soil. In the soil water balance and irrigation module, information on soil characteristics and environmental conditions is combined with information on crop characteristics to assess yield reductions caused by temporary water shortage, crop water requirements, and net and actual irrigation requirements of each crop at each parcel in the course of the growing season.

In the soil fertility and crop nutrient requirement module, total crop macro-nutrient requirements, their supply from natural sources and the associated nutrient-limited yield level, and the fertilizer requirements are estimated.

| SOIL TYPE NAME | CROP NAME | POTENTIAL YIELD (KG/HA) | NUTRIENT LIMITED YIELD (KG/HA) |
|---|---|---|---|
| C:\ARIS\SOIL\u1-ir | Maize | 11,638 | 2,082 |

CROP IRRIG. REQUIREMENTS AT FIELD INLET

| jan | feb | mar | apr | may | june | july | aug | sep | okt | nov | dec | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 20.9 | 6.7 | 10.0 | 19.8 | 9.7 | 0.0 | 0.0 | 0.0 | 67.1 |

CROP MICRO-NUTRIENT REQUIREMENTS (KG/HA)

| Nitrogen | Phosphorus | Potassium |
|---|---|---|
| 608 | 476 | 0 |

**Table 4. Format of crop-soil-climate-yield table (CSCTAB)**

***Biophysical land evaluation structure***

The overall structure of the biophysical land evaluation process is presented in figure 16; it shows that the module comprises the following sub-processes:

Process 4.1.1 selects, calculates and prepares the required weather data for crop growth simulation from any of the following available datasets:

- Average monthly weather data
- Average monthly weather data with actual daily rainfall
- Actual daily weather data, including daily rainfall.

Process 4.1.2 selects, prepares and provides the required physical, chemical and irrigability properties of any soil unit for crop growth simulation.

Process 4.1.3 selects, prepares and provides all required crop data for crop growth simulation. These data include the physiologic and phenologic properties, crop nutrient requirements and some management characteristics (e.g. phenologic development, seed rate, etc.) of all prospective crops (and varieties) for a given environment.

Process 4.1.4 contains a modified version of the summary dynamic crop growth simulation model (Penning de Vries, 1983) developed by Van Kraalingen and Van Keulen (1988), which is used to simulate crop growth and yield formation on the basis

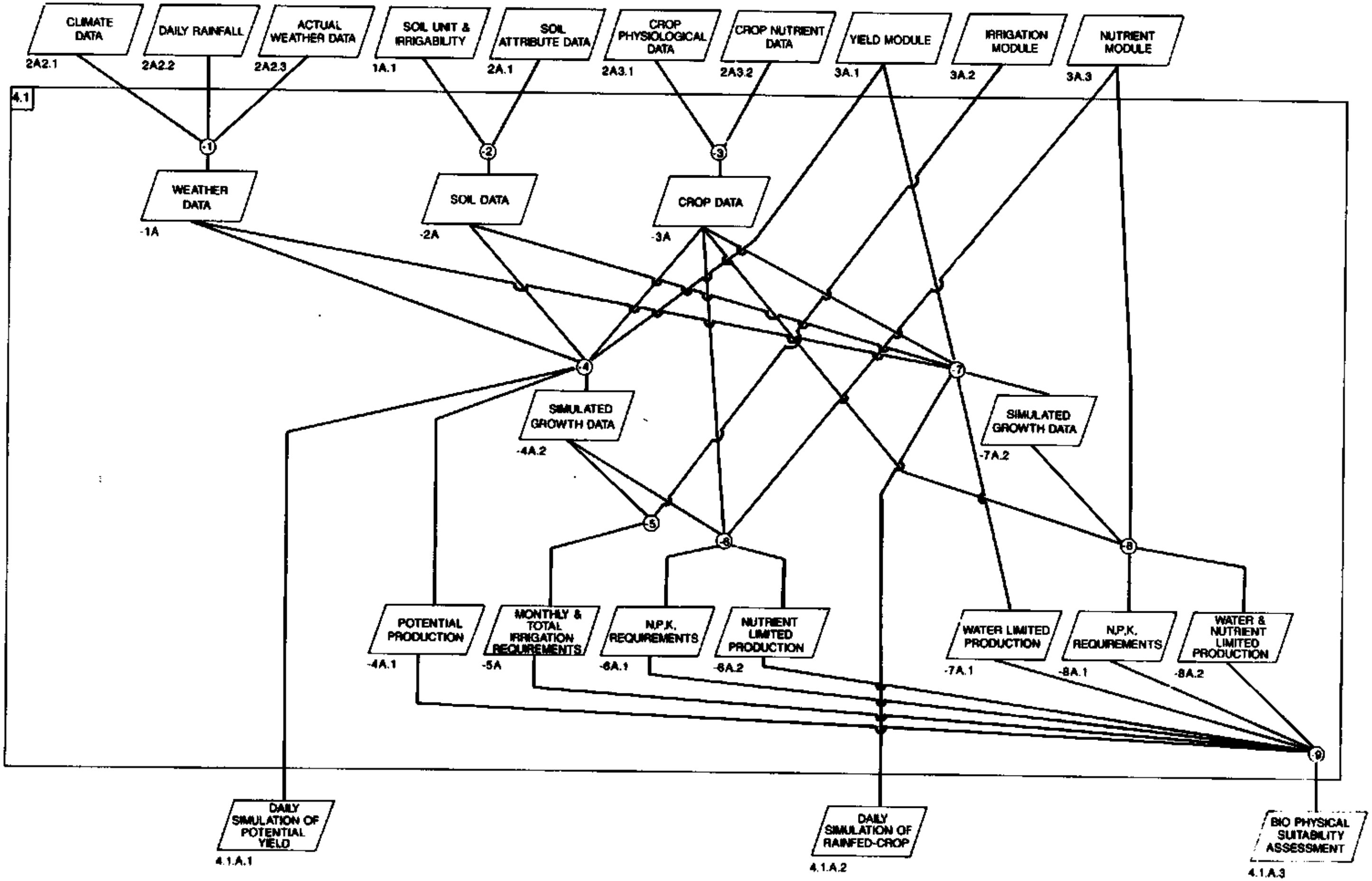


Figure 16. Schematic presentation of biophysical land evaluation process

of crop genetic properties and environmental conditions. The growth of a crop is simulated from emergence to maturity on the basis of physical and physiologic processes, as governed by their responses to environmental conditions. The major processes are CO2 assimilation, respiration, partitioning of assimilates to various plant organs and transpiration.

The model follows a hierarchic approach. At the highest hierarchic level, solar radiation and temperature are the only environmental conditions considered. At the second level, moisture availability is introduced as a possible growth-limiting factor, while at the third level, availability of macro-nutrients (N,P,K) is considered. This concept is illustrated in Figure 17.

The basis for the calculation of dry matter production is the rate of gross CO2 assimilation of the crop, which is determined by the level of irradiance, the green area of the crop capable of intercepting the incoming radiation, the photosynthetic characteristics of individual leaves of the crop species, air temperature and the ratio of actual to potential crop transpiration.
Part of the assimilates formed are used by the crop in respiratory processes to provide energy for maintenance of existing tissue. The remainder is available for increase in structural dry matter. The conversion efficiency of primary photosynthetic products into structural plant material depends on the chemical composition of the material being formed. The total increase in dry weight of the crop is partitioned over the plant organs, roots, leaves, stems and storage organs. The partitioning pattern in the course of the growth cycle of the crop is a species (cultivar) characteristic and is governed by the phenologic development of the crop (cultivar), defined as a function of air temperature.

Transpiration refers to the loss of water from the crop to the atmosphere through the open stomata in the leaves. Transpiration losses are replenished by water uptake by the roots from the soil. Within the optimum soil moisture range the losses are fully compensated, and transpiration and hence assimilation proceed at their potential rates. Outside that range the soil can be either too dry or too wet. Both conditions lead to reduced water uptake by the roots, in a dry soil because of water shortage, in a wet soil because of oxygen shortage. The consequence is partial dehydration of plant tissue with the associated reduction in stomatal opening. Actual transpiration then falls short of the potential and assimilation is reduced. These effects are quantified and used to calculate the reduction in growth compared with the highest hierarchic production situation.

In the model, the soil is divided into a number of compartments (De Wit and Van Keulen, 1972), and soil moisture content of each compartment in the total rootable soil depth is tracked throughout the growing season by means of a water balance. In the water balance, all incoming and outgoing flows of water are quantified and the changes in water content in the various compartments are calculated. Incoming water comprises

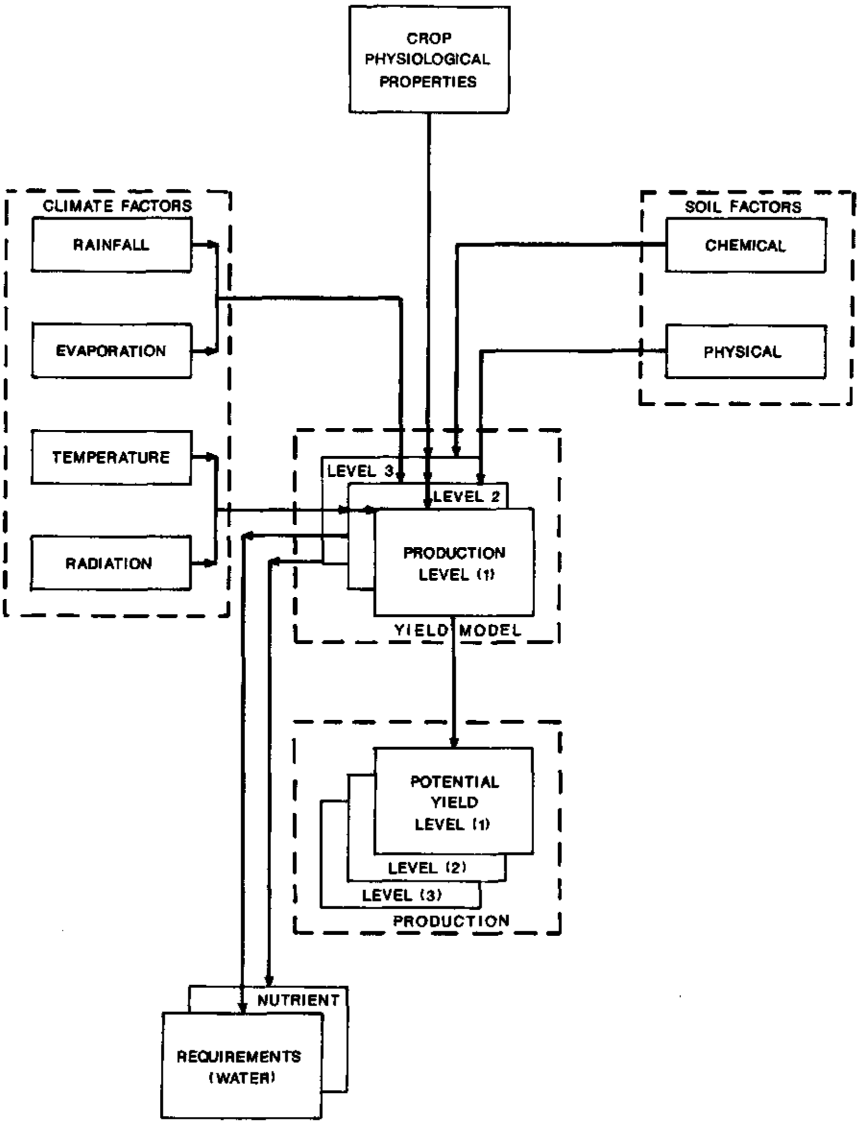


**Figure 17. Schematic presentation of crop growth simulation model**

precipitation, irrigation and capillary rise from the ground-water table. Outgoing watercomprises soil evaporation, crop transpiration and percolation of excess water (above field capacity) to deeper compartments.

Potential production, or the maximum possible production of a crop (cultivar) in a given environment, is determined by its genetic properties, and is calculated under the assumption that throughout its growth cycle the moisture content in the root zone is optimum, all nutrient requirements are met, and complete control over weeds, pests and diseases has been achieved. The model can assume different levels of management, and on that basis calculates the potential production of each crop. This has been achieved by providing the capability to allow changes in the intervals of irrigation, options for fertilization and finally to apply a management coefficient in the course of crop development.

Process 4.1.5 calculates crop water requirements and irrigation requirements at the field inlet 'from the daily statistics of the water balance in the root zone in the course of the growing period. The values are calculated separately for each month of the year and incorporated in the temporary file.

Process 4.1.6 calculates the nitrogen, phosphorus and potassium requirements of the crop to realize full potential production. Nutrients are needed in certain quantities for optimum functioning of the plant. If their supply is limited, nutrient concentrations in the plant tissues decrease to an absolute minimum value. Under such conditions, crop production is determined by the ratio of nutrient supply and minimum nutrient concentration (Van Keulen and Van Heemst, 1982).

Nutrient requirements and supply are calculated following the "quantitative evaluation of the fertility of tropical soils (QUEFTS)" system (Janssen et al., 1990). In this system, the amounts of nitrogen, phosphorus and potassium potentially available from natural sources for a reference crop with a standard growth cycle are first estimated using empirical relationships between soil chemical properties and nutrient supply. Actual uptake of a nutrient, for example nitrogen, is identical to the potential only if the supply of the other elements is balanced. If phosphorus supply strongly limits crop yield, its concentration in the tissue will approach the minimum value, but concurrently the nitrogen concentration in the plant tissue will approach its maximum level, and actual nitrogen uptake may be limited to the P-determined crop yield multiplied by the maximum nitrogen concentration. The same reasoning applies for the other nutrients.

For each of the nutrients N, P and K, the relationship between uptake and yield of a reference crop is established, for both the situation in which the nutrient is fully diluted and the situation in which the nutrient concentration is maximum. Actual uptake of each nutrient is then calculated from its potential supply, taking into account the potential supply of the other two nutrients. From the actual uptake of N, P, and K, and their yield uptake ratios at minimum and maximum concentration, yield ranges are established. The actual yield is obtained by averaging the six yields for paired nutrients, provided that the yield of any combination of two nutrients does not exceed the upper limit of the yield range of the third one.

The QUEFTS approach assumes a linear relationship between nutrient uptake and the length of the growth cycle. Therefore, actual nutrient uptake for a specific crop (cultivar) is calculated as the uptake of the reference crop multiplied by the ratio of the length of its growth cycle and that of the reference crop. The required contribution from fertilizer is derived from the difference in nutrient requirements for potential yield and the uptake from natural sources. The fertilizer application requirement is then calculated taking into account the expected recovery fraction, as a function of environmental conditions and management practices (Van Keulen and Van Heemst, 1982).The results of this process, the N, P, K fertilizer requirements for potential production and nutrient-limited production, are included in a temporary file.

Process 4.1.7 uses the same principles as process 4.1.5 and simulates water-limited production of each crop/land unit combination, taking into account rainfall (amount and distribution), physical properties of the soil, such as maximum water-holding capacity, and water transport characteristics and rooting depth of the crop. At this production level, no irrigation is applied, but the crop is supposed to be free of weeds, pests and diseases and optimally supplied with nutrients. The results of the simulation are recorded in a temporary file.

Process 4.1.8 uses the principles of process 4.1.6 in combination with the results of process 4.1.7 to calculate the nitrogen, phosphorus and potassium requirements to realize the water-limited yield, and to derive the water- and nutrient-limited yield. The results are included in a temporary file.

Process 4.1.9 calculates the production potential of each crop-soil-climate combination with specified levels of inputs. This is estimated by averaging the potential yield and crop input requirements over the years for which the crop production was simulated (averaging of data in the temporary file).

If the calculated average yield exceeds a preset minimum economic yield for the crop in the region, its value is incorporated in the crop-soil-climate-yield table (CSCTAB) and further processing will follow; otherwise the result is ignored and simulation for another crop will start.
Finally, when growth simulations for all crop-soil-climate combinations are finished, a suitability index is calculated for each. The crop-soil-climate-yield table is sorted according to potential yield, suitability index or nutrient-limited yield of each

| CROP NAME | POTENTIAL YIELD KG/HA | NUTRIENT LIMITED YIELD | SOIL NAME (TYPE) | TOTAL IRRIGATION & NUTRIENT REQUIREMENTS | | | |
|---|---|---|---|---|---|---|---|
| | | | | WATER (cm) | N | P | K |
| Barley-dr | 5,465. | 2,808. | C:\ARIS\SOIL\mo-sa | 0.0 | 208. | 188. | 0. |
| | 5,031. | 3,074. | C:\ARIS\SOIL\mj | 0.0 | 237. | 156. | 0. |
| | 4,944. | 1,749. | C:\ARIS\SOIL\ps | 0.0 | 222. | 186. | 0. |
| | 4,898. | 1,272. | C:\ARIS\SOIL\ag | 0.0 | 286. | 173. | 0. |
| | 4,762. | 4,001. | C:\ARIS\SOIL\EB-SA | 0.0 | 53. | 114. | 0. |
| | 4,473. | 2,747. | C:\ARIS\SOIL\ul | 0.0 | 109. | 148. | 0. |
| | 4,432. | 2,407. | C:\ARIS\SOIL\mo | 0.0 | 217. | 146. | 0. |
| | 4,012. | 2,618. | C:\ARIS\SOIL\eb | 0.0 | 189. | 93. | 0. |
| | 3,759. | 1,492. | C:\ARIS\SOIL\sb-sa | 0.0 | 136. | 139. | 0. |
| | 2,771. | 2,368. | C:\ARIS\SOIL\ul-sa | 0.0 | 107. | 72. | 0. |
| Barley-ir | 6,904. | 1,483. | C:\ARIS\SOIL\sb-sa | 20.4 | 339. | 276. | 0. |
| | 6,576. | 1,288. | C:\ARIS\SOIL\ag | 24.4 | 390. | 242. | 0. |
| | 6,512. | 4,434. | C:\ARIS\SOIL\EB-SA | 36.7 | 161. | 186. | 28. |
| | 6,505. | 2,640. | C:\ARIS\SOIL\eb | 24.3 | 347. | 200. | 0. |
| | 6,474. | 2,791. | C:\ARIS\SOIL\ul | 27.8 | 233. | 231. | 0. |
| | 6,371. | 2,823. | C:\ARIS\SOIL\mo-sa | 46.7 | 263. | 225. | 0. |
| | 6,366. | 2,426. | C:\ARIS\SOIL\mo | 29.0 | 336. | 227. | 0. |
| | 6,327. | 3,106. | C:\ARIS\SOIL\mj | 32.4 | 315. | 209. | 0. |
| | 6,100. | 2,431. | C:\ARIS\SOIL\ul-sa | 27.4 | 319. | 215. | 0. |
| | 5,495. | 1,737. | C:\ARIS\SOIL\ps | 5.5 | 260. | 212. | 0. |
| Maize | 12,761. | 2,111. | C:\ARIS\SOIL\ul-sa | 58.5 | 754. | 509. | 0. |
| | 12,753. | 1,298. | C:\ARIS\SOIL\sb-sa | 51.2 | 721. | 529. | 12. |
| | 12,740. | 2,705. | C:\ARIS\SOIL\mj | 53.9 | 737. | 495. | 0. |
| | 12,555. | 2,106. | C:\ARIS\SOIL\mo | 51.5 | 743. | 502. | 0. |
| | 12,157. | 2,414. | C:\ARIS\SOIL\ul | 50.7 | 623. | 487. | 211. |
| | 12,122. | 2,288. | C:\ARIS\SOIL\eb | 48.4 | 720. | 457. | 0. |
| | 12,009. | 1,519. | C:\ARIS\SOIL\ps | 57.1 | 689. | 497. | 0. |
| | 10,736. | 1,084. | C:\ARIS\SOIL\ag | 55.0 | 682. | 444. | 0. |
| | 9,952. | 2,350. | C:\ARIS\SOIL\mo-sa | 53.7 | 547. | 414. | 0. |
| | 9,238. | 3,517. | C:\ARIS\SOIL\EB-SA | 39.7 | 414. | 351. | 241. |
| Sugarbeet | 67,201. | 7,923. | C:\ARIS\SOIL\ps | 57.2 | 875. | 621. | 0. |
| | 67,059. | 6,724. | C:\ARIS\SOIL\sb-sa | 50.4 | 863. | 625. | 0. |
| | 66,973. | 10,886. | C:\ARIS\SOIL\mo | 57.1 | 901. | 601. | 0. |
| | 66,852. | 5,916. | C:\ARIS\SOIL\ag | 55.8 | 938. | 605. | 0. |
| | 66,318. | 12,580. | C:\ARIS\SOIL\ul | 50.8 | 776. | 595. | 114. |
| | 66,302. | 21,651. | C:\ARIS\SOIL\EB-SA | 68.1 | 698. | 546. | 182. |
| | 66,283. | 12,670. | C:\ARIS\SOIL\mo-sa | 54.1 | 815. | 593. | 0. |
| | 65,738. | 10,862. | C:\ARIS\SOIL\ul-sa | 68.8 | 886. | 591. | 0. |
| | 65,718. | 12,069. | C:\ARIS\SOIL\eb | 45.9 | 885. | 555. | 0. |
| | 63,128. | 14,039. | C:\ARIS\SOIL\mj | 43.5 | 833. | 552. | 0. |
| Wheat-dr | 7,737. | 2,751. | C:\ARIS\SOIL\mo-sa | 0.0 | 400. | 324. | 0. |
| | 6,873. | 2,913. | C:\ARIS\SOIL\mj | 0.0 | 410. | 276. | 0. |
| | 6,671. | 3,938. | C:\ARIS\SOIL\EB-SA | 0.0 | 220. | 235. | 132. |
| | 6,656. | 1,675. | C:\ARIS\SOIL\ps | 0.0 | 388. | 304. | 0. |
| | 6,586. | 2,587. | C:\ARIS\SOIL\ul | 0.0 | 293. | 281. | 58. |
| | 6,469. | 1,197. | C:\ARIS\SOIL\ag | 0.0 | 448. | 284. | 0. |
| | 6,224. | 2,246. | C:\ARIS\SOIL\mo | 0.0 | 393. | 269. | 0. |
| | 6,120. | 2,454. | C:\ARIS\SOIL\eb | 0.0 | 381. | 223. | 0. |
| | 6,058. | 1,425. | C:\ARIS\SOIL\sb-sa | 0.0 | 334. | 280. | 0. |
| | 5,278. | 2,339. | C:\ARIS\SOIL\ul-sa | 0.0 | 306. | 208. | 0. |
| Wheat-ir | 8,975. | 2,615. | C:\ARIS\SOIL\eb | 24.4 | 550. | 337. | 0. |
| | 8,974. | 1,281. | C:\ARIS\SOIL\ag | 24.4 | 590. | 378. | 0. |
| | 8,972. | 2,414. | C:\ARIS\SOIL\ul-sa | 27.4 | 550. | 373. | 0. |
| | 8,963. | 1,496. | C:\ARIS\SOIL\sb-sa | 20.4 | 510. | 398. | 0. |
| | 8,960. | 4,333. | C:\ARIS\SOIL\EB-SA | 36.8 | 347. | 320. | 173. |
| | 8,863. | 2,770. | C:\ARIS\SOIL\ul | 27.9 | 419. | 365. | 97. |
| | 8,862. | 3,078. | C:\ARIS\SOIL\mj | 32.3 | 520. | 349. | 0. |
| | 8,842. | 2,427. | C:\ARIS\SOIL\mo | 28.9 | 537. | 365. | 0. |
| | 8,163. | 2,778. | C:\ARIS\SOIL\mo-sa | 3.3 | 423. | 339. | 0. |
| | 7,247. | 1,698. | C:\ARIS\SOIL\ps | 5.5 | 423. | 327. | 0. |

**Table 5. Format and example of the biophysical suitability table (actual weather data and perfect management)**

prospective crop on each soil type, and a biophysical suitability table is produced (table 5). The suitability index is defined as the gross income of the yield minus the costs of irrigation and fertilizer applications (cost of materials and related operations). The suitability table provides a realistic estimate of the suitability of each soil type for a specific crop, according to its yield potential when fully irrigated and fertilized, or according to natural fertility of the soil. In the case of full irrigation and fertilization, it also provides the total irrigation requirements, and the N, P, K fertilizer requirements.

### 5.2.3.1.2 Definition of the tactical planning model

Tactical planning uses a single objective linear programming model, called "optimization model", to design a tactical land use plan for one production cycle. The model assumes decision making under certainty, and integrates the biophysical suitability of the available land, realistic resource and management-to-product relationships and supply of scarce resources to derive the best tactical land use plan that satisfies the existing constraints and provides the maximum contribution to the objectives of the enterprise. For the purpose of this study, it was assumed that the overall objective of the enterprise is to maximize the total activity return of the enterprise, subject to the existing management and physical constraints.

In this model, various production activities characterized by their technical coefficients --specifying their resource requirements such as crop, water, land, agricultural machinery, labour and material inputs, together with the corresponding available resources (constraints)-- are defined and used to maximize total gross margin of the farm enterprise.

The result of the tactical planning process is a cropping pattern which maximizes the profits (objective function) with respect to a set of fixed farm constraints, the value of the objective function, the economic value of each crop (shadow prices), and the limiting and non-limiting (binding and slack) factors of the production processes in the plan. The value of the objective function is used to evaluate the impact of different decision rules and provides a measure for analyzing the performance of a variety of alternative plans (scenarios). The shadow prices of the activities (non-basic) indicate by how much the value of the objective function will change if an additional unit of the activity is forced into the final plan, and the shadow price for disposal activities provides information on productivity of added resources (for definitions see Beneke and Winterboer, 1973). The binding constraints in the production process indicate the resources that are in short supply, such that additional availability would increase the value of the objective function; the non-binding constraints indicate factors for which a slack exists, i.e., a marginal increase in their availability will not affect the value of the objective function (zero shadow price).

By introducing different constraints and variable resource supplies, different management and production policies can be simulated and their consequences for the input and output parameters can be analyzed.

The cropping pattern derived from the tactical planning consists of the total area of each crop on each soil type. In this formulation, a crop produced under a different production technique is considered as a different crop (activity). To derive the total area of each crop, the area of the same crop planned on different soil types and under different production techniques must therefore be aggregated.

The linear programming model consists of highly interdependent components, mainly activities, technical coefficients, constraints and the objective function.

*Activities*

For MAIC, the activities incorporated in the model are:

- Growth of each crop currently occurring in the region using different production techniques. Each crop growing on a specific type of land with specified amounts of inputs and level of management is considered a separate activity, e.g., irrigated wheat crop on different soil types are considered different activities.
- Purchasing required amounts of fertilizer (N, P, and K) for the entire plan.
- Hiring the required labour at different times of the year for different crop husbandry operations.

All alternative techniques are included in the activity set, without a priori judgement of their relevance, because the results of the analysis will indicate their appropriateness in view of the objectives and the specified technical and economic constraints.

*Technical coefficients*

The technical coefficients reflect the demand per unit of activity on the resources (amounts of inputs required per unit of activity), or its contribution to the objective function (gross margin). By convention, coefficients representing a demand carry a positive sign and those representing a contribution to the supply of resources carry a negative sign.

**Constraints**

Resources required for activities (such as land, labour, water and agricultural equipment) are available in limited quantities, and they may therefore act as constraints for the level at which an activity can be selected. Beneke and Winterboer (1973) classified these constraints in three main categories:

- Resource or input restrictions, including the most limiting constraints on different resources, such as various categories of land, irrigation water and different agricultural

## PROPOSITIONS

1- In the current practice of agricultural management systems, many technical data are collected that are not integrated into the management decisions.

2- A major contribution towards sustainable agricultural development can be expected from an appropriate resource information system that supports proper planning, monitoring and evaluation functions. *(This thesis)*

3- Planning is a dynamic process; its dynamics can be realized through a proper monitoring and evaluation system.

4- Integration of GIS and modelling capabilities to explain and simulate different phases of decision making in agricultural environments offers a real possibility to improve resource management and planning for sustainable agricultural development.*(This thesis)*

5- With increasing capacity and availability of computer processing techniques, it is feasible to develop and apply comprehensive land use planning methods which include crop growth simulation models, large-scale mathematical programming models and geographic information analysis. *(This thesis)*

6- Land use planning has agronomic, economic, social and political dimensions. It is a multiple decision problem with conflicting objectives. It requires methodologically sound decision support systems for the integrated analysis of inter- and multi-disciplinary phenomena.

7- Among normative models of decision making, linear programming models allow proper integration of knowledge from various disciplines and provide a rather natural framework for farm planning. *(This thesis)*

8- At the moment, crop growth simulation models are the best tools to quantify the relative productivity of different lands, long-term yield variability, and the relative importance of the growth factors, as a basis for land use planning.

9- For quantitative analysis of spatial data, new methods for preparation of thematic maps, on the basis of remote sensing techniques and direct use of all point observations and a proper spatial interpolation method in a GIS are needed.

10- The advent of GIS has created a great potential for the management and analysis of spatial information and communication of the results of analyses to decision makers. To date the information management and presentation features of GIS have received heavy emphasis.

11- The purpose of technological development is to provide an abundance of goods and services for the betterment of mankind. Corporate control of technological development is preventing this, and is increasing rather than decreasing the differences between the rich and the poor. It is the duty of the intellectual community to guard science and technology against this corporate domination.

12- Different cultural and economic conditions require different technological approaches; thus, direct transfer of western technology is not the ultimate solution to all problems of the developing countries.

13- Technological development in third world countries cannot be generated or stimulated by only diffusing capital, hardware, software and operational training. This should be supplemented by educational programmes that allow upgrading/adaptation of the technology to the local conditions.

14- The educational programme of each society follows its development objectives. In many instances, training of elites from third world countries according to the educational programme of western society is non-functional, because their societal objectives are completely different.

15- Aid programmes for the development of third world countries are most effective if they are directed towards educational/training programmes which are adapted to the problems and needs of developing countries.

16- ITC should stay.

M.A.SHARIFI

machines at different periods of the year.

- External restrictions derived from policies affecting the plan, including minimum production levels for some crops, area allotments, markets and prices.
- Subjective restrictions imposed by the enterprise itself, including internal production policies, crop rotation constraints and production levels for certain commodities desired for non-economic reasons such as self-sufficiency in the requirements of the dairy farming sector of the enterprise.

***Objective function***

The objective function, i.e., the target function of the optimization model, maximizes the total activity returns in terms of gross margin minus the total costs of purchasing fertilizers and hiring required labour at different times of the year, subject to the existing constraints, prices and yield expectations.

In developing the linear programming model, the difficult tasks are deriving accurate technical coefficients, defining meaningful constraints and estimating reliable benefit expectations and realistic resource-to-product relationships. Estimating input-product relationships is one of the critical steps. The model can specify only the type and quantity of data needed and the user should supply reliable estimates of the amount and distribution of the required resources in the production process. For each production technique, coefficients can be derived from statistical data, practical experience, or empirical or theoretical models (Van Diepen et al., 1991).

In the general practice of mathematical programming, most information on the production coefficients, suitable field time restraints and costs are derived from experimental and cost accounting data from another situation. Such data are normally the by-product of projects conducted in other environments and for other purposes; they may therefore not be directly applicable for the area under study. Reliable estimates of price expectations, benefits, products, production coefficients, and identification of meaningful restraints appear to be critical, and the limiting factors in the application of linear programming models.

The special features of the different models in ARIS have removed, to a large extent, the main limiting factors for the application of linear programming models in land use planning. These are:

- The biophysical land evaluation module provides realistic input/output response relationships between yield and major natural factors of the agricultural environment, and different levels of inputs. It provides reliable estimates of production potential and production response functions to macro-nutrient and irrigation applications.

  By using input/output response relationships between potential yield, macro-nutrient fertilizer and irrigation, the potential yield at zero irrigation and fertilizer and the potential yield with no limitation on water and fertilizer can be calculated and incorporated in the model to derive the optimal amounts of water and fertilizer which suit the system environment.

- In the course of planning, monitoring and evaluation activities, data on the resource inventory, inputs, outputs, cost accounting, and activity records of the farm operations are collected, stored and organized in the respective databases of the TDBMS and SDBMS sub-systems. These databases contain updated data on all aspects of the enterprise, and therefore can provide accurate estimates of the technical coefficients and the existing restraints of the production processes.

- Development of a realistic farm planning model requires refined treatment and identification of field time constraints. In other words, effective planning requires an estimate of workability of the land and availability of labour and agricultural machinery in a specific period. The only information available for formulating field time expectations for planning purposes are weather data and records of field operations. In ARIS, these types of data are recorded and routinely updated. Using these data, acceptable probabilities that a particular operation can be completed in a timely manner can be developed. Moreover by analysis of the data, the most limiting elements of the production system (in time and space), such as agricultural equipment, labour or water, in the complex agricultural environment can be diagnosed.

#### 5.2.3.1.3 Definition of the operational planning model

The operational plan is derived through application of a decision model called "allocation model", which has a satisficing behaviour, and uses the geographic information system (SDBMS) capabilities to assign each parcel to a specific crop to meet the target set in the tactical planning process. In assigning a crop to a particular tract of land, the allocation model should consider the proper priority parameters.

For MAIC, allocation is a multi-objective decision problem with the following objectives and constraints.

Objectives:

- Optimum allocation of a crop to a parcel based on the biophysical suitability of the parcel (objective 1).
- Minimization of conveyance losses in the irrigation network (objective 2).
- Minimization of the transportation costs based on the distances between each field and its relevant delivery points, taking into account the types of connecting roads

(objective 3).

Subject to the following constraints:

- Meeting the demand for each crop established in the tactical planning process.
- Crop rotation constraints.

The relative importance of each objective may be different to the decision maker; the final decision variable is therefore derived by assigning a preference weight to each objective corresponding to its relative importance in the decision making process. The allocation model should allow implementation of different weights for each objectives; hence, depending on the situation, the decision maker may change the effect of different decision variables on the final plan.

One of the comprehensive methods of formulating this problem is composite programming. In this approach, multiple objectives and their weights are combined into a single objective function. Choosing the form of the composite objective function is an important decision. For the present purpose, the sum of the weighted achievements of the various objectives appears to be a proper form, whose maximization will lead to an optimum solution of the problem. Hence:

$$W1 * OB1 - W2 * OB2 - W3 * OB3 = GOAL \text{ (maximized)} \quad (1)$$

Where:

OB1 = the degree of realization of objective (1), i.e., the optimum allocation of crops to a parcel based on its biophysical suitability.

OB2 = the realization of objective (2), i.e., the minimized transportation costs.

OB3 = the realization of objective (3), i.e., the minimized conveyance losses.

W1, W2, W3 = are the weighting factors for each objective, corresponding to its relative importance in the decision making process.

Subject to:

- Objective type constraints

- The optimum allocation of a crop to a parcel, based on its suitability, is realized if the sum of the suitability indices is maximized. This objective can be expressed as:

$$SUM(C,S,P)SUIT(C,P)*AREA(P)*XA(C,S,P) - OB1 = 0.0 \quad (2)$$

Where:

SUIT(C,P) = Suitability of parcel "P" for crop "C" expressed in terms of gross margin of each crop.
AREA (P) = Area of parcel "P" in hectares.
XA (C,S,P) = Choice of assignment of crop "C", to be delivered to store "S", and grown on parcel "P".

- Minimum costs of transporting each crop from each parcel to its respective store through the existing road network can be translated into:

$$\mathrm{SUM(C,S,P)\ PROD(C,P)*AREA(P)*TCOST(C,S,P) - OB2 = 0.0} \qquad (3)$$

Where:

PROD(C,P) = Productivity (yield) of crop "C" at parcel "P", (kg/ha).
TCOST(C,S,P) = represents the transportation cost of one unit of crop "C" (kg) from parcel "P" to store "S".

- Conveyance losses of irrigation water are a function of the canal structure, canal length, flow rate in the irrigation canal and the total irrigation requirements of each crop at each parcel with specific physical soil characteristics. This can be formulated as:

$$\mathrm{SUM(C,S,P)\ WREQ(C,P)*AREA(P)*LOSS(P))/FLOW(P)\ *XA(C,S,P) - OB3 = 0.0} \qquad (4)$$

Where:

WREQ (C,P) = represents the irrigation water requirements of one hectare of crop "C" on parcel "P".
LOSS (P) = represents the total conveyance loss in the irrigation network from the source to the sink, in liters per second.
FLOW (P) = represents the flow rate in the tertiary canal in liters per second.

- Other types of constraints:

  - Total demand for each crop can be translated into:

$$\mathrm{SUM(P,S)\ AREA(P) * XA(C,S,P)\ .GE.\ AREA(C)} \quad \text{(for all C)} \qquad (5)$$

Where:

AREA (C) = represents the total required area of crop "C" in hectares.

- Store capacity for each product expressed in:

SUM(P) PROD(C,P)* AREA(P)*XA(C,S,P) .LE. CAPS(C,S)
(for all C & S) (6)

Where:
CAPS (C,S) = represents the capacity of store "S" for crop "C", (kg).

- The requirements of each parcel (parcel demand) are translated into constraint (7).

SUM(S) XA(C,S,P) .LE. 1
(for all C & P) (7)

- Crop rotation rules can be translated into the follow-up constraint for winter crops (8) and other crops (9).

SUM(P,C1,S) XA(C1,S,P) - SUM(P,C2,S) XA(C2,S,P) .LE. 0.0 (8)
Where C1 represents winter crops and C2 represents other crops

SUM(C3,S) XA(C3,S,P) - SUM(C4,S) XA(C4,S,P) .LE. 0.0
(for all P)
(those parcels that were used last year for crop C4) (9)

Where C3 represents the prospective crops for the next year based on the rotation rule, and C4 represents crops that were cultivated last year.

- Furthermore, each parcel should be assigned to only one crop.

SUM(C,S) XA(C,S,P) .EQ. 1
(for all P) (10)

- It is essential that the solution be either zero or one because we are handling an assignment problem, where a crop is assigned to a parcel, represented by 1, or if not, represented by 0.

XA(C,S,P) is either 0 or 1. (11)

This set of equations contains all objectives and constraints, and in theory the solution should provide an optimum allocation pattern; however, its practical application is subject to some serious computational and operational problems. As is evident from the formulation of the assignment problem, it involves integer programming which, apart from the high costs of computation (Cevaal and Oving, 1979), has an inherent problem that puts a severe limitation on the actual application of the formulation (Vreke, 1991).

Especially with a large-scale farm enterprise such as MAIC, the computational and operational problems are almost insurmountable. The hundreds of parcels, about 10 crops and several stores for each crop, create a large-scale mixed-integer programming problem that is far beyond operational applicability. To this constraint we should add the operational problems of data collection and data handling for such a model, such as preparing the required data for the solution of the minimum cost flow problem (briefly explained in subsection 5.2.2).

To overcome these problems and to develop an operational solution, the same approach was formulated differently and solved by applying a spatial decision model. This model transforms the crop allocation problem, which is a multiple objective problem, into a minimum cost flow problem and uses the geographic information system capability to derive the minimum cost path through the network. The new formulation creates the possibility to arrive interactively at a solution for the multiple objective problem and a suitable (meaningful) presentation of the results in a manageable and communicable form (maps) to the users. In this formulation, the decision maker starts with the allocation of one crop at a time based on his preference and continues to address all crops. He can assign any priority weight to any of the objectives. The operational and computational constraints of the problem are removed in this way by applying the capability of the spatial database management system (SDBMS).

In the new formulation, the three objectives are first reduced to two objectives by combining either objectives one and two or one and three. For the first case, the conveyance loss of each parcel used by each crop is calculated [COLOSS(C,P) in equation 12] and combined with the suitability index of the parcel, e.g., using a monetary conversion factor, to calculate a new allocation index for each parcel [ALLOINDEX(C,P) in equation 13]. The same procedure could be applied for the transportation costs.

$$\mathrm{COLOSS(C,P) = (WREQ\ (C,P) * AREA(P) * LOSS(P))/FLOW(P)} \qquad (12)$$

$$\mathrm{ALLOINDEX(C,P) = SUIT(C,P) - W * COLOSS(C,P)} \qquad (13)$$

where:

W = is the special weight or unit cost of the water

In this way each parcel is assigned an allocation index as a function of its biophysical suitability and the conveyance loss in the irrigation network serving it. This allocation index can be converted into an equivalent impedance, representing the resistance to flow towards the parcel. The actual allocation problem is then converted into a distribution problem in which a set of goods (area of each crop) should be distributed from different stores (STORE(C,S)), each with a capacity of (CAPS(C,S)), to a set of parcels, each with a demand equal to its area (AREA(P)), through the existing road network in such a way that the total cost is minimized.

This formulation uses the road or canal network for transport of material. The "material" in this case is water, crop yield or the total area of each crop (as available goods of a centre) to be distributed over the suitable parcels (demand of customers) at minimum costs. Each parcel has a cost inversely proportional to its suitability index for each crop and a demand equal to its area. Each canal or road link has an impedance (cost) for water transport or delivery of crop yield to its store. The impedance is the amount of resistance (cost) required to traverse each unit of road or canal. Depending on the objective, it can be expressed in different units, e.g., as actual monetary costs, passage time or passage length; in general it can be defined as a function of length and type of link. For the present model, parcel impedance is represented by equation 14, road link impedance by equation 15, and the canal link impedance by equation 16.

$$IMP(P) = W1/(ALLOINDEX(C,P)) \qquad (14)$$

Where:
W1 = Priority weight of suitability in the allocation.

$$IMP\ (R) = W2 * Wr * L(R) \qquad (15)$$

Where:
L(R) = Length of the road link (m)
IMP(R) = Impedance of the road link
W2 = Relative weight of each type of road link; this weight is proportional to the cost of transport per unit length of each road type.
Wr = Priority weight reflecting the relative importance of the transportation cost with respect to the suitability.

$$IMP\ (C) = W3 * Wc * L(C) \qquad (16)$$

Where:
L(C) = Length of canal link (m)
IMP(C) = Impedance of the canal link
W3 = Conveyance loss of water per unit length in each canal type.
Wc = Priority weight reflecting the relative importance of the conveyance loss with respect to suitability.

Each store for each crop is represented by its capacity, which is described in terms of area (total capacity of the store in weight units, divided by the average yield per hectare of that particular crop in the region). This formulation allows introduction of any combination of assignments of priority weights to the transportation cost, conveyance loss and actual biophysical suitability of the parcel. The planner, on the basis of his/her preference, can select the appropriate weight and by varying the relative weight factors study their impact on the actual allocation plan. If we neglect the transportation costs of the network (assuming road impedance equal to zero), allocation will be based on only parcel impedance defined as a function of its biophysical suitability and the conveyance loss in the irrigation network.

In this approach, the crop-to-parcel allocation is based on the minimum cost flow through the road or irrigation network. If road network is taken, the allocation will be on the basis of the total impedance calculated from the sum of the road impedance between parcel and the respective store (transportation cost) and the parcel impedance (suitability and conveyance loss of each parcel). In this method, the allocation procedure is performed interactively, and the result can be presented in a map or tabular form.

The crop rotation constraint (constraint 2) is implemented using the normal database operations. When starting allocation of a crop, all parcels that can be used for that crop according to the crop rotation rule are first selected, and allocation is performed for only those parcels. Since these types of data are stored in the thematic databases, the procedure is easily implemented.

***Allocation model structure***

The allocation model structure is graphically presented in figure 18.

Process 4.3.1 uses appropriate functions from the allocation model, and combines the basic spatial data (administrative, road and irrigation network maps) with information about transportation costs and conveyance losses to generate the required maps.

In this process, the soil unit map and administration map of the region are combined to obtain the effective area and determine the different soil types of each parcel (outputs 4.3.1.A.1 & 4.3.1.A.2). The conveyance loss of water for each parcel used by a specific crop (eq. 12) is a function of crop, crop irrigation requirements (function of soil and climate) and conveyance loss in the canal network from source to the field inlet and the flow rate of the canal. It is expressed in physical terms, but can be transformed to any other units, such as actual costs (money), or any other index which reflects the importance of the water losses in the region.

The conveyance loss of water at each parcel inlet is a function of canal length (parcel inlet and source), type of canal and conveyance loss per unit of the canal. This is

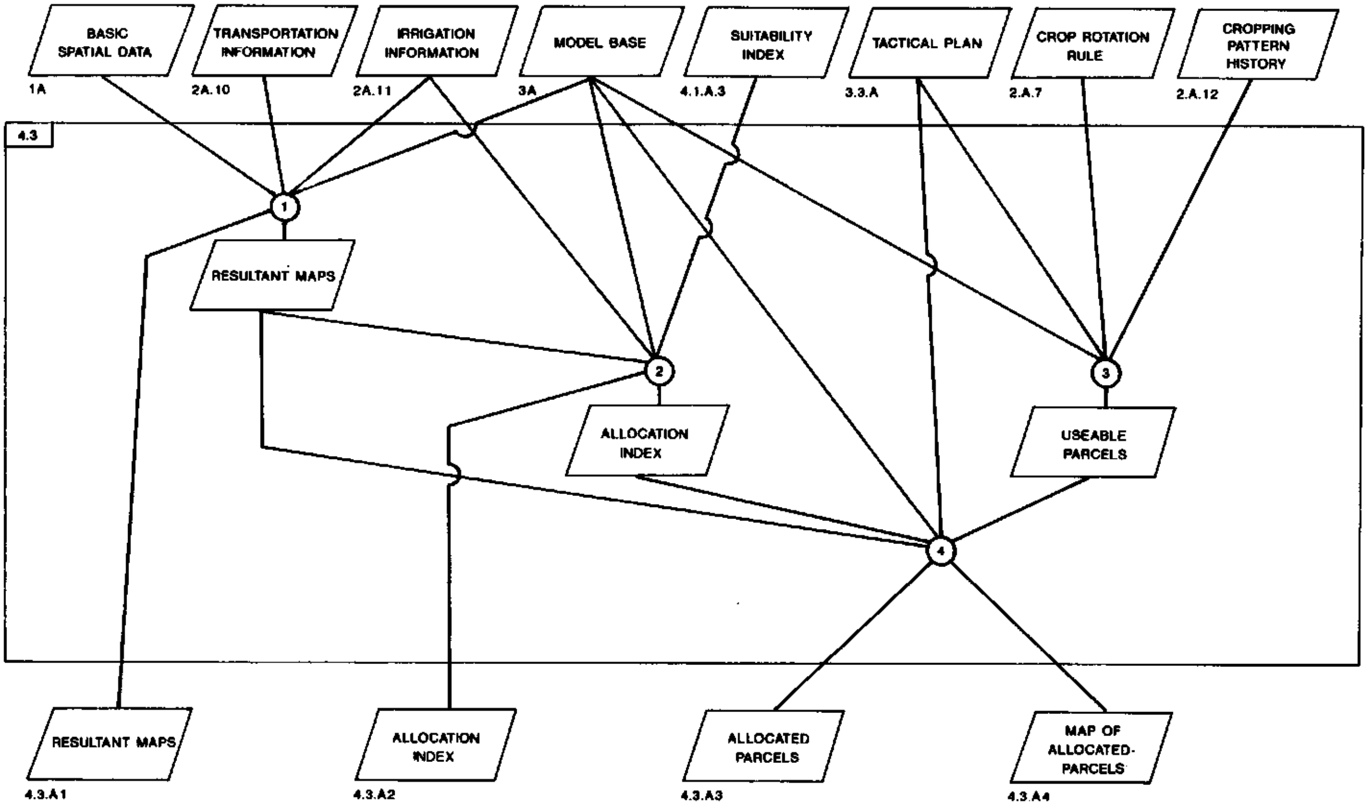


Figure 18. Graphic presentation of the operational planning model

calculated by using module "prepare-1" (module 3.A.5) in terms of actual water losses per second at the field inlets. The conveyance loss for each canal link is calculatedaccording to equation 16 and recorded as an attribute of the parcel in the relevant file in the TDBMS. The conveyance loss of each parcel is obtained by aggregating the conveyance losses of all the canal links that are used to bring water from reservoir to parcel. The output map of this process is the administration map with conveyance loss of each parcel (output 4.3.1.A.3).

Transportation costs are a function of the distance of each parcel to its specific store, the type of connecting road, and the unit transportation cost of each crop product (i.e., per unit weight of the crop product). These costs are calculated for each road link and each parcel (road length between the centre of each parcel and the specific store of that crop). By applying appropriate factors, these costs can be expressed in terms of the actual cost (money) or in terms of a special index (travelling time). The road impedance is calculated according to equation 15 and recorded as an attribute of the road link and parcel in the relevant TDBMS data file. The output of this process is the road map and impedances (tabular) of all the road links inside and outside the parcels (output 4.3.1.A.4).

All outputs of this process (graphically presented in figure 19) are derived once and remain unchanged in the course of the allocation process.

Process 4.3.2 uses the appropriate functions from the allocation model to calculate the allocation indices of all parcels which are put on record as attributes of the respective link in the road or irrigation network. In this process, the suitability index and total irrigation requirements of each soil type for each crop (derived in the process of biophysical land evaluation) are used to update the respective soil data file (intermediate file between biophysical land evaluation and operational planning); this intermediate file is used to update the corresponding values in the files related to the effective areas (map 4.3.1.A.1). Using a relational database operation, the attributes corresponding to suitability indices and irrigation water requirements in the combined administration and soil unit map (map 4.3.1.A.2) are updated. Next, the biophysical suitability and irrigation water requirements of each soil type for each crop are transformed into the suitability index and irrigation requirements per administrative unit. This is done using module "prepare-2" (module 3.A.6) which calculates the weighted average of the component parts of the suitability index and irrigation requirement (per hectare) of each parcel (output 4.3.2.A.4).

The total conveyance loss in the irrigation canals serving each parcel, with a specific crop, is a function of the irrigation requirement of the crop (taking into account soil properties and climatic conditions) and the conveyance loss in the canal network from source to the field inlet (per unit time) and the flow rate of the canal (calculated in

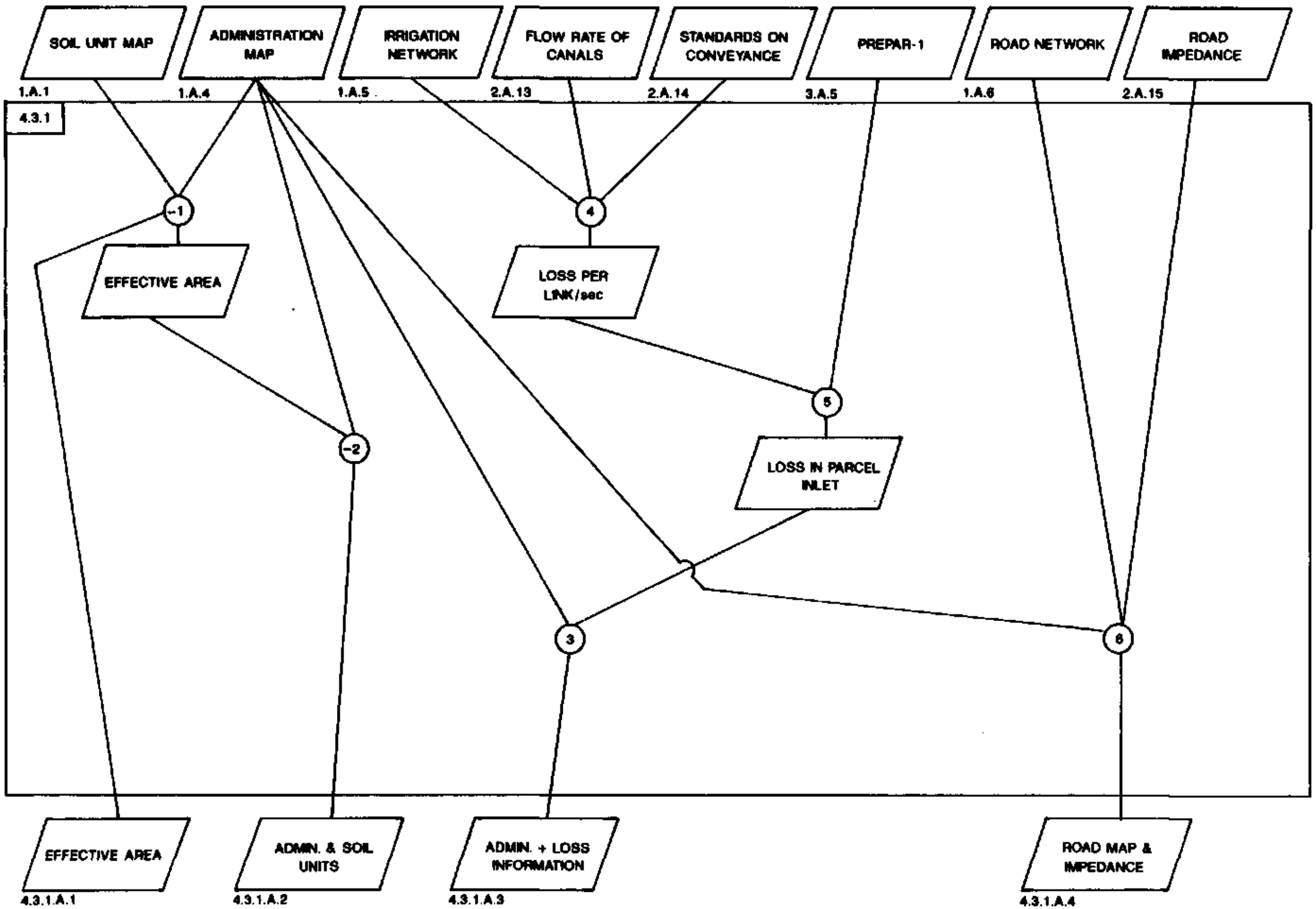


Figure 19. Graphic presentation of process 4.3.1 of operational planning model (Spatial data preparation)

process 4.3.1 according to equation 12). This can be calculated in terms of actual water losses or, after transformation, be expressed in terms of actual cost (money) or anyother index reflecting the importance of water losses in the region. The allocation index is a composite variable derived from the combination of either biophysical suitability and transportation cost or biophysical suitability and conveyance loss. In the latter case, the biophysical suitability index of each parcel for a particular crop and the conveyance loss in the irrigation network for the same crop at the same parcel are combined according to equations 12 and 13. The allocation indices of the parcels are converted into parcel impedances according to equation 14 (output 4.3.2.A.5). Finally, the impedances of the parcels in the road/irrigation network map (output 4.3.1.A.4) are set equal to the impedances of the parcels in the administrative map (4.3.2.A.5) to prepare the final map for the actual allocation (output 4.3.2.A.6). These indices (impedances) are calculated for each parcel with respect to each crop and recorded as an attribute of the parcel for use as an allocation criterion in the actual allocation process. This process is graphically presented in figure 20.

Process 4.3.3 selects all parcels that can be assigned to a specific crop according to the crop rotation rules. This is a conventional query of the database containing the historical cropping patterns of parcels in the rotation period, in relation to the rotation table (rotation rules).

Process 4.3.4, using "allocate" (module 3.A.3.3) of the allocation model, allocates the suitable parcels to the various crops on the basis of minimum cost flow between the parcels and the specified sources, and finally generates a map of the allocated parcels to each crop. If the parcel impedance has been calculated using the biophysical suitability index and the conveyance loss, the allocation is based on the demand for each crop (set by tactical planning), the location and capacity of the respective stores, and the total impedance from the parcel to each store through the road network. If the parcel impedance has been calculated using the biophysical suitability index and the transportation costs of the crop (in this case for each crop only one store is permitted), then the allocation is based on the demand and the total impedance from the parcel to the source of water distribution through the irrigation network. The planner can select either of the two, based on his preference. This process is graphically presented in figure 21.

### 5.2.3.1.4 Definition of processing functions for supportive planning

Supporting plans support the implementation of the basic plan. They evaluate the consequences of the plan on the basis of accounting definitions. They comprise several accounting models which provide various estimates, such as:

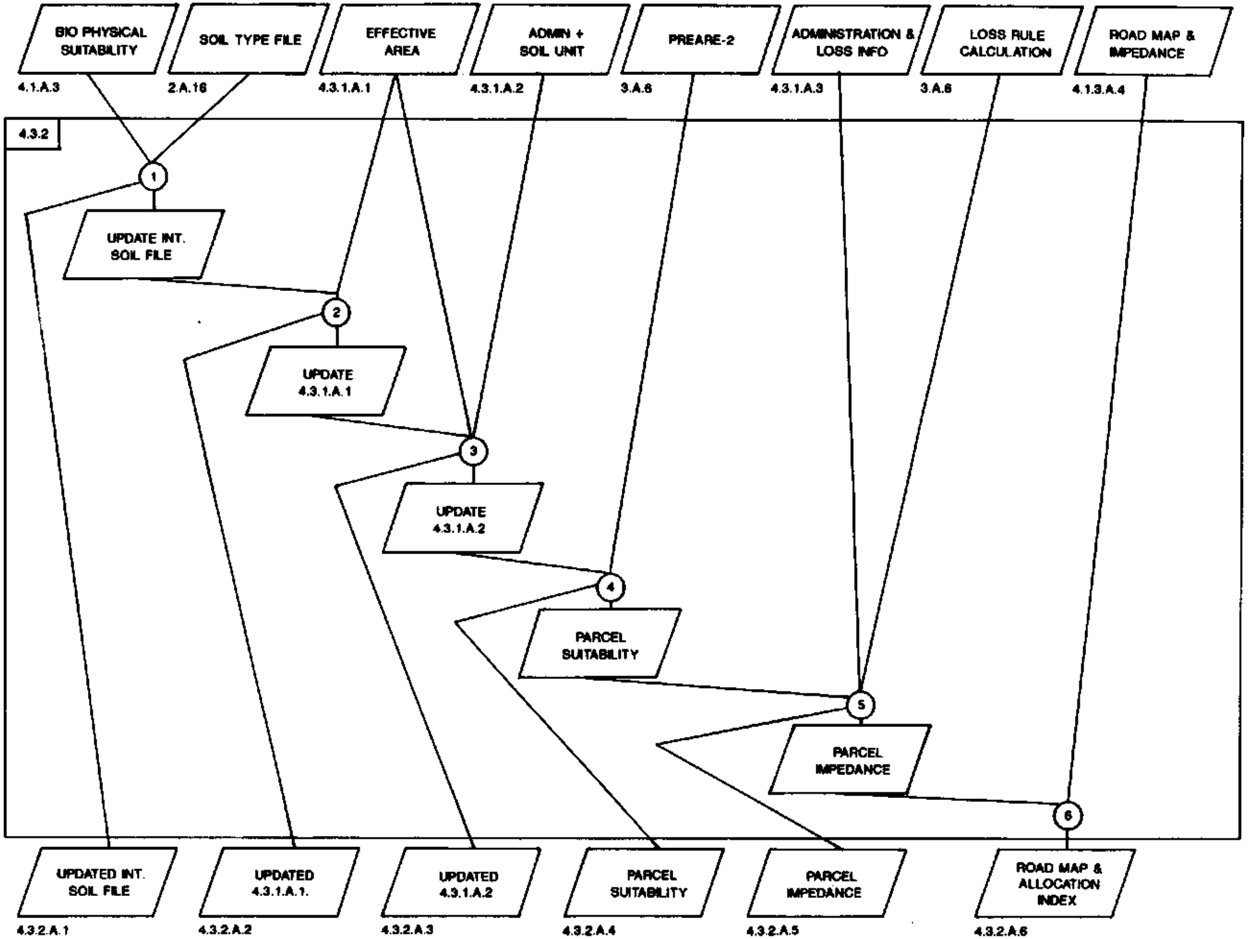


**Figure 20.** **Graphic presentation of process 4.3.2 of operational planning model**

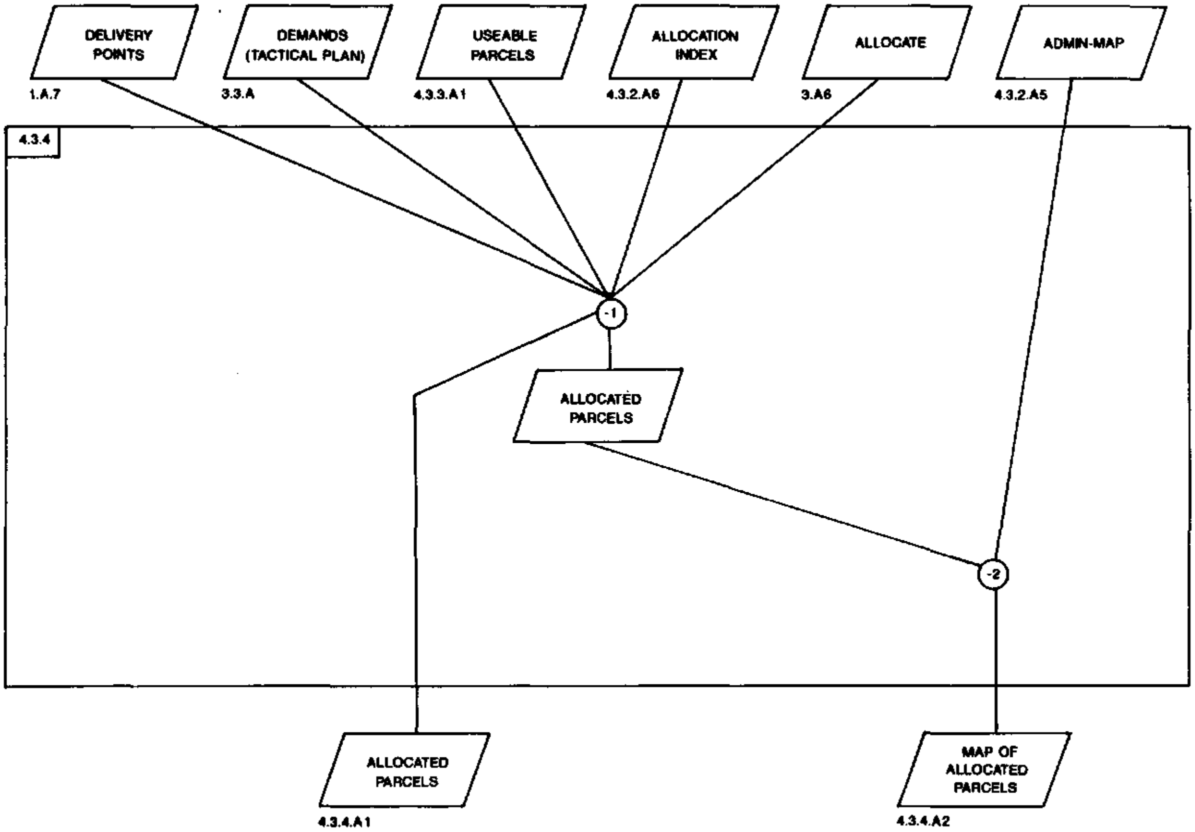


**Figure 21.** Graphic presentation of "Allocate" process

- Total material requirements for each cropping pattern at each management level.
- Predictive reports that estimate production and production requirements for each cropping pattern.
- Plan of operation for each cropping pattern at each management level.

### 5.2.3.2 Definition of major processing functions in the monitoring and evaluation sub-system

Processing functions in monitoring and evaluation consist mainly of capacities to derive standards of performance and perform transaction processing, report processing, inquiry processing, and analysis of possible decisions or courses of action. This consists of accessing series of databases and uses data analysis, information analysis, accounting and crop simulation models to derive standards and produce summary, comparative and other types of required reports. These include:

- Crop growth simulation model to establish performance standards for each parcel assigned to a crop in the course of operational planning. This is basically the same process used in the biophysical land evaluation process, run with the current weather data (planning period).
- Procedures for generating summary reports and performing data analysis operations according to prespecified rules. These are standard relational database procedures.
- Information analysis procedures, which include data analysis capacities and application of a series of small models to calculate for each crop at each parcel:
  - The cost per hectare.
  - The actual yield per hectare.
  - The overhead cost per hectare.
  - The operational cost per hectare.
  - The material cost per hectare.
  - The agricultural machinery cost per hectare.
  - The cost of fuel, oil and transport per hectare.

### 5.2.4 Definition of modules and major functions in the model base sub-system (process model)

The major modules and processing functions included in the model base (process model) are defined below. Each of these represents an important process in the agricultural production system, and is therefore considered essential for deriving the required information and supporting management decisions (different phases of the decision making process).

### 5.2.4.1 Definition of crop growth simulation and irrigation modules (modules 3.A.1 & 3.A.2)

On basis of existing theory, essential elements of computerized summary crop growth simulation models developed by Van Kraalingen and Van Keulen (1988), WOFOST (Van Diepen et al., 1987) and WHEAT (Van Keulen and Seligman, 1987) have been combined into a single modular model that allows quantification of attainable yield for potential and water-limited conditions. The crop irrigation module was integrated in this model, which is used in processes 4.1.4 and 4.1.7.

The overall structure of the crop growth simulation and irrigation modules are presented graphically in figure 22. The inputs, outputs and major processing functions of this module are:

*Inputs*

| | |
|---|---|
| 5.1.1.A | Weather data. Even though in some cases weather data may be represented by "long term average weather data", defined as "climatologic data", for convenience here "weather data" is used. |
| 4.1.2.A | Soil physical data, including maximum rooting depth. |
| 4.1.3.A | Crop physiologic and phenologic data. |

*Outputs*

The main outputs of the crop growth simulation and irrigation module are:

5.1.4.A1: This includes day number, daily irrigation requirements and total seasonal irrigation requirements. If desired, the daily values of state variables, rate variables, and forcing variables of the crop, soil and environment can also be stored in the respective data files.

4.1.4.A2: This consists of the statistics (i.e., the integrated values over the crop growth cycle) of the water balance, including the following characteristics:

- Total crop transpiration
- Total drainage
- Total soil evaporation
- Total irrigation requirements
- Maximum rate of crop transpiration and day number ofoccurrence.
- Maximum rate of soil evaporation and day number of occurrence.
- Minimum rate of soil evaporation and day number of occurrence.

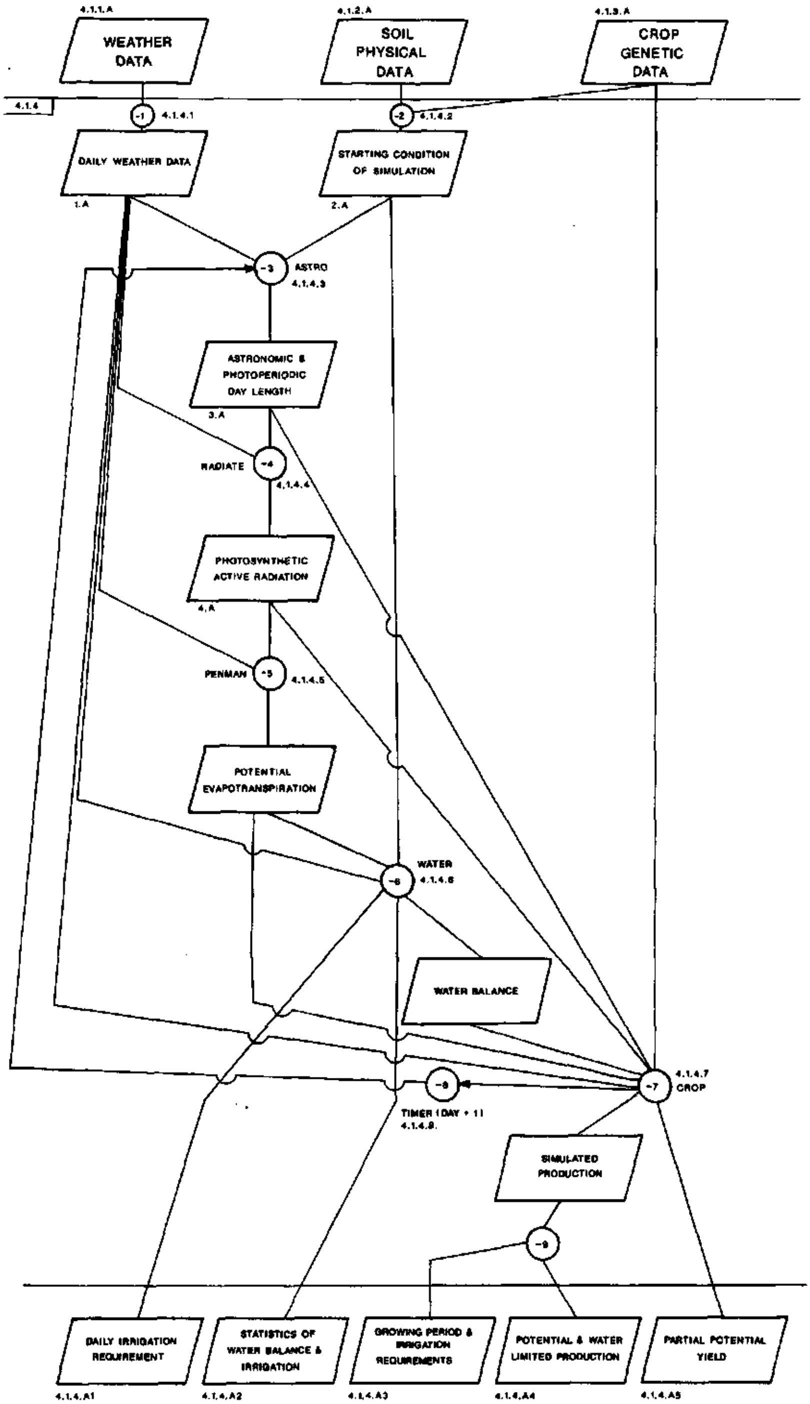


**Figure 22.** Graphic presentation of crop growth simulation module (process 4.1.4)

- Maximum daily rainfall and maximum rate of drainage and day number of occurrence.

4.1.4.A3: Length of growing period, i.e., the period between crop emergence and maturity.

4.1.4.A4: Potential or water-limited production; depending on the selected level (1 or 2), the following characteristics are given:
- Maximum weight of leaves during the growing period.
- Maximum weight of stems during the growing period.
- Actual yield per hectare.

4.1.4.A5: Intermediate production values, which include a table presenting the dynamics of crop growth for the respective production levels. It gives at pre-specified time intervals the year, day number, weight per hectare of leaves, stems, roots, and storage organs, leaf area index, development stage, rooting depth and the value of the reduction factor for assimilation due to water shortage. For production level 1, the reduction factorhas no meaning and is therefore omitted.

***Processes*:**

- Process 4.1.4.1 selects and prepares the required weather data from the relevant data file for the requested period to be used in further processes. The relevant data file is specified by the user on the basis of the availability of weather data.

- Process 4.1.4.2 considers the combination of crop and land type from the irrigation point of view and decides whether the prospective crop can grow on the selected land. If the crop needs irrigation, and the land is not suitable for irrigation, crop growth simulation is not performed for that combination. If the land is irrigable and the crop is not irrigated, the simulation is performed.

- Process 4.1.4.3 ( ASTRO) reads day number (Julian calendar) and geographic latitude of the site to calculate astronomical day length, the photoperiodically active day length, and declination of the sun. This process is presented graphically in figure 23.

- Process 4.1.4.4 (RADIAT) reads total daily radiation, astronomical day length and declination of the sun, and calculates for three moments during a day (selected on the basis of criteria derived from application of the Gaussian integration algorithm) the sine of solar elevation, and the flux densities of the diffuse (PARDIF) and direct (PARDIR) components of photosynthetically active radiation (PAR), using an average atmospheric transmission coefficient. These characteristics are used to calculate daily

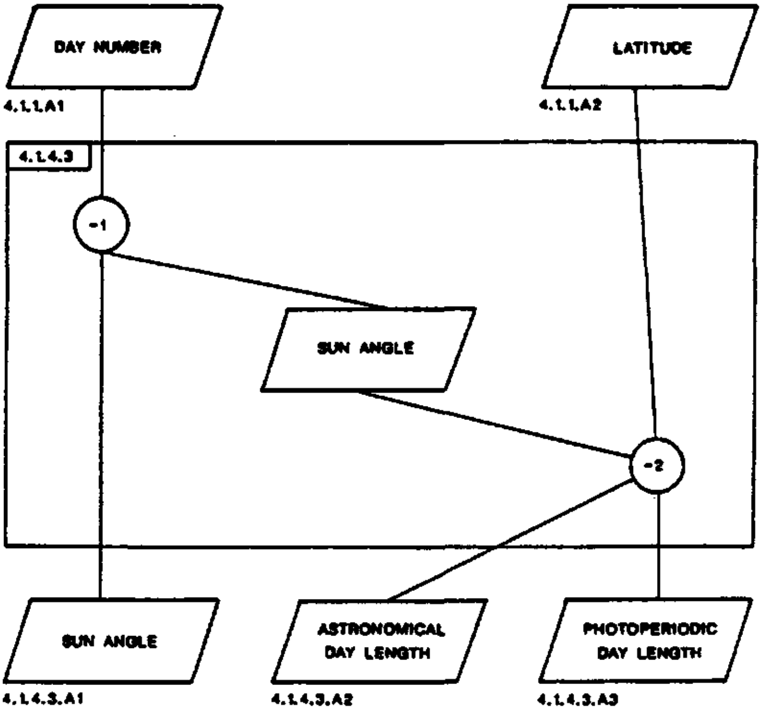


**Figure 23. Graphic presentation of ASTRO (process 4.1.4.3)**

gross carbon dioxide assimilation of the crop (Goudriaan,1986). This process is presented graphically in figure 24.

- Process 4.1.4.5 (PENMAN) uses the Penman method (1948,1956) to calculate the potential evaporation of open water, potential soil surface evaporation and potential canopy transpiration. In this process, saturated vapour pressure is calculated according to Goudriaan (1977) and net outgoing longwave radiation according to Brunt (1932). A more detailed presentation of this process is given in figure 25.

- Process 4.1.4.6 (WATER) basically consists of two modules: WATER1 for potential production and WATER2 for water-limited production.

  WATER1 reads the soil data file and uses potential soil surface evaporation, total leaf area index and total crop transpiration to calculate the water balance at production level 1. At this production level, soil depth is considered non-limiting and soil moisture content is assumed to be continuously at field capacity. WATER1 calculates daily soil evaporation and crop transpiration and yields total water requirement. Outputs of this process are cumulative crop transpiration and soil surface evaporation, and their sum, which is the total crop water requirement.

  WATER2 reads the soil data file and uses potential soil evaporation, total leaf area index, total transpiration, rainfall, position of the root-tip, rooting depth, development stage and maximum development stage for irrigation application to calculate the water balance at production level 2. It simulates the crop in the actual environment using soil data, and calculates the water balance for each soil compartment, taking into account soil surface evaporation, crop transpiration, infiltration of rainfall and irrigation and capillary rise from the ground water table.

  This process first calculates for each compartment the residual water storage capacity from current moisture content and moisture content at field capacity, and then infiltration of rainfall in the various compartment. Subsequently, the contribution of each compartments to soil surface evaporation is calculated. Capillary rise is calculated as a function of the distance to the ground-water table and the soil moisture suction in the compartment. The moisture content of each soil compartment is then updated by adding capillary rise and subtracting transpiration and soil evaporation. Total water content in the root zone is then calculated; if available water is less than % 50 of its maximum value, irrigation is applied to restore soil moisture content in the root zone to field capacity, using the infiltration procedure (only irrigated crops are considered). The irrigation requirement is then corrected for the field application efficiency using a coefficient related to the physical characteristic of the soil (Bos and Nugteren, 1974).

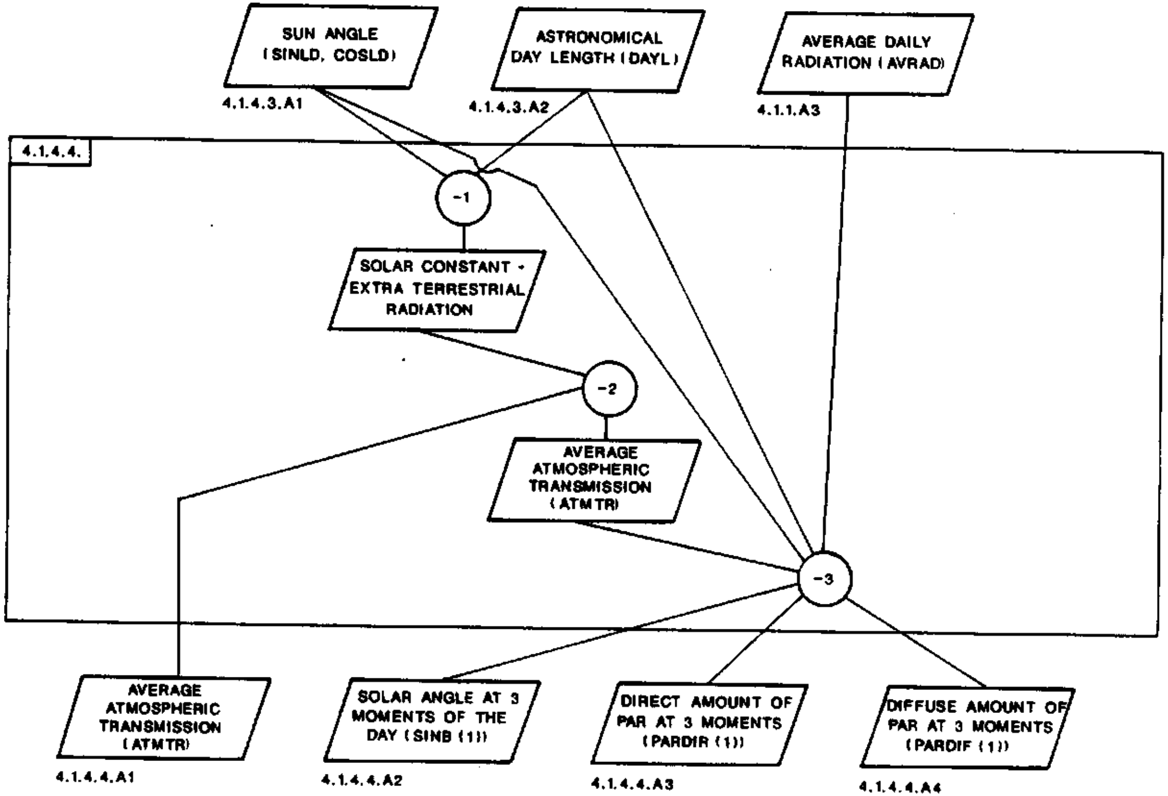


**Figure 24. Graphic presentation of RADIAT (process 4.1.4.4)**

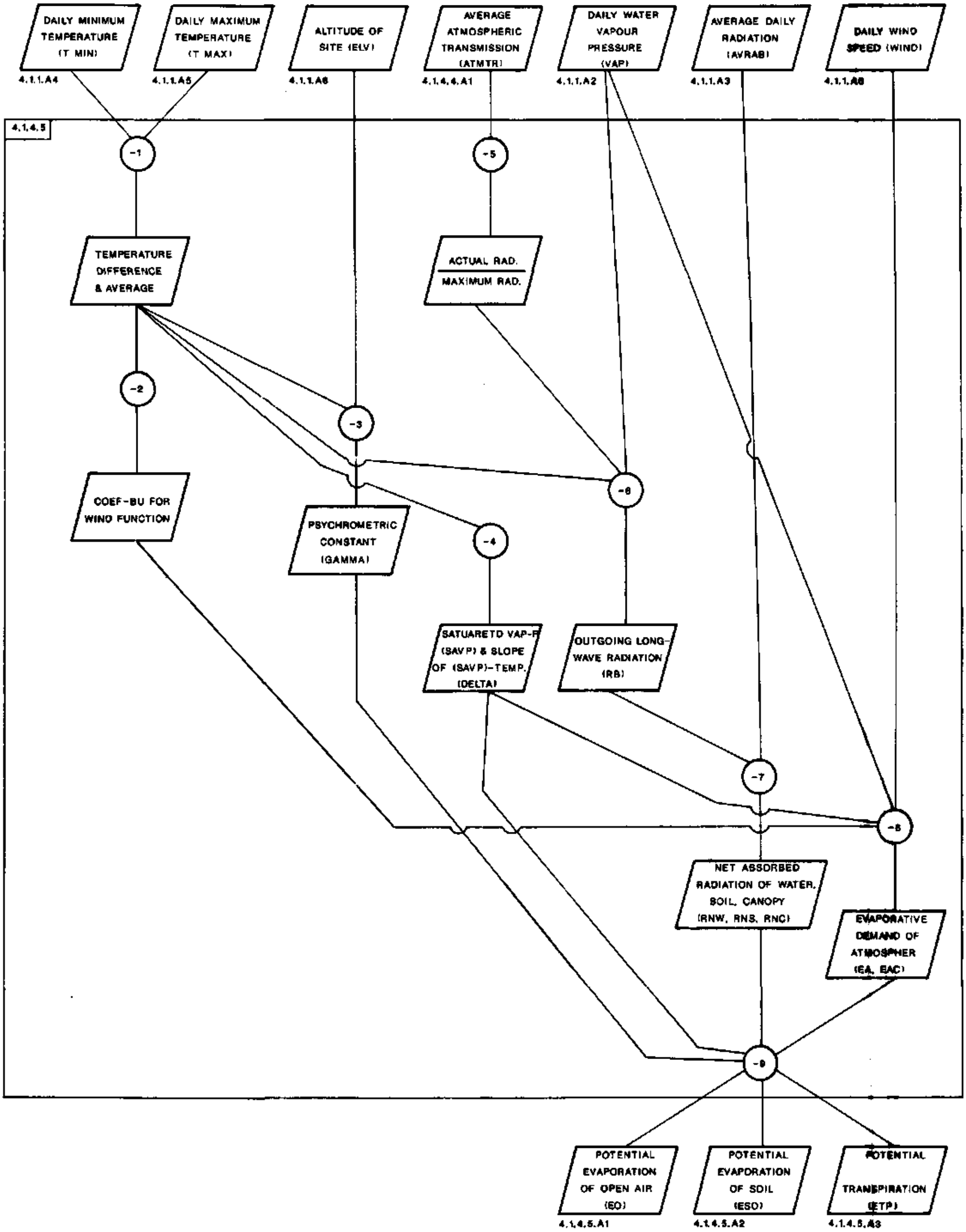


**Figure 25. Graphic presentation of PENMAN (process 4.1.4.5)**

All variables pertaining to the water balance, including the water content of the various soil compartments, are transferred to the relevant file and a check on the water balance (conservation of mass) is performed. A more detailed presentation of this process (WATER2) is given in figure 26.

- Process 4.1.4.7 (CROP) performs the actual simulation of crop growth in the environment generated through sub-processes 4.1.4.1 to 4.1.4.6. Crop uses daily temperature, day length, photosynthetically active radiation, solar elevation, latitude of the location, and relative water content, depth, thickness and number of soil compartments.

This process first calculates the phenologic development rate in the vegetative phase (for grain crops before anthesis) and then initializes or updates the state variables, consisting of weights of roots, stems, storage organs, development stage and rooting depth. To take into account the limited lifespan of leaves, the total leaf mass is subdivided into age classes, for each of which physiologic age (expressed as a temperature sum) is tracked separately. Leaf area is calculated from leaf weight using a temperature-dependent specific leaf area. Total green area of the canopy is obtained by adding the green area of stems and storage organs to leaf area.

The soil compartment in which the root-tip is located is identified and, by taking into account the activity of roots as a function of soil moisture content, total active root length and potential rate of water uptake per unit active root length are obtained. Actual uptake per unit active root length follows from that value and the effect of soil moisture content on water uptake by the root. Integration over the rooted depth yields total uptake by the root system.

Daily potential gross CO2 assimilation is calculated from incoming radiation and intercepting green area. Subsequently, the reduction factor for gross assimilation due to water stress is calculated as the ratio of actual transpiration to potential transpiration. Actual daily gross canopy assimilation follows from the potential value, taking into account the effect of both water shortage and air temperature. The development rate for post-anthesis development is calculated from the basic rate, corrected for air temperature.

The available assimilate for growth is calculated from gross assimilation by subtracting maintenance respiration requirements of the various plant organs, obtained from their weight and ambient temperature. Subsequently, the partitioning factors for assimilates to the various plant organs, obtained as a function of crop development stage, are used to distribute the available assimilate and calculate the growth rates for leaves, stems, roots and storage organs, taking into account growth respiration. At this stage, the growth assimilation rate is corrected for the management efficiency.

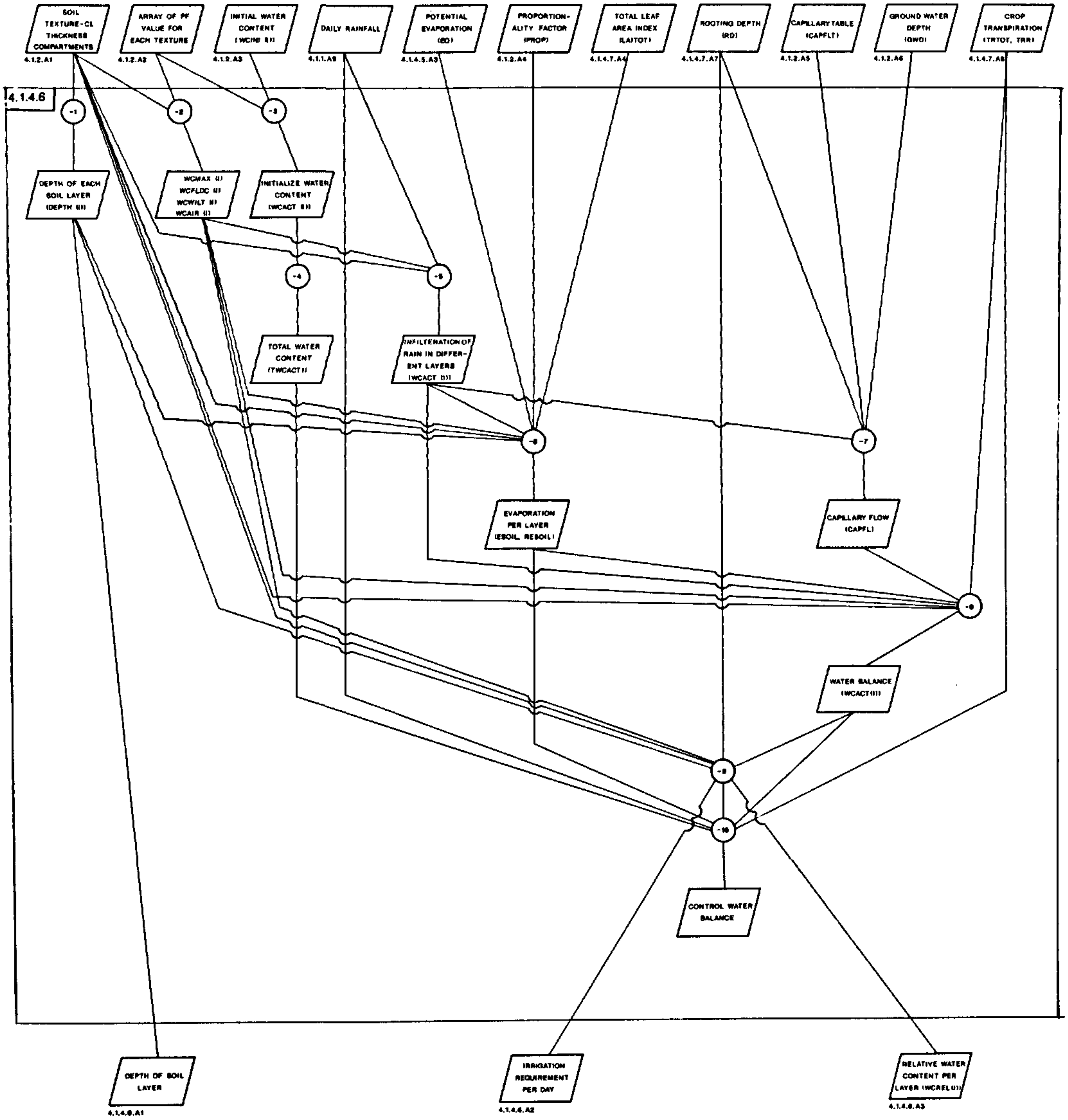


Figure 26. Graphic presentation of WATER (process 4.1.4.6)

Death rates of leaves due to water stress and high LAI (shading effect) are calculated and saved for further calculation of leaf area development.

Subsequently, root extension growth is considered. If the root tip is located in a dry soil compartment, or no assimilates are available for root growth, or the maximum rooting depth has been reached, extension growth is halted. Alternatively, rooting depth increases with a crop-specific daily root extension rate.

Finally crop-growth related variables, i.e., photosynthetically active radiation, day length, maximum assimilation rate, leaf area index, potential and actual daily gross assimilation, respiration, available assimilate for growth, growth rates of the various organs and death rates of leaves, can be stored in an output file. Figure 27 shows this process graphically.

- Process 4.1.4.8 updates time at each time step until the development stage for maturity has been reached and simulation encounters a "finish" condition.

- Process 4.1.4.9 calculates the growing period and monthly irrigation water requirements of the irrigated crops. It records the potential or water-limited production of the crop, the maximum production of different crop organs and the monthly irrigation requirement in a temporary file.

#### 5.2.4.2 Definition of the crop nutrient module (module 3.A.3)

This module uses the QUEFTS concept (Janssen et al., 1990) to estimate nutrient-limited production and the nitrogen, phosphorus and potassium requirements for realization of potential and water-limited production of each crop at any parcel. This module is used in processes 4.1.6. and 4.1.8. The inputs, outputsand different sub-processes of this model are presented graphically in figure 28. The inputs, outputs and major processing functions of this module are:

***Inputs:***

- Potential yield of each prospective crop.
- Length of the growing period of the crop.
- Potential weight of vegetative organs (leaves and stems) of each prospective crop.
- Crop nutrient and fertilizer data.

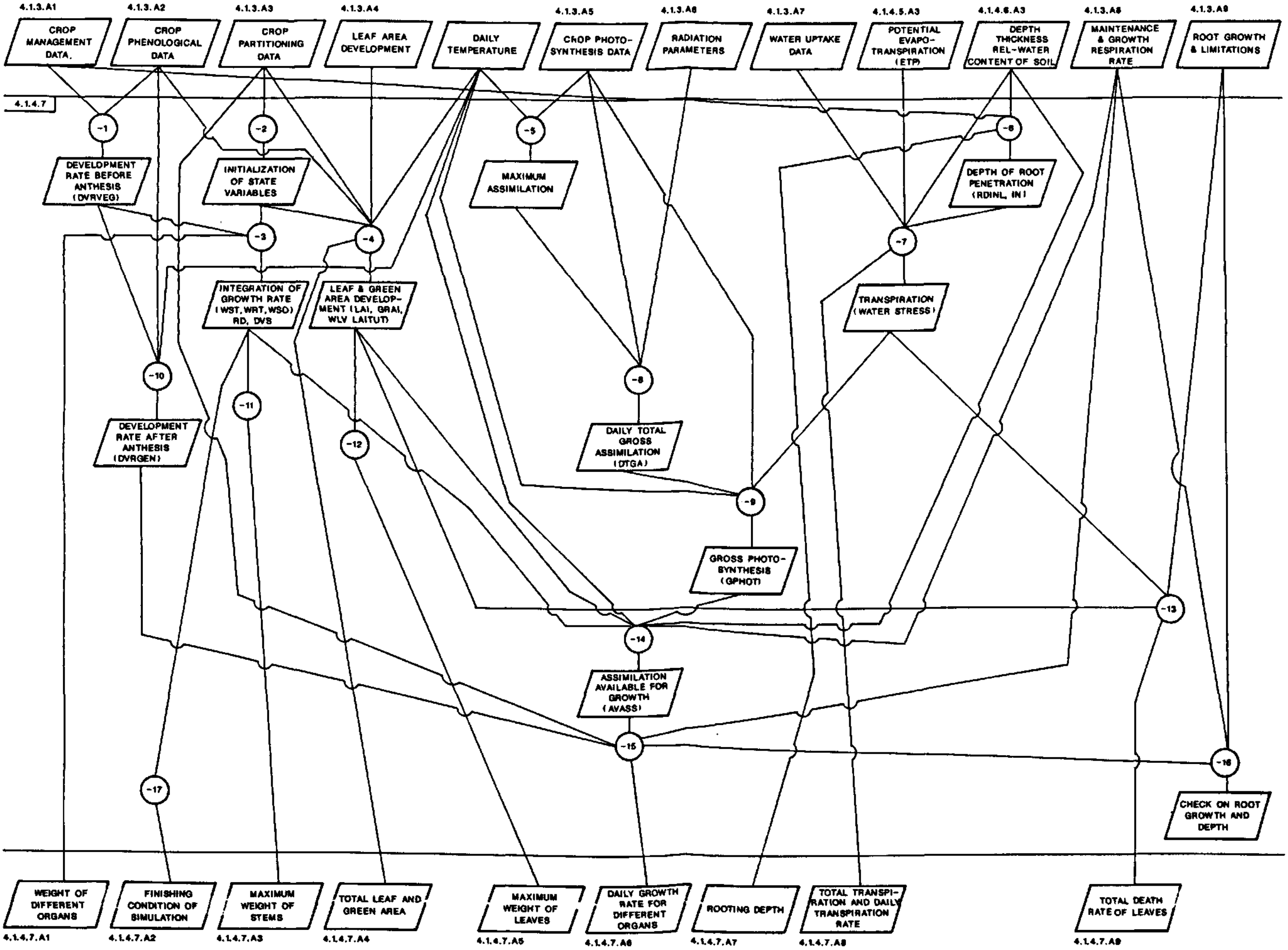


**Figure 27. Graphic presentation of CROP (process 4.1.4.7)**

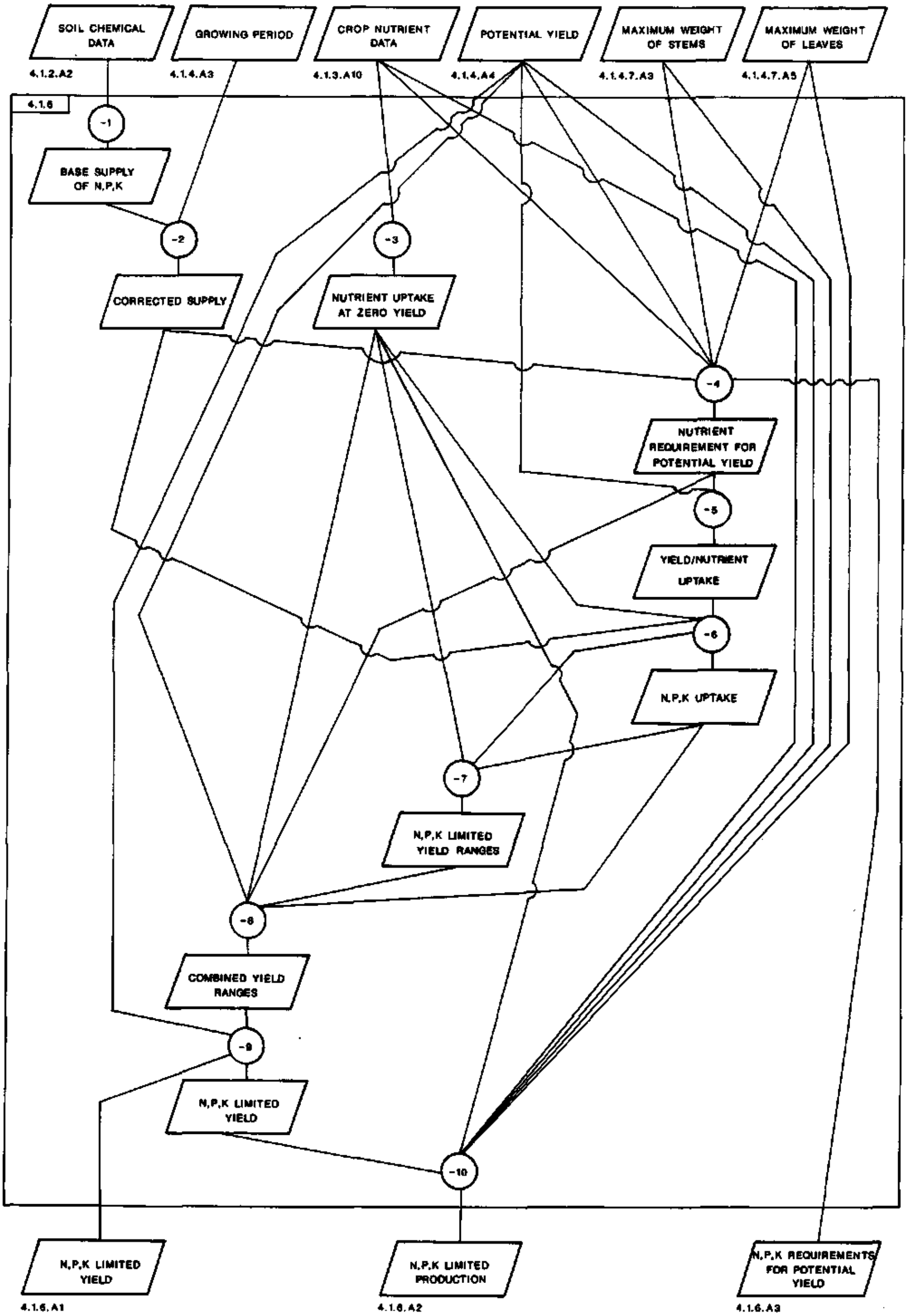


**Figure 28. Graphic presentation of NUTRIENT (process 4.1.6)**

Crop nutrient data include the maximum and minimum N,P and K concentrations in vegetative and storage organs of each prospective crop. Fertilizer data refer to the recovery fraction of each fertilizer to be applied. Only the crop nutrient and fertilizer data should be supplied by the user; the rest of the input data are derived in the crop growth simulation process.

***Outputs:***

- N-, P-, and K-limited yield of each crop, i.e., the yield potential based on nutrient supply from natural sources.
- Nutrient (N, P and K)- limited production of various plant organs and harvest index of the crop.
- N, P, and K requirements for realization of the potential production of the prospective crop.

***Processes:***

- Process 4.1.6.1 uses semi-empirical relationships between soil chemical properties and soil nutrient supply to estimate the quantities of nitrogen, phosphorus and potassium that can potentially be supplied by the soil from natural sources.
- Process 4.1.6.2 corrects the calculated base supply of nutrients for the length of the growing period of each crop. This process assumes a linear relationship between nutrient supply and length of the growth cycle.
- Process 4.1.6.3 calculates the weighted mean concentration of each element (N, P and K) in the vegetative and storage organs of each prospective crop, and the minimum N, P, and K requirements associated with zero yield, defined as the minimum amount of vegetative material required before the production of any storage organ starts.
- Process 4.1.6.4 estimates the nutrient (N, P, and K) requirements for potential yield assuming maximum concentration of each element. The process takes into account the base supply of N, P, and K and calculates the additional amount that should be added to the soil in the form of fertilizer. For converting the nutrient requirements into fertilizer requirements, a user-specified standard recovery fraction of fertilizer nutrients is used.
- Process 4.1.6.5 estimates yield-nutrient uptake ratios for nitrogen, phosphorus and potassium at minimum and maximum dilutions.
- Process 4.1.6.6 estimates actual uptake of each element from its potential supply by comparing the nutrients in pairs. Thus the relationship between the actual uptake and the supply of each element is calculated twice as depending on the supplies of the other two elements. This results in two estimates of the actual uptake for each of the three elements. In conformity with the law of the minimum, the lower estimates are considered more realistic and used further in the process.

- Process 4.1.6.7 uses the uptake-yield relationship and the actual uptake of nitrogen, phosphorus and potassium to establish the expected yield levels at maximum and minimum element dilutions.
- Process 4.1.6.8 combines the yield ranges for the preceding process, two-by-two, and estimates the respective limited yield per pair. In this way, six yield estimates are established.
- Process 4.1.6.9 calculates average weighted yields for the paired nutrients to arrive at the final yield estimate, provided that the yield for any combination of two nutrients does not exceed the upper limit of the yield range of the third nutrient.
- Process 4.1.6.10 estimates the N-, P-, and K-limited production of plant organs on the basis of the dry matter distribution of plant organs in the optimum situation. The resulting estimates of the weights of leaves, stems and storage organs, and a harvest index of the nutrient-limited crop are stored in the system.

### 5.2.4.3 Definition of the optimization model

In MAIC, management is interested in deriving a cropping pattern that maximizes total profit and suits the biophysical suitability of the land, the available agricultural machinery, irrigation water availability, crop rotation and production policy. It is also interested in the total labour requirement during each month and the total fertilizer requirement of the cropping pattern. To achieve these goals, a linear programming model was used. The matrix structure of such a model is shown in table 6, and its components and formulation are specified below.

*Activities*

Activities or decision variables consist of:
- Selection of crop C on soil S with irrigation application code R and fertilizer application code K, [XA(S,C,R,K)].
- Hiring labour type L for all operations at time T, [XL(L,T)].
- Buying fertilizer of type F in the production process, [XF(F)].

*Coefficients*

Coefficients reflect the demand on the resources per unit of activity, including:
- Yield of crop C on soil S with irrigation application code R and fertilizer application code K, [yield(S,C,R,K)].
- Fertilizer requirements of crop C on soil S with irrigation code K from fertilizer type F, [FERT(S,C,K,F)].
- Agricultural equipment requirements of crop C from equipment type E at time T, [EQUIP(C,E,T)].

| ROWS | SOIL TYPES | | | | | R.H.S |
|---|---|---|---|---|---|---|
| | S1 | | | | S2 | |
| | *FERTILIZED* | | *NON-FERTILIZED* | | | |
| | C1 | C2 | C1 | C2 | | |
| PRODUCTION POLICY | | | | | | |
| CROP ROTATION | | | | | | |
| IRRIGATION REQUIREMENTS | | | | | | |
| EQUIPMENT REQUIREMENTS | | | | | | |
| DIFFERENT SOIL TYPE | | | | | | |
| IRRIGABLE LAND | | | | | | |
| INPUTS REQUIREMENTS | | | | | | |
| LABOUR REQUIREMENTS | | | | | | |
| OBJECTIVE FUNCTION | GROSS MARGIN ESTIMATE OF EACH CROP (PER/HA) | | | | | MAXIMIZED |

**Table 6. Matrix structure of the linear programming model**

- Irrigation water requirements of crop C on soil S with irrigation code K at time T, [WATER(S,C,R,T)]
- Labour requirements of crop C from labour type L at time T, [LABOUR(C,L,T)].
- Selling price of crop C, [SELP(C)].
- Purchasing price of fertilizer F, [COSTF(F)].
- Minimum production requirements of crop C, [MINPRO(C)].
- Maximum permitted area of crop C in the cropping pattern, [ROTA(C)].
- Maximum amount of water available for irrigation at time T, [WATMAX(T)].
- Maximum amount of agricultural equipment type E available at time T,

[EQUIMAX(E,T)].
- Area of soil type S, [SOILA(S)].
- Maximum area of irrigable land at soil type S, [SOLIR(S)].
- Cost of hiring one day of labour type L, at time T, [COSTL(L,T)].
- Variable costs of crop C on soil S with irrigation application code R and fertilizer application code of K, [VARCOST(S,C,R,K)].

*Objective function*

The objective function that should be maximized is the total activity return in terms of gross margin minus the costs of hiring labour and buying fertilizer, subject to the existing constraints, prices and yield expectations.

SUM (S,C,K) GROSS(S,C,K)* XA (S,C,R,K) -
SUM (F) COSTF (F) * XF (F) -
SUM (L,T) COSTL (L,T) * XL (L,T) = MAXIMUM (17)

Where gross margin is defined:

GROSS (S,C,K) = (YIELD (S,C,K)* SELP (C) - VARCOST (S,C,K) (18)

Subject to the following constraints:

- Production constraints:
  SUM (S,R,K) YIELD(S,C,R,K) * XA(S,C,R,K) .GE. MINPRO (C)
  (for all C) (19)
- Rotation constraints:
  SUM(S,R,K) XA(S,C,R,K) .LE. ROTA (C)
  (for all C) (20)
- Water constraints:
  SUM(S,C,R,K) XA(S,C,R,K) * WATER(S,C,K,T) .LE. WATMAX (T)
  (for all T) (21)
- Agricultural machinery constraints:
  SUM(S,C,R,K) XA(S,C,R,K) * EQUIP(C,E,T) .LE. EQUIMAX(E,T)
  (for all E & T) (22)
- Soil constraints:
  SUM(C,R,K) XA(S,C,R,K) .LE. SOILA(S)
  (for all S) (23)
- Irrigability constraints:
  SUM (C,R,K) XA (S,C,R,K) .LE. SOLIR(S)
  (for all S) (24)
- Total fertilizer requirements:

SUM(S,C,R,K) FERT(S,C,K,F) * XA(S,C,R,K) -
XF (F) .LE. 0.0
(for all F) (25)

- Total labour requirements:
SUM(S,C,R,K) LABOUR (C,L,T) * XA(S,C,R,K) -
XL (L,T) .LE. 0.0)
(for all L & T) (26)

#### 5.2.4.4 Definition of modules in the allocation model (module 3.A.5)

The allocation model consists of modules that include series of map manipulation functions, models and relational database queries. Only the modules are described below.

Module Prepare-1 (3.A.3.1) establishes the shortest path between each field inlet and the water reservoir through the irrigation network, and calculates the aggregated conveyance losses between the source (reservoir) and each sink (parcel). This calculation takes into account the length and losses of all canal links in the path. The results, i.e., the conveyance loss in the irrigation network (in liter/second), is recorded as an attribute of each parcel.

Module Prepare-2 (3.A.3.2) combines two maps (an attribute map and an adminstrative map) and calculates the weighted average of the selected attribute by administrative unit (parcel). This is used to transform the biophysical suitability and irrigation water requirement of each soil type for each crop into the biophysical suitability and irrigation water requirement of the parcel.

Module Allocate (3.A.3.3) assigns links in the network to the closest centre ( if allocation is performed through the road network, centre refers to the any specified store; if allocation is performed through the irrigation network, centre refers to the water reservoir) or on the basis of the minimum cost of flow through a network. Because links are assigned to a centre, a portion of that centre's resources are distributed to meet each link's demand. The allocation continues until the maximum impedance limit is reached along all paths allocated to the centre, or until the centre resource capacity is exhausted by the cumulative demand of all links allocated to the centre. In this case, parcel impedance is a function of its suitability for a crop, link impedance is a function of the cost of transport through the network, and the demand is a function of the capacity of the store or the actual required area of the crop.

### 5.2.4.5 Definition of the supportive planning functions

Supportive planning functions are simple accounting models, which on the basis of the given standards estimate the total input and logistics requirements of the basic plan. On the basis of the crop operation calendar, they derive the actual operational plan for each management unit at different periods of time.

### 5.2.4.6 Definition of the monitoring and evaluation functions

The general processing functions of the TDBMS and SDBMS sub-systems of ARIS are standard DBMS and GIS functions. In the DBMS, several small models for analysis of information are defined and applied in the system.

- Actual yield per hectare of a crop:

$$Yij = Pij/AGj \tag{27}$$

Where:

Yij = Average production per ha of crop i in parcel j

Pij = Harvested production of crop i from parcel j

AGj = Total harvested area of crop i in parcel j

- Variable costs per hectare of each crop:

Analysis of the system environment (section 5.2.1) shows that currently the fixed costs of production cannot be calculated at any level. The actual variable production costs of each crop at parcel level cannot be estimated either, because the required data for such detailed calculations are not available and cannot be systematically collected in the present situation. For the purpose of evaluation, an imputed variable production cost for each crop at each parcel is calculated:

$$VCOST(i,j) = COSTL(i,j) + COSTMA(i,j) + COSTMAC(i,j) + COSTM(i,j) + COSTCO(i,j) \tag{28}$$

Where:

VCOST(i,j) = the variable cost per ha of crop i on parcel j.

COSTL(i,j) = the imputed labour cost of one ha of crop i on parcel j.

COSTMA(i,j) = the imputed maintenance and fuel cost of the existing agricultural equipment in the section for production of one ha of crop i on parcel j.

COSTMAC(i,j) = the imputed maintenance and fuel cost of the existing agricultural equipment in the central mechanization unit for production of one ha of crop i in parcel j.

COSTCO(i,j) = the cost of contracted operations for one ha of crop i on parcel j.

COSTM(i,j) = the actual material cost of one ha of crop i on parcel j.

- The imputed labour cost [COSTL(i,j)] for each parcel is calculated by distributing the total labour cost of the section over the total normalized area of all different crops in the section. To calculate the normalized area, a labour coefficient has been defined. Labour coefficients refer to the relative labour requirements for production of each crop.

$$FL(i) = 10 * COST(i) / MINCOSTL \qquad (29)$$

Where:

Fl(i) = the labour coefficient of crop i.

COST(i) = the average cost of labour for production of one ha of crop i in the section.

MINCOSTL = the average cost of labour for production of one ha of the crop that has the minimum labour requirements in the section.

Subsequently, the normalized area of each section (NAREA) is calculated according to:

$$NAREA = SUM\ (i)\ AREA(i) * FL(i) \qquad (30)$$

Where :

SUM = takes the sum of all crops in the section.

AREA(i) = the total area of crop i in the section.

The imputed labour cost is calculated according to:

$$COSTL(i,j) = TLCOST * AREA(j) * FL(i) / NAREA \qquad (31)$$

Where:

TLCOST = the total annual labour cost of the section.

- COSTMA(i,j) is calculated similarly to COSTL(i,j), by calculating a mechanization coefficient, normalizing the area, distributing the total annual costs of mechanization over the normalized area, and calculating the imputed cost of each parcel. The same principles are used for the calculation of the imputed cost of central mechanization COSTMAC(i,j).

- COSTM(i,j) is calculated on the basis of monitoring the system. The system keeps track of all material inputs used in the production process of each crop (i) on each parcel (j).
- COSTCO(i,j), like COSTM(i,j), is calculated on the basis of monitoring.

## 5.3 System input requirements

Using the procedure explained in Chapter 2, the content and structure of all input information sets are identified below, and further analyzed with respect to the organizational structure to design the data collection procedure and input forms. As a result of these activities, the information sets, their constituent data items and their relationships were identified and used to design the data collection procedure and forms. For the sake of brevity and simplicity, the data requirements of each model and major processing functions are briefly discussed. The format of data collection forms are given in the ARIS system documentation.

### 5.3.1 Input requirements of the land use planning sub-system

The land use planning sub-system, as presented graphically in figure 13, consists of the biophysical land evaluation, the tactical planning, the operational planning and the supportive planning models. They require different types of data; some are spatial and others are attributes of the spatial features, as described briefly below.

#### 5.3.1.1 Input requirements of the biophysical land evaluation model

The input data requirements for the biophysical land evaluation process as shown in figure 16 can be divided into three main groups:

- Agroclimatic data
- Crop data
- Soil unit and irrigability properties

The detailed data requirements for each of these categories are defined and distributed over the data collection form and given in the ARIS system documentation. Here each of the categories is briefly discussed.

***Agroclimatic data requirements:***

The biophysical land evaluation model requires the following data on agroclimatic properties of the planning environment (project area):

- Daily minimum and maximum temperatures.
- Daily global radiation, or data on the actual daily sunny hours.
- Daily rainfall.
- Average daily windspeed.
- Average water vapour pressure, or data on average daily relative humidity.
- Locational parameters characterized by latitude,longitude and elevation.

If daily global radiation is not available, it can be estimated from the number of sunshine hours using the Angstrom formula. Average water vapour pressure can also be estimated using the Goudriaan formula (Goudriaan, 1977) and relative humidity.

The agroclimatic characteristics can be supplied to the system in one of the following forms:

- Average monthly weather data with average monthly rainfall, and number of rainy days.
- Average monthly weather data with actual daily rainfall.
- Actual daily weather data with actual daily rainfall.

*Crop data:*
Data on crop characteristics are subdivided into the following groups (for detail see Van Keulen and Wolf, 1986; Penning de Vries et al., 1989):

- Crop physiologic properties which include:
  - Photosynthesis characteristics
  - Respiration (maintenance and growth) characteristics
  - Dry matter distribution characteristics
  - Water uptake parameters
  - Leaf area development
- Crop phenologic characteristics
- Crop management data
- Crop nutrient data

*Soil unit and irrigability property:*
The biophysical land evaluation process is based on growth simulation of the prospective crops in each land unit of the planning environment. Each land unit is assumed to be a homogeneous area in terms of soil physical, chemical, weather and irrigability characteristics. This uniform area is determined by a preprocessing function called "process 1" (figure 29), with the assumption that
(i) the weather characteristics of the station are a valid presentation of the weather in the planning area, and
(ii) a uniform thematic map of the soil physical and chemical properties and a

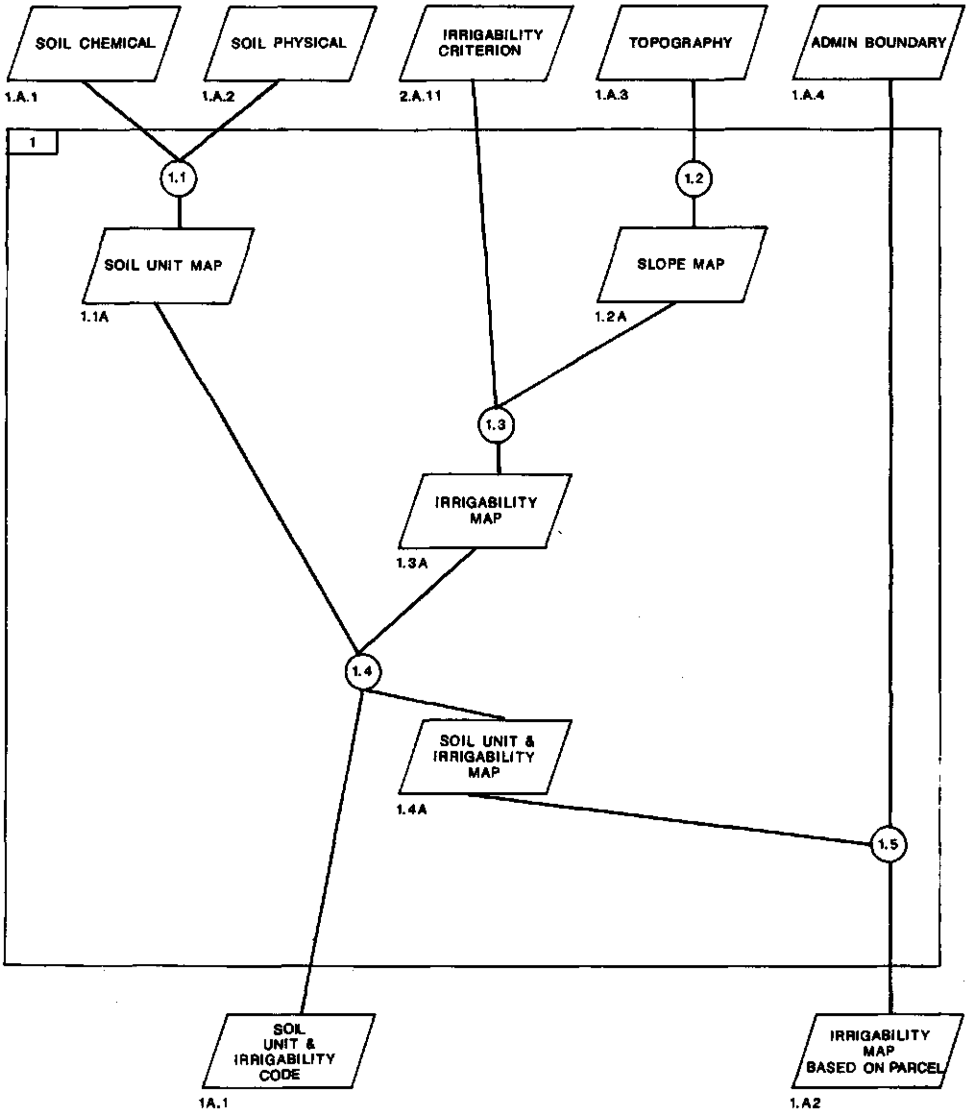


**Figure 29. Graphic presentation of process 1 (land irrigability)**

topographic map of the region are available. This process, a spatial one, consists of overlay processing and digital elevation modelling, and requires as input soil physical data, soil chemical data, topographic data and the administrative map of the region, together with the relevant criterion to define irrigability.

The biophysical land evaluation model provides the option to define a soil profile of up to 10 compartments. Each compartment is assumed to be homogeneous, but may consist up to three texture classes. Each texture class is defined by a function relating PF (logorithm of soil moisture tension in cm) values to volumetric water content of the soil. The total number of compartments, their thicknesses, initial water contents, and texture classes should be defined. The depth of the ground-water table and the corresponding capillary table ( Van Keulen and Wolf, 1986) for the respective texture class should be introduced.

Soil chemical properties are used to determine the natural fertility, i.e., the supply of macro-nutrients from natural sources. The approach assumes no limitation in trace elements and considers only the supply of nitrogen, phosphorus and potassium to a crop. The natural nutrient supply capacity of the soil is estimated using as basic data PH-H2O, organic carbon, P-Olson, and exchangeable K. The cation exchangeable capacity (CEC), base saturation and p-total will give additional confirmative information.

#### 5.3.1.2 Input requirements of the tactical planning model

The input data requirements of the tactical planning process, as explained in subsection 5.2.4.3, are:

- Technical coefficients per hectare of each prospective crop. This includes the demand on the different resources per units of activity at different periods of the growing season. These are basically of two types:
  - Those derived through the biophysical land evaluation model, i.e., yield of prospective crop and the water and fertilizer requirements for its realization.
  - Those to be supplied by the user, i.e., purchasing prices of fertilizers and water, hiring rates of different labour, selling prices of different crops, requirements for different types of agricultural equipment and different types of labour.
- Resource availability at each planning unit. This includes the availability of different resources at different times in the growing period, i.e., availability of different soil type, irrigable land, irrigation water and different type of agricultural equipment.
- Planned cropping pattern.
- Production policy for the planning unit. This imposes the management policy for the minimum production of some crops, for reasons other than their economic value.

### 5.3.1.3 Input requirements of the operational planning model

The input data requirements of the operational planning model are grouped in the following classes:

- Basic spatial data, including:
  - Soil unit type map
  - Road network
  - Irrigation network
  - Location of stores or delivery points
  - Administrative boundary map
- Basic attribute data including:
  - Impedance of road network
  - Flow rate of irrigation canal
  - Conveyance loss information in the irrigation network
  - Capacities of the store or delivery points
  - Crop rotation rules
  - History of cropping rotation at each parcel, for the past few years (minimum 4 years).
- Data derived from the biophysical land evaluation model including:
  - Biophysical suitability indices of each soil unit for each prospective crop.
  - Irrigation water requirements of each soil unit for each prospective crop.
- Data derived from the tactical planning model, including the optimum cropping pattern (demands on each prospective crop).
- Priority and weights of different decision variables including:
  - Allocation order of each prospective crop.
  - Weights indicating the relative importance of transportation cost, irrigation loss and biophysical suitability factors in the allocation procedure.

### 5.3.1.4 Input requirements of the supportive planning functions

The input requirements of the supportive planning functions are:

- Basic annual land use plan of the enterprise.
- Input material requirements of each prospective crop.
- Standards for the requirements on different agricultural equipment.
- Operational calendar for each prospective crop.
- Administrative structure of the enterprise.

The basic plan is derived through the operational planning process, and the physical input requirements are estimated by the biophysical land evaluation model. The rest of the data should be supplied to the system by the user.

### 5.3.2 Input requirements of the monitoring and evaluation sub-system

The smallest management unit in the organizational structure of the enterprise (figure.7) was taken as a reporting unit, and for each type of these units a special data collection form was designed. There are basically three types:

- Basic data collection forms. These forms, used at the initialization of the system to provide the basic data requirement of the sub-systems, include the following:
  - Parcel history information.
  - Available agricultural machinery and implements.
  - Crop operational calendar for each crop.
- Daily and monthly data collection forms. These are used by each management unit to report its daily and monthly activities, and include the following data:
  - Daily farm operation activities (DFOA).
  - Daily local plant protection activities (DLPPA).
  - Daily local agricultural mechanized activities (DCAMA).
  - Daily farm material consumption (DFMC).
  - Monthly report on salary paid to the personnel of each management unit (COSTS).
  - Monthly report on the cost of spare parts used for each management unit (COSTM).
- Occasional data collection forms. These are used when special operations are required or if the basic data have to be updated. They are:
  - Crop harvesting information (CHI).
  - Crop area changes (CAC).
  - Changes in the quantity of existing agricultural equipment and implements (purchase or breakdown).

The formats of all these forms are included in the ARIS system documentation. The content of these forms has been discussed with the various user groups and the management of the operational units within the enterprise to verify their applicability, as well as availability and possibilities of collecting all specified data items.

# CHAPTER 6

## DATA SYSTEM DESIGN AND REALIZATION
## OF THE
## PROTOTYPE SYSTEM

The data system of ARIS was designed, and its initial prototype was realized according to the specified method described in Chapter 2. Data system design and realization of a prototype system comprised the design and development of the proper data and program structure to translate the system specification, defined in the preceding stage, into a computerized information system. This included mainly design of the data model, process model, data processing model, selection of proper hardware and software, adaptation of the models to hardware/software configurations and finally realization of the prototype system. In the course of realization, where appropriate, existing modules (processes) were selected, modified if necessary, and integrated into the system.

### 6.1 Data system design

A data system was developed to collect, store, retrieve and process data sets and presents the results of the analysis to the decision makers in a manageable, quickly communicable form (Lundeberg et al., 1978). The data system design comprises of development of the data model and the process model and the consistency check between these two models.

### 6.1.1 Data model

The result of this activity is the data models for attribute and spatial data (this does not include all the additional special attribute tables originate from spatial data modelling). Figure 30 illustrates the entity relation model (E-R) of all attribute data. All tables in the dotted box are the attribute tables related to the spatial data (built in SDBMS). The contents of each table (relation) and a definition of its characteristics are given in the ARIS documentation.

Spatial data were modelled using the topologic vector data model approach. From the geometric aspect, all terrain features are represented by sets of line (arc) and point (node) features, together with their topologic relationships. As a result, different types of thematic information represented on a paper map, as a map layer generally describing only one map feature (one attribute), are treated as a basic unit of storage (data layers),

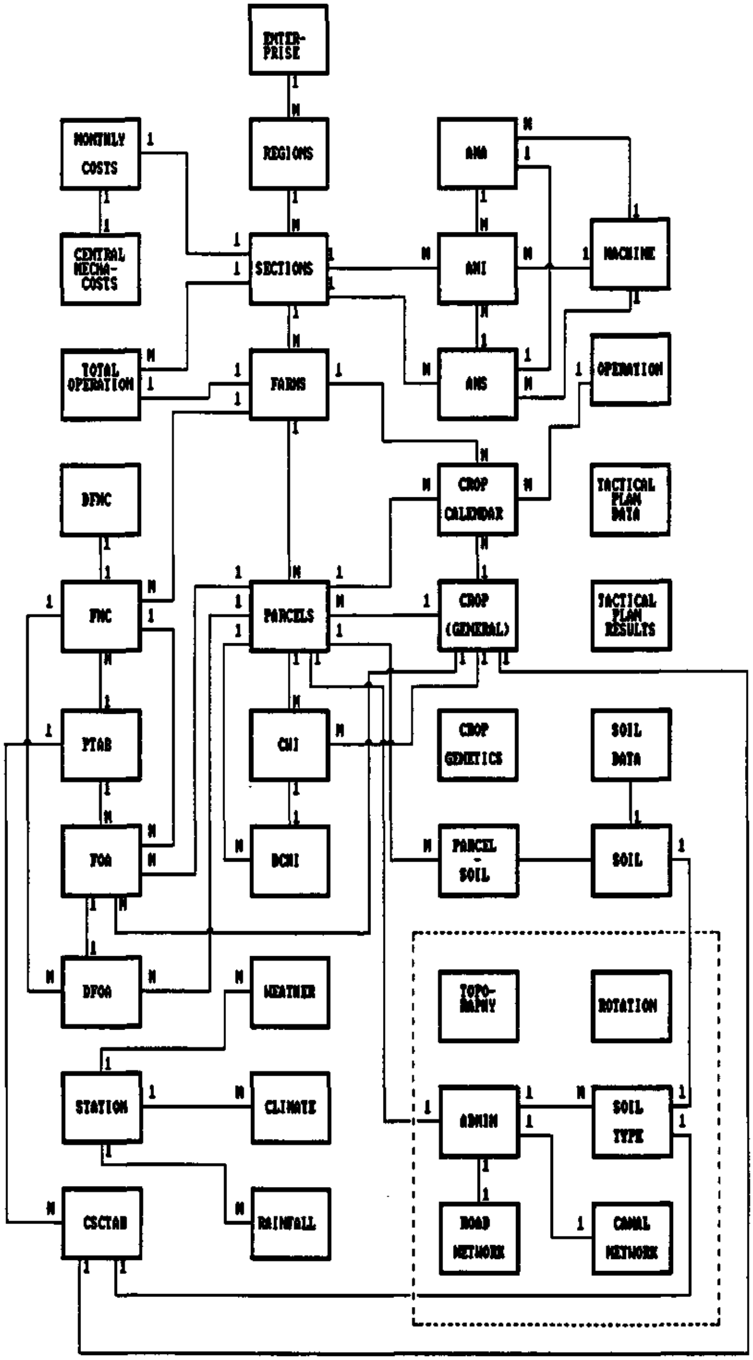


Figure 30. Entity-relation model of attribute data

containing both the locational data and thematic attributes of map features.

According to the input data requirements (section 5.3), the spatial data used in the system comprise the following:

- Topographic layer representing each contour line (line feature) and its value in the attribute table.
- Road layer, representing the road network (line feature) with its attributes, i.e., road class and impedance.
- Canal layer, representing the irrigation network (line feature) with its attributes, i.e., canal type, conveyance loss and maximum allowable flow rate.
- Administrative layer, representing the location of different parcels (area feature) with their attributes, i.e., area.
- Soil layer, representing different soil units (area feature) with their attributes, i.e., soil type, biophysical suitability index and the irrigation water requirement for each prospective crop.

### 6.1.2 Process model

According to the description in Chapter 2, all functions and analysis capabilities are grouped into the following:

- Required processing capabilities for the land use planning sub-system.
- Required processing capabilities for the monitoring and evaluation sub-system.

The designs of these processing functions are briefly described.

#### 6.1.2.1 Process model for the land use planning sub-system

The process model for the land use planning sub-system consists of all processing functions defined in subsection 5.2.3.1 and 5.2.4. It includes processing functions for implementing biophysical land evaluation, tactical planning, operational and supportive planning. The required functions for biophysical land evaluation and tactical planning are drawn mainly from the special applications software using the data in the spatial and non-spatial databases. When this software is called for execution, the required data are generated according to the given specifications and exported to the application program. The respective outputs are subsequently imported back into the relevant databases and handled accordingly. Operational planning uses the integrated analysis of spatial and non-spatial data, and supportive planning uses mainly the analysis capabilities of the DBMS.

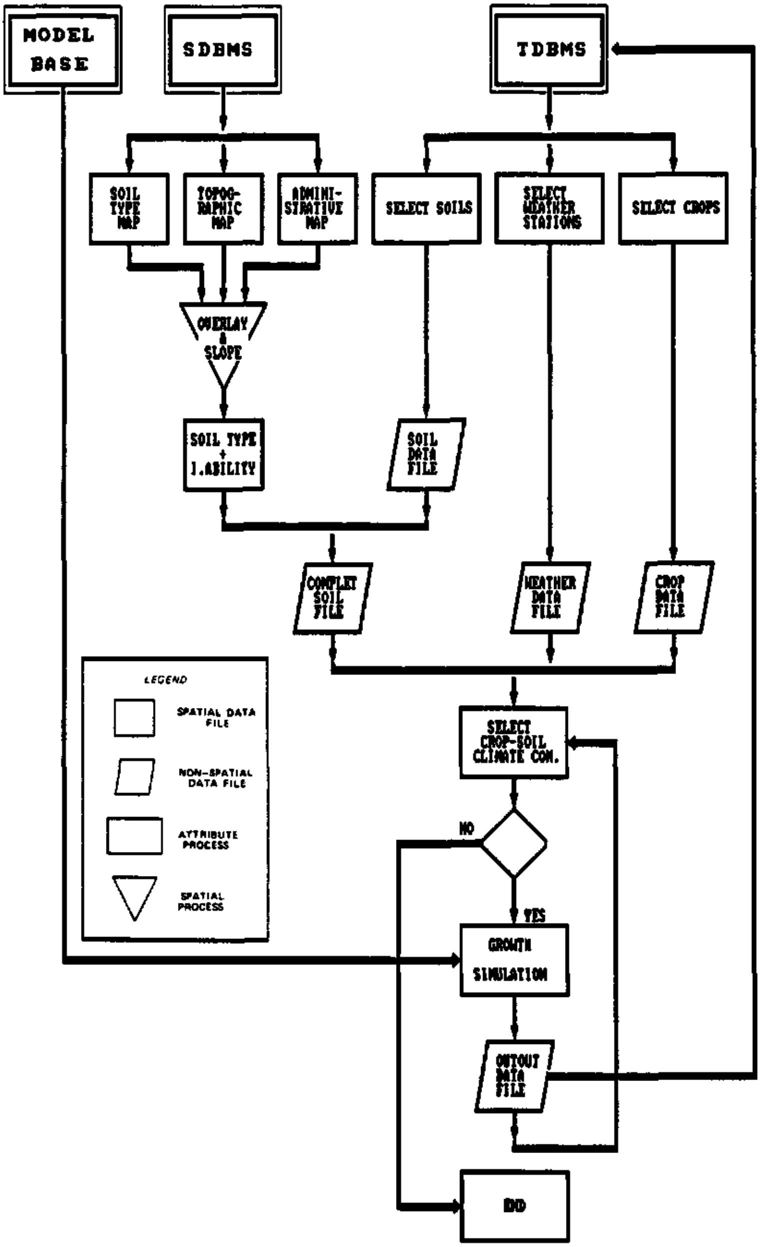


Figure 31. Flow chart of the biophysical land evaluation model

*Process model for biophysical land evaluation*

The biophysical land evaluation process is shown schematically in figure 31. All functions and processes applied in biophysical land evaluation (defined in subsection 5.2.4.1) are integrated in one program called "crop growth simulation", which requires three input files, i.e., weather, soil and crop data.

These files are prepared using the DBMS by selecting the prospective crops, the weather station, type and duration of weather data and the soil types from their respective databases. A program then prepares and exports the relevant data (crop, weather and soil) into three separate data files. If daily weather data are used, the file may include weather data of many years, from which the daily data are available. If climatic data are selected, the daily weather data will be generated in the crop simulation program. The daily rainfalls are generated using a special random generator routine, and the remainder of the weather data are derived by linear interpolation.

To differentiate land suitable for irrigated crops, using the SDBMS capabilities and on the basis of an irrigability criterion, a slope class map is generated and overlaid with to soil type map to identify the irrigable land. An irrigability code (1 for irrigable and 0 for non-irrigable) is then added to the soil data file. The crop growth simulation program reads the data and automatically runs the crop growth simulation for all selected crop-climate-soil combinations, and generates an output file containing the biophysical productivities of the land, with estimates of the water and macronutrient requirements for each combination (crop-soil-climate). Subsequently, the simulation results for each crop-soil combination in the output data file are averaged over the years for which the weather data are selected and used (Van Keulen, 1988). The final result is transfered to the relevant table in the DBMS and used for queries and further processing.

*Process model for tactical planning*

Tactical planning, which uses a linear programming (LP) algorithm, basically follows the same principles as the biophysical land evaluation. The LP model, which is stored in the model base, takes an input data file (tact.dat) and produces an output data file containing the tactical plan (tact.res). The input file can be prepared with the help of the DBMS, and the output can be exported to the relevant tables in the DBMS.

*Process model for operational planning*

Operational planning benefits mainly from the capabilities of the SPDBMS. In the course of this activity, a crop is assigned to each parcel on the basis of the biophysical suitability of the parcel, the conveyance loss in the irrigation canal, the transportation costs, the crop rotation and the demand for the crop (which is set by the tactical plan). The process is interactive and iterative. In each iteration, one crop is allocated to the most suitable parcels. Therefore, prior to starting the process, the order of crops for allocation should be selected on the basis of their relative importance to the enterprise.

To combine different objectives into a single decision criterion, the relative importance of different objectives, i.e., the biophysical suitability, conveyance loss and transportation costs in the allocation process are assessed by policy makers and input to the process. As discussed in subsection 5.2.3.1.3, allocation can be based on the canal network as a conduit or the road network; the procedure is the same for both. In the following, the procedure using the road network is explained. This process is illustrated in figure 32.

When starting the process, the planner selects the first crop to be allocated. Then the biophysical suitabilities of different soil types for the selected crop are read from the CSCTAB (this was estimated during the biophysical land evaluation process) and used to modify the suitability index and irrigation water requirements of each soil type in the respective file. Next the biophysical suitability and irrigation water requirement of each parcel are derived by overlaying the soil type and administrative maps of the region, and calculating the weighted averages of suitability indices and the irrigation water requirements of different soil types in each parcel.

The conveyance losses in different types of irrigation canal, estimated using experimental or default values, are used to assign a loss figure to each segment of the irrigation canal (canal link). Using the network capabilities of the SPDBMS, the optimum route between source of water supply and each field inlet is selected and its corresponding conveyance loss is calculated (accumulated number of all losses of all the canal links from source to sink, in liters per second). This figure is only depends on the structure of the irrigation network, and therefore remains constant for all crops unless the structure of canal links is changed. Using the total irrigation water requirement of the crop in each parcel and the loss of water per second at the field inlet, together with the flow rate in the canals, the conveyance losses per hectare of crop are estimated. This is a soil, crop and area specific characteristics, implying different conveyance losses for parcels with the same soil and the same loss at field inlet with different sizes (area).

Subsequently, the biophysical suitability index and the conveyance loss of each parcel are combined into a single index. Since the suitability index is a measure of the gross margin of the crop in the parcel, the combined index can be derived using different techniques, e.g., by subtracting the monetary value of the conveyance losses from the suitability index, or by assigning a priority weights to each variable, and combining the weighted value of the result into a single criterion (Shakya, 1990; Brauewer, 1986). The latter was found more appropriate for present study. The combined index can be derived by applying any priority weight expressing the relative importance of water in the region.

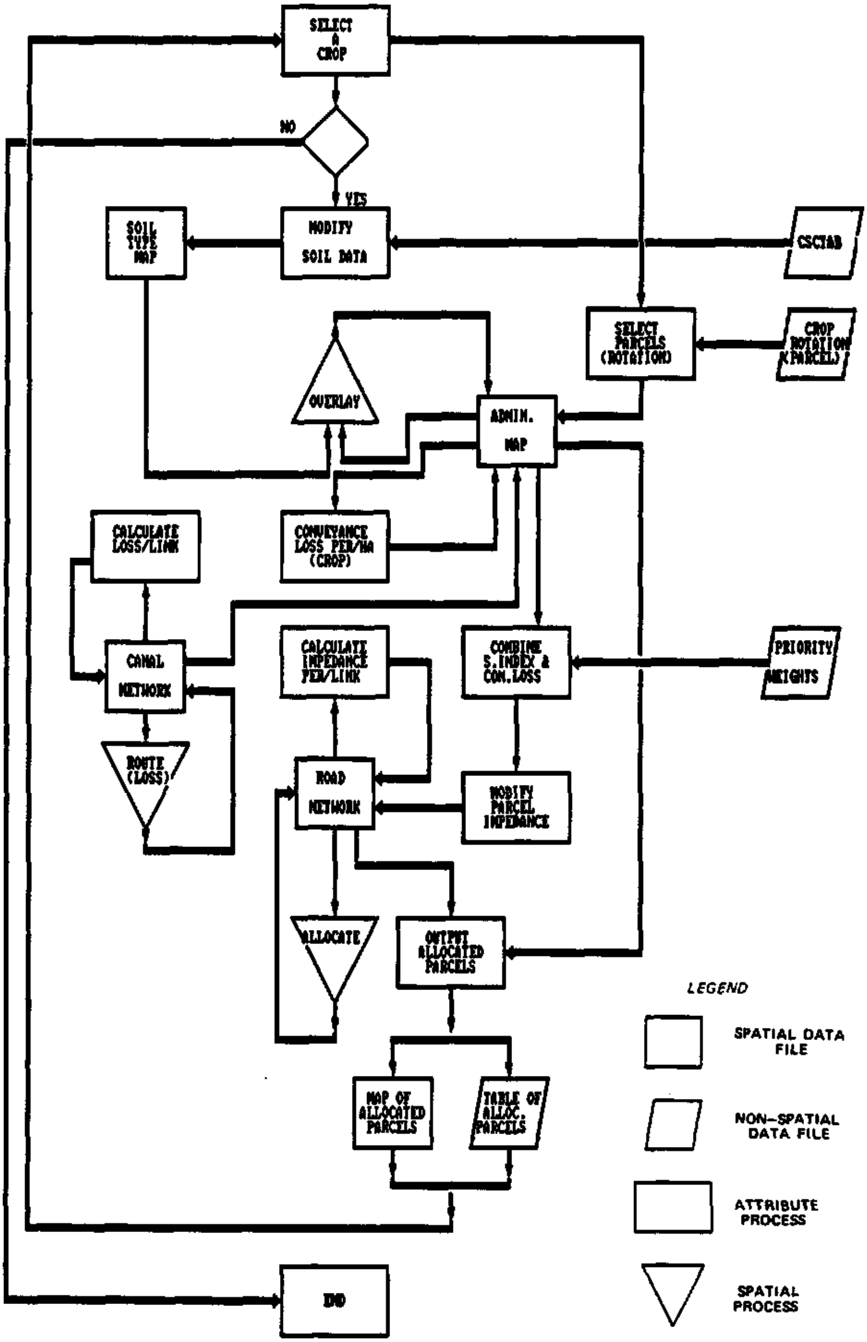


Figure 32. Flow chart of the operational planning model

Road impedance is calculated for each link in the road network based on the costs associated with transporting each unit of yield along that link. The costs can be defined in terms of actual monetary value, time or any other relevant unit. Using the parcel code as a key, the relationship is established between the road and administration data files, and through that relationship the combined indices of the parcels are transferred into the road attribute data file. The combined suitability index is then transformed into an allocation index (parcel impedance) according to equation 14 (subsection 5.2.3.1.3). This index, which is proportional to the inverse of suitability, is weighted in such a way that it expresses the relative importance of the combined index with respect to the road impedance.

By analyzing the parcel history file that contains the cropping sequence of all parcels over the years, all parcels that on the basis of the crop rotation rules can be used for the cultivation of the target crop in the current year are selected and flagged in the road data file to be used in the allocation process. Finally the road data file (coverage) is used in the allocation routine to allocate the suitable parcels to the selected crop. The allocation process is based on minimizing the total costs (impedance) of flow through the road network. It is an interactive process in which the planner selects the delivery points (location of the store or processing unit) for each crop and introduces its capacity and the program performs the actual allocation. The total capacity for each crop is derived on the basis of its demand (the area that should be allocated to each crop based on tactical plan) and its average yield per ha. Subsequently, on the basis of the total capacity, the capacity of each each store is determined and used in the allocation process. The allocated parcels are flagged in the relevant data file and can be used to generate any type of map or table output. The allocation proceeds in the same way until all parcels and crops are allocated and the actual land use plan is generated.

***Process model for supportive planning***

When the actual land use plan has been assessed, it can be used in combination with the relevant data files containing the crop operation calendar, yield estimates on different bases, material requirements, etc, to derive supportive plans such as a detailed operational plan, a logistic plan for the production process, and estimates of total crop production of various crops for transportation, storage and marketing. This process is shown schematically in figure 33.

#### 6.1.2.2 Process model for the monitoring and evaluation sub-system

Standards of yield performance in the given planning period and environmental conditions for each crop-parcel combination are established using the crop growth simulation model, or experimental data such as for instance the average production in the region, section, farm or parcel during the past years. The first uses basically the

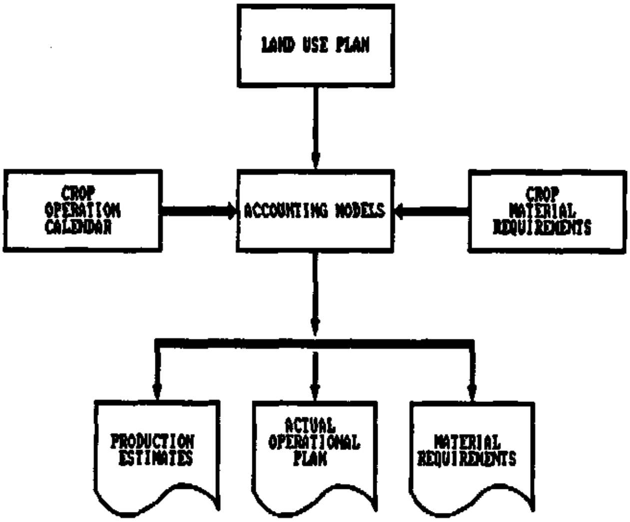


Figure 33. Schematic presentation of supportive planning

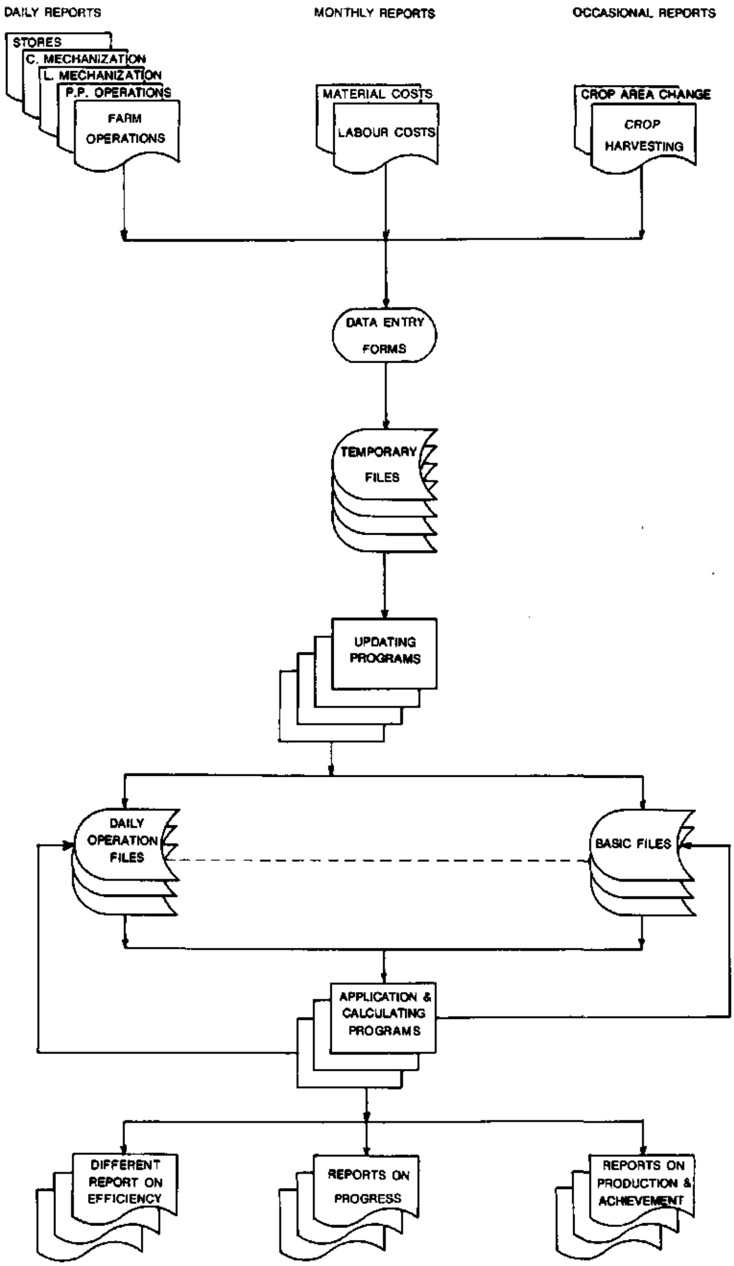


**Figure 34. General view of data flow in monitoring and evaluation sub-system**

same simulation program as the biophysical land evaluation process, but uses only the weather data of the planning period and corrected for management efficiency. In the second method, average values are calculated from the parcel history file using standard database operations.

Other processing functions in monitoring and evaluation consist mainly of transaction processing, report processing, inquiry processing and analyses of possible decisions or courses of action. This includes developing, updating and accessing series of databases and application of a series of simple models (defined in 5.2.2.3 and 5.2.4.6) to produce summary, comparative and other types of required reports as defined in subsection 5.1.2. Since these are standard procedures in information system development using a relational data models, they are not discussed here. To demonstrate the concept, only the data flow of the sub-system is discussed briefly only .

The monitoring and evaluation sub-system is designed in such a way that, at system initialization, different types of data on the current situation of all activities and resources in each management unit are collected and stored in the system. Subsequently, very simple information about changes in the situation are reported every day to the system. The system assumes that the manager of each operational unit is aware of the major activities and events in his unit, so that he can easily complete the data collection forms. A schematized presentation of the flow of information in the monitoring and evaluation sub-system is given in figure 34.

The monitoring and evaluation sub-system is composed of reporting, control, monitoring and evaluation processes. The relationships among these processes are shown schematically in figure 35. These processes are designed mainly on the basis of the attribute data model and defined processing functions (5.2.3.2 and 5.2.4.6) using standard DBMS capabilities. A detailed descriptions of all required processes are given in the ARIS documentation.

### 6.1.3 Data processing model

The data processing model is the link between the data model and the process model: it checks the completeness and consistency of the dynamic (process model) and static (data model) parts of the information system. This is normally developed by preparing an entity life history (ELH) and the transaction matrix (Benyon, 1990). The ELH and the transaction matrix are given in the ARIS documentation. The ELH of only one entity, "parcels", is given in figure 36 for illustration.

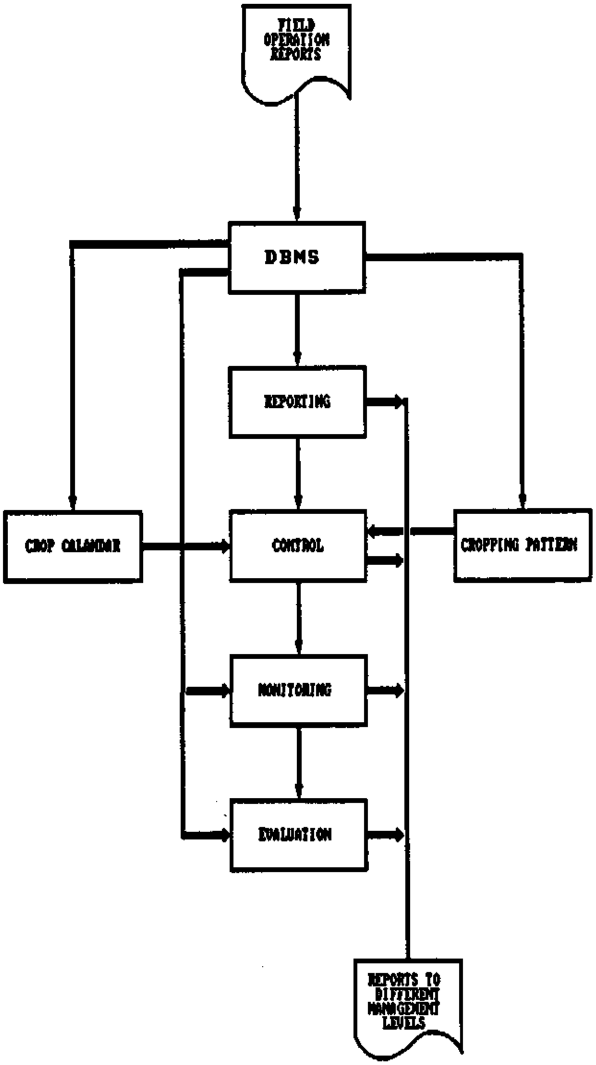


**Figure 35. Flow of information between different processes in the monitoring and evaluation sub-system**

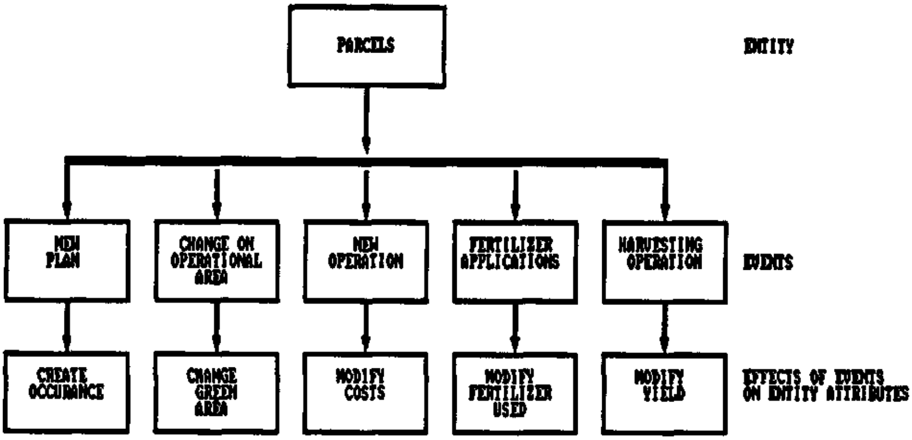


**Figure 36.** **Entity life history diagram (ELH) of "Parcels"**

## 6.2 Equipment adaptation and realization of a prototype system

Equipment adaptation includes determination of the specific hardware and software configurations on which the system should run, and adaptation of the equipment-independent data system model to the selected configuration (Lundeberg et al., 1978). This concluded the analysis and design phase of the information system, which results in a number of different models of the future information systems. Subsequent phase (realization) included building, testing and documenting information system according to the specification formulated in the design phase (information model).

### 6.2.1 Equipment adaptation

Equipment adaptation consisted of selecting the required hardware/software configuration, adapting the data system design to this configuration and developing the physical design of the data system. ARIS, according to its definition (among other things; section 3.4), should be appropriate in terms of hardware, software, relative ease of operation and maintenance requirements and follow-up procedures. It should work in a farm environment in developing countries, and thus must be easily usable, attainable and maintainable. Microcomputers based on the Intel 8086, 8088, 80286, and 80386 (or later) family of microprocessor chips running on MS.DOS 2.11 or a later operating system (IBM PC or compatible) are now available with appropriate servicing facilities throughout the world. Hence, such a configuration has been selected as the basis for system development and implementation. Of the existing commercial PC-based relational DBMS, "Data Ease" (DataEase, 1986) software was selected because of its ease of operation and maintenance and system development. For handling the spatial data, a PC version of a vector-based system with a topologic data structure and network functions was required. Of the existing SPDBMS, the Arc/Info (PC Arc/Info, 1989) was selected because of its functional capabilities and software availability.

The linear programming (LP) model developed for the tactical planning process normally includes a large set of linear equations, whose structure may change as a function of location and time. The required PC-based LP software needed to be capable of handling a large system with a high-level programming language to facilitate modelling and modifying this type of mathematical programming problem. For this purpose, the MicroLP Modeller and Optimizer of Scicon Limited (Scicon, 1989) was selected. Finally, for program development of all processing functions used in the biophysical land evaluation process, Fortran-77 compiler of the Ryan McFarland (RM/Fortran, 1986) was used.

On the basis of this configuration, the equipment independent data system was adapted and the physical design of the system was developed.

### 6.2.2 Realization of a prototype system

Realization of the information system included program development, file establishment, design of the manual components and instructions, system test and documentation. ARIS consists of three supporting sub-systems: the spatial, attribute and model bases; and two functional sub-systems: land use planning and monitoring and evaluation. The spatial and attribute databases comprise the data models of the relevant processes in the functional sub-systems, and the model base is the place where all required special applications software is stored. In fact, the two functional sub-systems include the supportive one. Thus realization of the functional sub-systems and their integration into one system implies realization of the entire system. As an illustration, realization of the two functional sub-systems is briefly discussed.

#### 6.2.2.1 Land use planning sub-system

The land use planning sub-system consists of the biophysical land evaluation, and tactical, operational and supportive planning processes. In the realization phase, each models was developed separately, and subsequently integrated into the system. Realization and integration of each model included the following:

- Development of the relevant processes, i.e., program development for each process, program testing, integration of all processes into the model, and testing the model for consistency.
- Organization of input and output data, i.e., creating databases, providing facilities to add, modify and update the databases, and also the capability to select and prepare the required input data sets for execution of the model. Organization of output data also consisted of providing facilities to import the output of the model into the DBMS and other relevant software for graphic and spatial representation of the result.
- Documentation of the process, which includes preparing the relevant manuals describing implementation, operation and maintenance of the model.

***Biophysical land evaluation model***

According to the design specification, this model consists of crop growth simulation and irrigation and the crop nutrient modules, which are integrated in a biophysical land evaluation model.

The crop growth simulation and irrigation module was developed on the basis of the computerized summary crop growth simulation model developed by Van Kraalingen and Van Keulen (1988). This model was developed on the basis of existing theory and combining the essential elements of WOFOST (Van Dippen et al., 1987) and WHEAT (Van Keulen and Seligman, 1987) into a single modular model that allows quantification of attainable yield under optimum and The model is a general crop growth simulation model in which plant-subroutines for different crops could be incorporated. This model was originally developed to simulate growth of sorghum and millet.

To generate the proper environment for crop growth, the model makes use of average monthly weather data with actual rainfall, or actual daily weather data. It allows for a soil profile of up to ten (10) compartments, which may comprise up to three soil types. Each soil type is characterized by a function that relates PF (logarithm of soil moisture tension in cm) values to volumetric water content of the soil.

The model consists of two major parts: the MAIN program and the subroutine PLANT. The MAIN program generates the environment, and plant simulates crop growth in that environment by calculating the growth rate of its various components. To take into account crop-specific characteristics, for each crop a separate PLANT subroutine is required to be linked to the MAIN program.

To meet the requirements of ARIS, the following modifications were made to the original model:

- A generally applicable PLANT subroutine has been developed, that for each crop, requires crop- and/or cultivar-specific information from a crop data base, to simulate potential and water limited production. This also facilitates calibration of the model and makes it more "user-friendly".
- Since in many cases actual daily rainfall data are not available, a subroutine has been introduced that generates a daily rainfall pattern on the basis of the given total monthly rainfall and the given number of rainy days, according to a gamma distribution as proposed by Geng et al., (1986).
- Introduction of the influence of a ground-water table to allow quantification of capillary rise in the water balance.
- Introduction of the option for irrigation application and calculation of the irrigation requirements at monthly intervals.
- Introduction of procedures to calculate the phenological development rates before and after anthesis, based on exogenously supplied emergence, flowering and maturity dates of a crop or cultivar.
- Introduction of the option to include the contribution of a pod area and stem area to total green area index for the relevant crops.
- Introduction of the possibility to calculate the maximum weight of leaves and stems in the course of crop growth cycle and the actual weight of yield.
- Introduction of possibility to use weather data relating to two successive calandar years, because all crops emerging in autumn complete their growth cycle in the subsequent calendar year.
- Since rainfall of less than 10 mm per/d is considered not effective for crops, rainfall

is considered, only if its total over two conscutive days exceeds 10 mm.

The crop nutrient module was based on the program developed by Noij, (1988) following the QUEFTS concept (Janssen et al., 1990). The program estimates the fertilizer requirements for realization of potential production on the basis of estimated concentrations of the macronutrients in economic product and crop residues at harvest, and the supply of nutrients from natural sources. On the basis of calibration results, the relevant concentrations of P and K were set at the average between the maximum (max) and minimum (min), and that for N at (min + (max-min)*3/4).

Subsequently, the crop growth simulation and irrigation module, and the crop nutrient modules were modified for integration in the biophysical land evaluation model, and finally interfaced with the DBMS to allow the following functions:

- Organizing the input/output data using the DBMS facility
- Menu-driven operations
- Selection of prospective crop/ soil/ weather data for a given station in a specific period of time from the menu.
- Running the program for all specified crop-soil-weather combinations, and estimating the production potential, monthly irrigation water requirements and macro-nutrient requirements to attain the full production potential.
- Export the output of the program to graphics software to graphically present the results of the crop simulation.

### *Tactical planning model*

A linear programming model consists of an objective function and a list of constraints and a set of linear relations between decision variables. The model can be expressed in an algebraic formulation in which the coefficients and variables are represented by symbolic names. To solve a particular problem, numerical values have to be supplied for the coefficients. However, the mathematical formulation together with the data alone are not sufficient for the optimization program; they must be converted into an LP matrix before being presented to the optimizing software.

According to Williams (1990), the main hurdle in the successful application of a mathematical programming model often lies with the interface between the user and the computer, not in computing the solution. Some of the difficulties can be avoided by freeing the modeller from the specific requirements of the package used to formulate the model. One of the possibilities is the use of high-level programming languages which facilitate the formulation of and input of data into the model.

In developing the tactical planning model, The MicroLp Modeller and Optimizer software developed by Scicon Limited (1989) was used. Modeller, which is an ultrahigh-level language, was used to define the problem, facilitate data input, and produce output reports. At this stage of ARIS, this model is not fully integrated into the DBMS, and input to the model is prepared according to the Modeller format. However, DBMS can be applied to change data, run the program or examine results.

### *Operational planning model*

The Arc/Info geographic information system was used to handle spatial data in realizing the operational planning model. Arc/info includes a network module that provides the capability to model the flow of resources through a network. It can determine optimal paths for the movement of resources through a network "Route" (shortest-route model), and the distribution of resources to and from centres through a network (Allocate). Here network is defined as a system of connected linear features (links) that form a framework through which resources flow,(ESRI, 1989).

In Arc/Info, allocation is a process of assigning links in the network to the closest centre. As links are assigned to a centre, a portion of that centre's resources are distributed to meet each link's demand. The allocation continues until the maximum impedance limit is reached along all paths allocated to the centre, or until the centre's resource capacity is met by the cumulative demand from all links allocated to the centre.

To include biophysical suitability, an artificial link connecting any point inside each parcel to its nearest access road was added to the road network. This link carries all attributes of the parcel, such as parcel code, parcel area, biophysical suitability index for each crop, and its irrigation water requirements.

Since the designed system is only a prototype, no attempt was made to integrate Arc (which is an SDBMS) with DataEase (which is a DBMS); instead, the Info relational DBMS was used to handle the attribute files related to the spatial data, and communication between the two software packages (Info and DataEase) was established using their import-export facilities.

### *Supportive planning model*

All supportive plans were derived using a series of accounting models in relation to the land use plan, crop material requirements, crop operational requirements and related databases containing the basic spatial and attribute data. These use the special query languages of the selected spatial and attribute database management systems (SPDBMS and DBMS).

### 6.2.2.2 Monitoring and evaluation sub-systems

Monitoring and evaluation is primarily a "data processing system" which handles transactions and produces reports. It represents the automation of monitoring and evaluation processes to support management. It mainly includes transaction processing, report processing, inquiry processing and simple analysis capability. All of these capabilities were developed using the DataEase-query language, basically included the following:

- Building the attribute data model.
- Producing the data entry forms and programs for updating the data files, using on-line entry with a subsequent batch processing to allow direct validation of data.
- Developing the data entry procedure.
- Producing query programs for the processing functions (section 5.2) and to produce the required reports.
- Organizing all queries and input forms in a menu-driven system which is user-friendly and easy to operate and maintain.
- Documenting the system and providing the relevant manuals for operation and maintenance.

A detailed descriptions of all these activities is given in the ARIS system documentation. The evaluation process is also includes crop growth simulation process, which is used for setting up the standards for meauring the performances.

### 6.2.2.3 Integration of the land use planning and monitoring and evaluation sub-systems

The land use planning sub-system and the monitoring and evaluation sub-system are actually two different systems which, according to the design specifications, are integrated to improve the functionality, applicability and performance of the system as a whole. Just as they complement each other in the management functions, they also do so in information system development. The output of the planning sub-system is the essential input to the monitoring and evaluation sub-system, which in turn provides essential data for the planning sub-system. Moreover, implementation of monitoring and evaluation improves the quality of data used by the planning sub-system and vice versa.

The two sub-systems were integrated by building one data model for all attribute data and one for the spatial data, using their respective database management systems. The attribute database was subsequently interfaced with the application software through the DBMS. Since most transactions and processes use attribute data, the DBMS is used to supervise the operation and establish proper links between different components of the system. Thus all system operations--including input, updating and preparing data, processing functions, producing outputs of different formats and utility and maintenance operations of the system--are organized in a user-friendly menu structure.

# CHAPTER 7

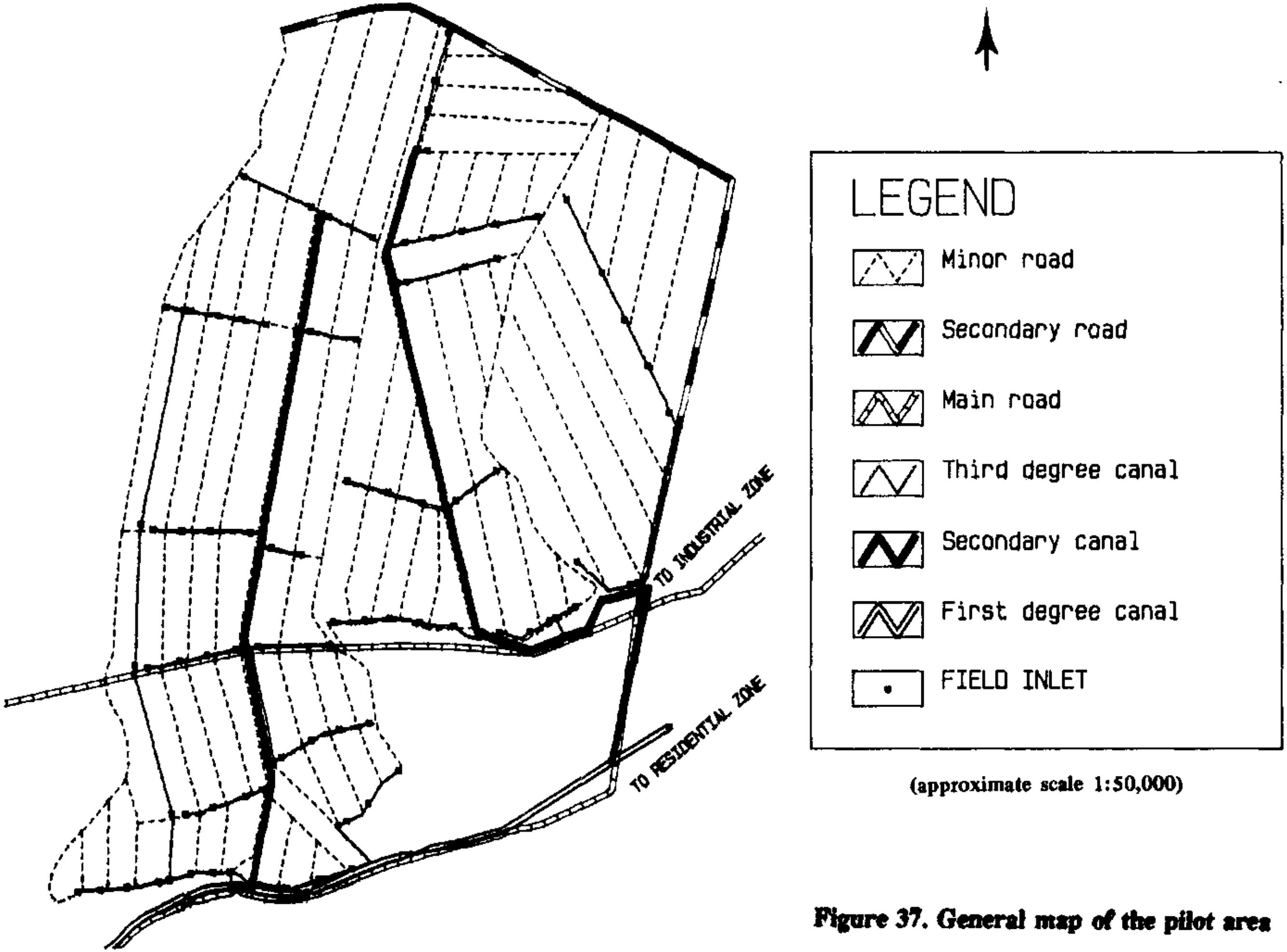
## EXPERIMENTATION WITH THE PROTOTYPE SYSTEM

As described in the preceding chapters, using special information system development procedures, an appropriate resource information system to support land use planning, monitoring and evaluation activities of an arable farming enterprise (MAIC) was designed, and its initial prototype was realized (ARIS). According to the prototyping approach (Jenkin, 1983), the next step is to apply the prototype system to refine the user requirements and revise and improve the system. This would require complete implementation of the prototype system in the MAIC environment, and was not feasible in the framework of this study. However, a prototype of the monitoring and evaluation sub-system was implemented and is already in operation at MAIC.

ARIS has a powerful process model and includes many complex mathematical models to simulate various aspects of the agricultural production system. Simulation, as defined by Naylor et al. (1966), is a technique "that involves setting up a model of a real situation (system), and then performing experiments on the model". Hence, simulation is necessarily a two-phase operation involving model development and experimentation. The models need calibration, validation and evaluation before being used for experimentation.

Monitoring and evaluation sub-systems, other than the crop growth simulation model, include straight-forward and simple processes, and do not require calibration and validation. However, the land use planning sub-system, comprising models of very complex processes of a dynamic system, does need calibration and validation. Experimentation with the system was therefore concentrated on the land use planning sub-system.

This experimentation focused on evaluation of the output and behaviour of the various parts of the land use planning sub-system and covered the planning procedure for a unit of the MAIC enterprise (Section 3), comprising an area of more than 2000 hectares of arable and irrigable land (figure 37). In the course of this work, the biophysical land evaluation model was calibrated and validated, using experimental data, for the major crops cultivated in the section and used for a biophysical land evaluation of the area. These results, together with the relevant socio-economic data of the enterprise, were then incorporated in the tactical planning model to produce alternative land use plans (different scenarios). One of the alternatives was then selected and used to derive the actual operational plan, and subsequently all supportive plans for the basic plan were generated.



(approximate scale 1:50,000)

Figure 37. General map of the pilot area

## 7.1 Biophysical land evaluation

Experimentation with the biophysical land evaluation model comprised:

- data collection and preparation
- calibration and validation
- actual experimentation

### 7.1.1 Data collection

The biophysical land evaluation process requires three types of data, namely weather, soil and crop. These data were collected according to the data specification given in section 5.3.

*Weather data*

According to the Koppen classification, the pilot area (Dashte-Moghan) is in a semi-arid temperate zone, similar to the Mediterranean climate: warm to hot summers, high levels of radiation, and a concentration of modest rainfall in the winter months (MAIC, master plan). The climate differs from Mediterranean because it has a more even distribution of rainfall, including high humidities and significant precipitation in the summer months resulting from the easterly winds off the Caspian Sea. The nearest meteorologic station to the pilot area is "Parsabad synoptic weather station" approximately 15 km distant. This station was established in 1961 and is located at 39, 39 east longitude and 47, 54 north latitude at an elevation of 44 meters above sea level. The average monthly climatic data of this station for the period of 1967-1986 were used to characterize long-term weather conditions and the daily data of 1987-1990 for calibration/validation of the crop growth simulation model.

Examination of the average monthly rainfall data of this station in the period of 1967-1986 showed strong variations in monthly and total annual rainfall from year to year. In this period, average yearly rainfall was 299.1 mm, and the lowest and highest values were 72.9 mm in 1970 and 523 mm in 1982, respectvely. Comparison of the monthly average rainfall with any of the actual monthly values indicated that none of the actual values in 20 years was close to the average values. Figure 38 shows the variability in monthly rainfall of the first four months of the year in the 1967-86 period. These variations illustrate the error introduced by using average monthly data for crop growth simulation or any other type of yield estimate.

Another important aspect is the distribution of rainfall over a month (Jamee, 1990b). Table 7 shows the distribution of the average monthly rainfall. Experience indicates that

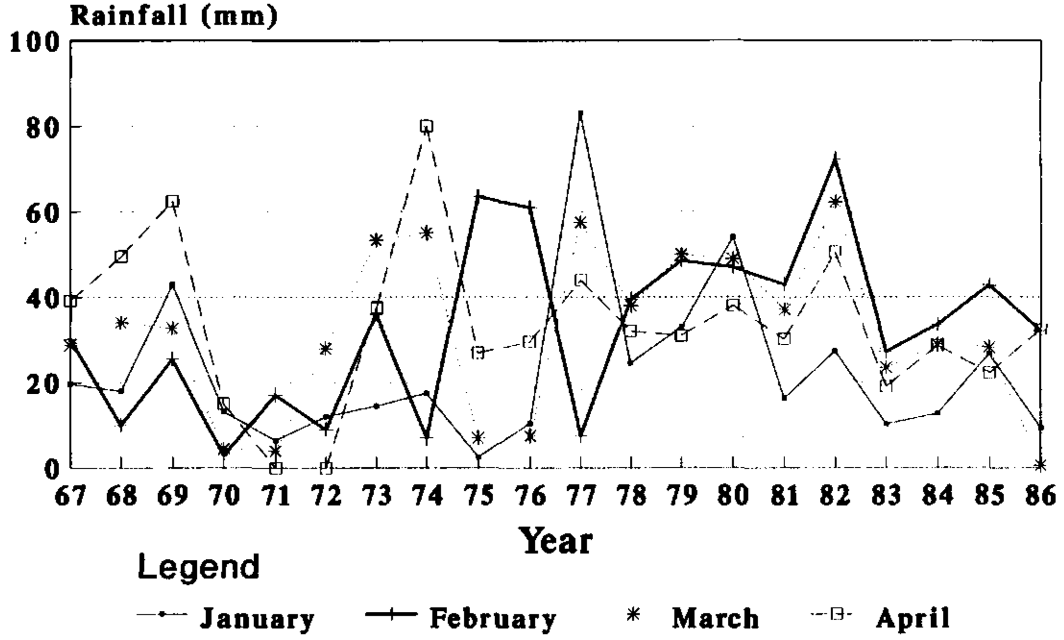


Figure 38. Distribution of the average monthly rainfall of the first four months of the year at MAIC during 1967-86

the daily rainfalls are effective if their amounts exceed 10 mm; otherwise their effect is minimal. Analysis of the rainfall distribution showed that in the pilot area a considerable proportion of rain falls in showers of less than 10 mm, and for this reason the crop growth simulation program was modified to take the rainfall into account only if its total in one (or two consecutive) day(s) is equal to or exceeds 10 mm.

Daily total global radiation at the surface of the earth is not recorded at Parsabad meteorologic station. It was estimated using the empirical relation (Angstrom formula) between radiation and measured duration of bright sunshine (Black et al., 1954):

$$Ri = RA\ (aA + bA*n/N) \tag{32}$$

where:

Ri = actual total global radiation (J/m2/d).

RA = the maximum radiation reaching the earth's surface in the absence of an atmosphere (Angot's value, J/m2/d).

n/N = the ratio of actual duration of bright sunshine (n) and the maximum possible duration (N) which is derived as a function of latitude and day of the year (Van Keulen and Wolf, 1986).

aA and bA = empirical constants, defined as a function of climate type (Frere and Popov, 1979).

| Month | Rainfall (mm) | | Max rainfall in 24 hour | Number of rainy days <1mm | Number of rainy days <10mm | Number of rainy days |
|---|---|---|---|---|---|---|
| | Total | Effective | | | | |
| jan | 22.8 | 14.8 | 22.3 | 4 | 0.9 | 5 |
| feb | 32.8 | 13.1 | 22.0 | 5 | 0.8 | 6 |
| mar | 31.5 | 17.1 | 61.5 | 6 | 0.6 | 7 |
| apr | 32.9 | 21.3 | 50.0 | 6 | 0.8 | 7 |
| may | 39.4 | 25.8 | 54.5 | 6 | 1.4 | 7 |
| jun | 26.9 | 22.7 | 39.0 | 4 | 0.8 | 5 |
| jul | 5.5 | 10.2 | 16.0 | 1 | 0.7 | 2 |
| aug | 5.8 | 7.1 | 27.0 | 1 | 0.7 | 2 |
| sep | 14.0 | 10.7 | 35.0 | 3 | 0.9 | 4 |
| oct | 30.8 | 19.3 | 26.0 | 5 | 0.9 | 6 |
| nov | 35.7 | 18.8 | 34.0 | 5 | 0.6 | 6 |
| dec | 21.0 | 14.6 | 18.0 | 4 | 0.4 | 5 |
| year | 299.1 | 195.5 | 61.5 | 50.0 | 9.4 | 62.0 |

**Table 7. Average monthly rainfall in Parsabad Station (1967-1986) (Absu, 1988; Jamee, 1990)**

Water vapour pressure, which also has not been recorded at the station, was derived using an empirical relation (Goudriaan, 1977):

$$Es = 6.11 \; ( e ** (17.4\ Ts/(Ts+239)))*\ R \qquad (33)$$

where:

Es = saturated vapour pressure (mbar)

Ts = surface temperature (C)

R = the relative humidity (fraction)

Relations 32 and 33 were incorporated in the data entry procedure of the system.

Daily meteorologic data for the period October 1988- October 1989 (used for growth simulation) were checked for completeness. Missing data were estimated by calculating the average values of the relevant characteristic from the remaining days of the month for which data were available. No quality assessment was carried out, simply because no other independent data were available.

The average monthly climatic data of Parsabad meterological station for the period of 1961-1981 (20 years) were compiled from various sources (Yekom, 1983; Sanati, 1987; Absu, 1989b; Jamee, 1990a; Jamee, 1990b) and entered into the system for further processing.

*Soil data*

The soils of the area have been studied in semi-detailed and detailed surveys, and are well documented in various reports. The project area has been surveyed in the following sequence:

- Semi-detailed soil survey and land classification of Moghan irrigation project by Dewan (1958).
- Detailed soil survey and land classification of Moghan irrigation project by Fammouri (1959-60).
- Detailed soil survey and land classification of the land under Canal A, by Yekom (1983).

During the last detailed soil survey of the project area (1983), approximately 72 profiles comprising 362 soil samples from some 72 profile pits and 658 samples from approximately 220 auger holes were collected and analyzed. On the basis of the previous surveys and the analysis results, the soils were classified in series. Figure 39 shows the different soil series together with the locations of all profiles and auger holes in the pilot area. Since each soil series is assumed to be homogeneous in terms of physiography, chemical and physical properties, a representative profile was selected for each one. A sample soil analytical report of one soil profile is given in the ARIS system documentation.

Land classification of the project area was based on combining the soil series properties with the other limiting factors such as topography, erosion susceptibility, drainage, flooding hazard, etc., according to the Iranian land classification system (ISI). Since land class is assumed to be homogeneous in terms of all physical and chemical properties and limiting factors, they were considered as land units for estimating the production potential of each prospective crop. The required quantitative values of the soil physical and chemical properties were derived from the soil analytical data for each representative profile.

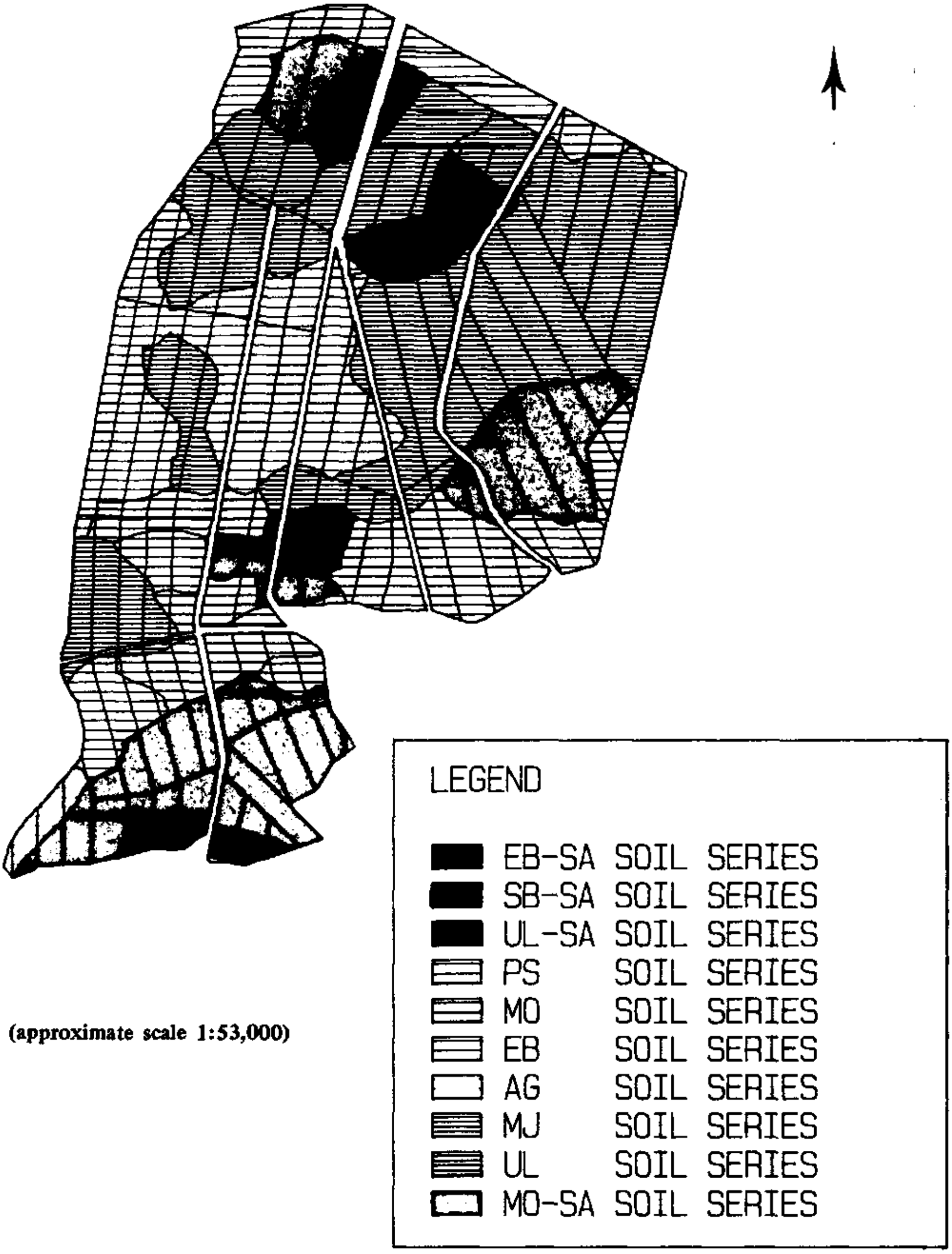
To differentiate between irrigable and non-irrigable land, using GIS capabilities and considering the topography of the land and the irrigability standards, an irrigability code was derived and assigned to each soil type. In the pilot area, all existing land are irrigable.

The soil moisture characteristics (Pf curve) of the different soil series of the pilot area were not available. They have been derived from available soil moisture characteristics for soils of temperate regions on the basis of soil texture (Wosten et al., 1987).

### *Crop data*

Specific information on physiologic, phenologic and chemical properties of the crop cultivars common in the pilot area was limited. However, sets of quantitative data on plant characteristics for different crop species and cultivars were collected by Van Diepen et al. (1988), Van Heemst (1988), Nijhof (1987), Groot (1987), Spitters et al. (1989) and Penning de Vries et al. (1989). From these sources, default values for the relevant crop characteristics of many crops (including those cultivated in the enterprise) were extracted and entered into the system.

All crop species and cultivars grown in the pilot area are of the spring type (i.e., having no vernalization requirements), of which wheat and barley are usually planted in autumn (Ultan, 1978). The exact phenological characteristics of wheat (cultivar Moghan-1) were extracted from reports (unpublished data at Ultan research station) covering the growing period of 1987-88, as listed in table 8.



(approximate scale 1:53,000)

Figure 39. Soil map of the pilot area

| Phenological date | Date | Julian Date |
|---|---|---|
| Planting date | 28:11:87 | 332 |
| Emergence date | 04:12:87 | 338 |
| Greening | 14:12:87 | 348 |
| Three leaves | 04:02:88 | 35 |
| Booting | 12:02:88 | 43 |
| Stemming | 19:03:88 | 78 |
| Heading | 28:04:88 | 118 |
| Flowering | 10:05:88 | 136 |
| Milky | 16:05:88 | 138 |
| Maturity (start) | 07:06:88 | 158 |
| Maturity (100%) | 18:06:88 | 169 |

**Table 8 Phenological development of Moghan-1 wheat cultivar in the growing period (1987-1988). Recorded in Ultan research station**

The growth of sugarbeet has been studied in the 1989 growing period in the Iranian Institute for Breeding. Data were recorded during periodic harvests in the course of the growing period on fresh weight of petioles, leaf blades, heads and beets, leaf area, dry-matter content, and the N, P, and K concentrations in the different organs. The experiments included different treatments with different planting dates on different soil types. A summary of part of the field observations is given in table 9.

To judge the overall performance of the biophysical land evaluation model, the maximum reported yields of different crops werecollected (table 10). The recommended seed rates and fertilizer applications and the amounts actually applied by successful farmers are listed in table 11. The recommended crop calendars of the major crops in the region are given in table 12.

| Phenological dates (Julian) | Weights of leaves (kg/ha) | Weights of beets (kg/ha) | Total Weights (DMT kg/ha) |
|---|---|---|---|
| 145 | -- | 1,000 | -- |
| 169 | 3,075 | 5,100 | 9,190 |
| 178 | 6,000 | 6,200 | 11,370 |
| 189 | 5,700 | 11,400 | 16,250 |
| 199 | 8,850 | 9,800 | 14,950 |
| 210 | 5,550 | 11,200 | 16,380 |
| 221 | 3,900 | 11,400 | 15,530 |
| 233 | 2,400 | 10,600 | 13,630 |
| 240 | 1,875 | 12,400 | 14,880 |
| 252 | 1,800 | 13,000 | 13,530 |
| 265 | 1,500 | 13,400 | 14,240 |

**Table 9. Experimental data on sugarbeet growth, MAIC, 1989 growing period. The crop was cultivated at 25th March 1989 in parcel 164-01 Section 4 of MAIC. The fresh weight of leaves and beets have been converted to dry matter, assuming 85 and 80 percent water in leaves and beets respectively (Kulivand, 1987).**

### 7.1.2 Calibration and validation

Models originating from exact sciences are in general based on detailed knowledge of the theory of the underlying processes, whose mathematical descriptions are exact. Such models usually do not require experimental verification to prove their validity. However, in ecology we are dealing with dynamic systems that are not man-made and in many areas our understanding of their basic principles is still rudimentary; hence proof is necessary that the behaviour of the models is in agreement with reality ( Van Keulen, 1976). Before sufficient confidence is placed in predictive results, the model should prove that it can satisfactorily explain existing historical data by comparing the results with those of the real system ( Rabbinge and De Wit, 1985). Evaluation of the performance of the models of agricultural production systems is thus an important part of the simulation.

| Crop | Farmer or MAIC (kg/ha) | Average of successful farmer * | Research station (kg/ha) | Achievable maximum * | Average simulation results | |
|---|---|---|---|---|---|---|
| | | | | | (1) | (2) |
| Wheat_ir | 7928 | 4632 | 6307 | 7000 | 8251 | 5215 |
| Wheat_dr | 2937 | 2937 | 3534+ | 3000 | 7318 | 3337 |
| Barley_ir | 7303 | 4000 | 5500 | 6000 | 6286 | 3668 |
| Barley_dr | 2416** | 2000 | 3390+ | 3000 | 5116 | 2550 |
| Maize | 12049 | 6043 | 13566 | 11000 | 12338 | 8735 |
| Sugar-beet | 80000 | 64800 | – | 54000 | 70800 | 45746 |

**Table 10. Maximum reported yield of different crops at the pilot region. In the table * designates figures that are derived from a survey of farmers production costs, techniques, and achievements in the pilot region. The survey was conducted by Jamee consulting company in 1987-88 (Jamee 1990). ** refers to the average yields at 1987-88 growing period, and + refers to the yield at 1987-1988; (1), refers to the average simulation results with management coefficient equal 1, and (2) refers to the yield with management coefficient equal to 0.7.**

| Crop | Recommended seed rate kg/ha | Recommended fertilizer kg/ha | | Fertilizer used by farmer kg/ha | | Average simulation results * (kg/ha) | |
|---|---|---|---|---|---|---|---|
| | | N | P | N | P | N | P |
| Wheat-irrigated | 150 | 150 | 250 | 125 | 312 | 248 | 193 |
| Wheat-dry farming | 140 | 120 | 110 | - | 80 | 118 | 104 |
| Barley-irrigated | 130 | 150 | 100 | 100 | 200 | 122 | 103 |
| Barley-dry farming | 120 | 100 | 100 | - | 80 | 58 | 56 |
| Maize | 26 | 400 | 350 | - | - | 486 | 350 |
| Sugarbeet | 14 | 300 | 350 | 300 | 600 | 557 | 395 |

**Table 11. Seed rate and fertilizer application of different crops within the pilot region. * refers to the results of the average simulation with management efficiency of 0.7). These figure are extracted mainly from Jamee, 1990a and Jamee, 1990b.**

| **Crop** | **Planting date** | **Harvesting date** |
|---|---|---|
| Wheat-irrigated | 25 Oct - 5 Dec | 15 Jun - 5 Jul |
| Wheat dry farming | Around 5 Nov | 15 Jun - 5 Jul |
| Barley irrigated | 25 Oct - 5 Dec | 5 Jun - 20 Jun |
| Barley dry farming | Around 5 Nov | 5 Jun - 20 Jun |
| Maize | 20 Mar - 20 Apr | 20 Aug - 20 Sep |
| Sugarbeet | 20 Feb - 4 Apr | 20 Sep - 20 Nov |

**Table 12. Recommended crop calendar for the major crops growing in the region**
***(data are extracted from different reports of consulting firms and Ultan research station)***

Evaluation of model performance consists of calibration, verification and validation. Calibration refers to selection of partially or unknown parameters or relations, so as to reach the best overall agreement between simulated and observed results (Van Keulen, 1976). Verification is concerned with establishing whether a model is a true or correct representation of reality (absolute truth), whereas validation is the assessment of usefulness and effectiveness of a model for specific purposes (Dent and Anderson, 1971).

As Dent and Blackie (1979) pointed out, model evaluation is a long-term process in which confidence in the model is enhanced (or reduced) through a succession of formal and informal tests. However, comparisons of simulated results with experimental data may reveal logical errors in the program (Jones and Kiniery, 1986).

The biophysical land evaluation model was evaluted with respect to its purpose, which is to estimate the biophysical production potential of land when used for different crop production systems at various levels of inputs in the pilot area (predictive applications).

***Model calibration***
For each prospective crop in the pilot area, the plant data were adapted in a calibration procedure through the following modifications (Van Diepen et al., 1988):

- Pre-anthesis and post-anthesis development rates calculated from the actual emergence, flowering and maturity dates of each prospective crop. Phenologic parameters of the model (pre-anthesis and post-anthesis development rates) for wheat, barley and sugarbeet were calculated using the actual daily weather data of the growing period in 1987-1988 and the related experimental phenologic data (tables 8,

9 and 12). The same parameters for maize were derived on the basis of the usual planting and maturing dates and the required temperature sum for silking, and the actual daily weather data of 1987-1988.
- Adjustment of the life span of the leaves.
- Use of the actual recommended and used seed rate for each prospective crop in the pilot area (table 11).
- Selection of the proper parameters, such as dry matter partitioning coefficients, specific leaf area, initial light use efficiency, on the basis of local information on crop performance from the pilot area (such as harvesting indices and phenologic data).

The calibrated plant data for the major crops in the pilot region are given in the ARIS documentation.

*Model verification*

The performance of the model was verified by comparison of its results with existing experimental field data. Where available, simulated and actual growth curves (i.e., the dynamics of above- ground dry matter accumulation) for the crop were compared; alternatively the general pattern of production as characterized by actual yield level, harvest index and the input requirements as simulated, and from actual practise were compared.

For sugarbeet, for which detailed data were available, the experimental and simulated growth curves for two different planting dates are shown in figures 40 and 41. From the graphs, it may be deduced that the simulated results are in reasonable agreement with the experimental results. Total dry matter and weight of the beets at final harvest are very close, and the growth of various organs in the course of the growing period show the same trend.

For other crops, i.e., wheat (irrigated and rainfed), barley (irrigated and rainfed), and maize, the simulated and experimental yields match quite well (comparison of the data in tables 10 and 11). The simulated yields with management coefficient eqal to one, are in most cases higher, which is understandable because the simulation assumes good management. The simulated fertilizer requirements are higher than those actually applied, because they were derived for the higher yield levels. Thus it may be concluded that performance of the simulation model and its results in terms of yields and input requirements are acceptable, especially for planning and evaluation purposes.

Determination of crop irrigation water requirements is one of the basic and most important parameters in the management of an irrigated farming scheme. This has of course received considerable attention in MAIC, and much work and investment has been devoted to it. In the last five years, three different studies have concentrated part of their efforts on determining crop irrigation water requirements. In each of the three studies, the Pan evaporation method (FAO, 1977) was used for estimating potential evapotranspiration and crop water requirements, but due to the application of different

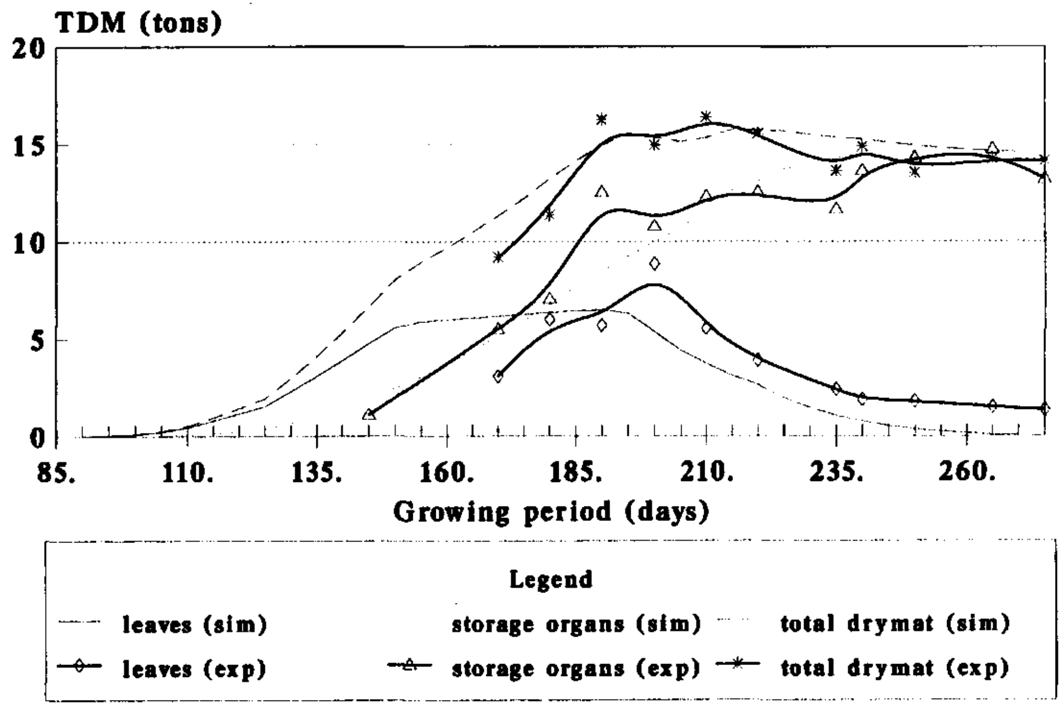


**Figure 40.** Comparisons of simulation results with experimental data (MAIC, growing period 1989, planting date 85)

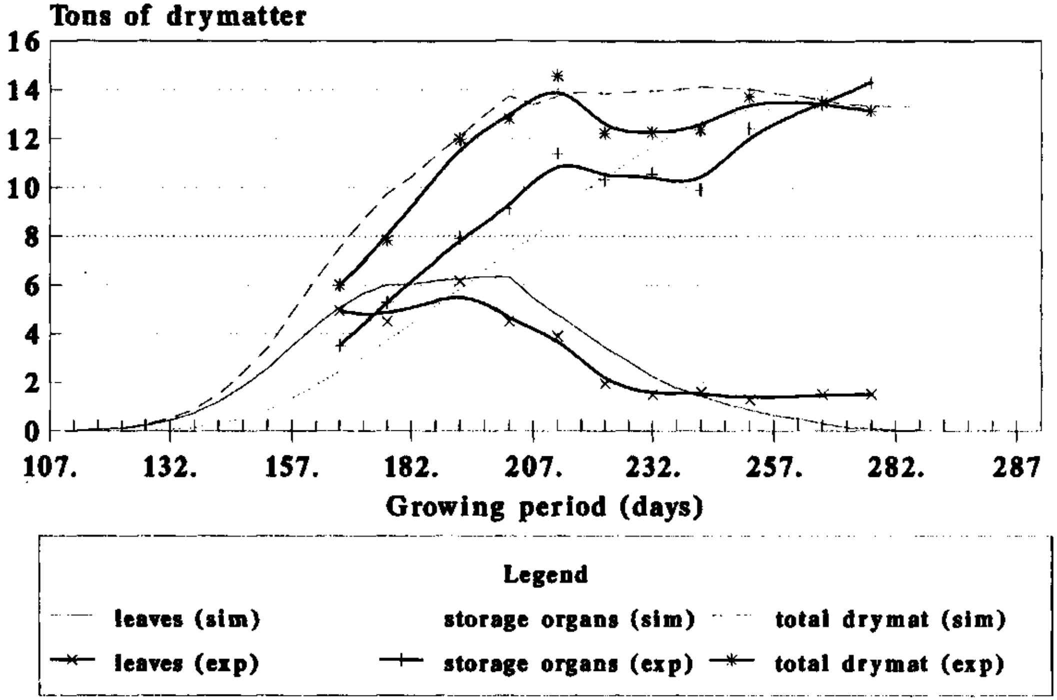


**Figure 41.** Comparisons of simulation results with experimental data (MAIC, growing period 1989, planting date 107)

Kc factors, as illustrated in table 13, they yielded widely different results. The method does not take into account the water holding capacity of the soil, which is a very important characteristic in determining crop irrigation water requirements.

| **Source** | **Wheat** | **Barley** | **Maize** | **Sugarbeet** |
|---|---|---|---|---|
| Absu, 1989a | 404 | 404 | 696 | 825 |
| Absu, 1988b | 346 | 346 | 646 | 778 |
| Jamee, 1990a | 345 | 325 | 659 | 808 |
| MAIC, 1990 | 250 | 230 | 476 | 584 |
| Simulation (1-year)* | 180 | 181 | 316 | 327 |
| Simulation (20-year)** | 194 | 172 | 397 | 441 |

**Table 13. Net total crop water requirements (mm) according to different sources. *, represents the results of simulation with the actual weather data (1988-1989), and ** represents the average of 20 simulations with the climatic data.**

The simulated numbers presented in table 13 were derived by calculating the average crop water requirements in different soils using first the actual daily weather data for the growing period 1988-89, and then the average monthly climatic data and running the 20 simulations for each crop. The figures are based on simulation of the daily water balance in the soil profile, subdivided into various layers (up to 10). Crop water requirements appear to be strongly influenced by soil physical properties. For example, as shown in table 15, for sugar beet it varies from 432 mm in soil series MJ (silty clay) to 689 mm in soil series EB-SA (silty clay loam). Since the applied method takes into account the water holding characteristics of the soil, it is expected to be more reliable than the others. However, results at this stage should be considered with caution, as the physical properties of the soils in the pilot area have not been measured, and had to be estimated on the basis of analogy (subsection 7.1.1).

### 7.1.3 Experimentation

The major applications of the biophysical land evaluation model in ARIS are (1) setting standards for the production performance of each crop in each parcel, and (2) characterizing the biophysical suitability of the land in the land use planning process. The first application is straight-forward; each year, at the end of the season, the simulation model can run using recorded meteorologic data to determine the production potential of the various soil types. This is transformed into a parcel production potential using an overlay process in a GIS.

The second application, i.e., estimating the biophysical land suitability for various crops, requires multiple runs of the model using long-term historical weather data. The weather data can be supplied in different forms: the first choice is actual daily historical data, an alternative is the historical monthly weather data with actual daily rainfall, and finally average climatic data with long-term average rainfall. If historical daily or monthly weather data are available, they should be used to derive production estimates for individual years first, from which an average is calculated (De Wit and Van Keulen, 1987) to be further processed for derivation of the biophysical suitability index of each land unit. If only climatic data are available, the model should be run as many as 20 times, applying a random generator for rainfall distribution, and the average production is then used for deriving the biophysical suitability index.

For the pilot area, unfortunately, daily historical data were available for only a very few years, and average monthly data were also limited. Monthly climatic data were therefore used for experimentation. To create a simulation environment that resembled as much as possible the real system, the following assumptions were made:

- Irrigation was applied when 50% of the available water in the root zone had been used.
- Irrigation was applied only up to a predetermined development stage (crop-specific).
- Field application efficiency of irrigation was assumed 0.6 (Yekom, 1985).
- There was free drainage, no contribution from capillary rise and no run-off (full infiltration of the rain).
- The initial water content in each soil layer was set at half the available water holding capacity.
- Emergence data for each crop were derived from the recommended planting data in the region.
- Initial total dry matter was derived from the recommended seed rate.
- Initial rooting depth was derived from the recommended planting depth.
- In the absence of pertinent information on the absolute and relative efficiency of crop husbandry for different crops within the enterprise, the "management efficiency" for all crops was set at 0.7. In the simulation model, this efficiency factor was applied to reduce the growth rate of various organs relative to their potential under optimal management. These coefficients were constant throughout the crop's life cycle.

The overall results of the simulation model for various crop-soil combinations, with the actual daily weather data (1988-1989) and management coefficent of one, are given in table 5.

These results, before or after correction for management efficiency, can be used for evaluation purposes.

For the biophysical land evaluation, average monthly climatic data (1961-1981) with management efficiency of 0.7 were used. Daily weather characteristics were obtained by linear interpolation of the respective average monthly data, except for rainfall which is distributed over the month using a special random generator (Rappoldt, 1988). The biophysical potentials of each crop-soil combination and their respective input requirements were obtained as the average of 20 simulation runs with different rainfall distribution patterns. The biophysical suitability indices of all crop-soil combinations were subsequently calculated by subtracting the costs of the inputs from the respective gross margins (tables 14 and 15). These results were further processed in the course of tactical and operational planning processes.

## 7.2 Tactical planning

Tactical planning uses a linear programming model to simulate the economic aspects of the farming systems. The model, which is explicitly normative or prescriptive, contains the major input- output relationships and the existing constraints of the farming systems. It simulates the economic behaviour of the system to derive the optimum cropping pattern, defined here as the pattern that maximizes the total profit of the system (profit maximization subject to the defined constraints). Before such a model is used for experimentation, it should be verified in relation to reality and validated in relation to its purpose. This includes data collection, verification, validation and experimentation, as explained below.

### 7.2.1 Data collection

For verification, validation and application of the tactical planning model, a quantitative description of all possible cropping systems in the enterprise is required. Such a description specifies the production of a system as a function of the degree of exploitation of limited resources, including human, natural and the external inputs (Veeneklaas et al., 1991).

On the basis of the exsiting cropping pattern of the pilot area, five main cropping systems were distinguished: wheat, barley, maize, sugar beet and alfalfa. Each crop--when cultivated on a different type of soil, fertilized or non-fertilized, irrigated or rainfed, first year cultivation or follow-up cultivation--forms a distinct cropping system and was treated separately. Quantification of the main physical inputs, i.e., water and macro-nutrient fertilizers, and estimates of the expected yields of wheat, barley, maize and sugar beet in different soil types and under different levels of management were derived from the biophysical land evaluation model (table 15). Growth simulation of alfalfa requires a different treatment because it is a perennial crop, and models for perennials are less well-developed. Thus empirical data were used for alfafa. Tactical planning could also be developed using the empirical data for all yield expectations and crop requirements; in fact, if such data are available, the generated plan will be more realistic (if ARIS is implemented all these data are provided in the course of operation).

Based on soil survey data (subsection 7.1.1), 10 soil series were distinguished, for each of which the area and the potential for irrigation (irrigability) was determined through GIS operations (table 16). According to the soil data, all soil series in the pilot area are irrigable.

According to the MAIC master plan, the most important constraints to farming in MAIC are related to the area that can be irrigated adequately during the peak water-consumption period (May and June). The cropping pattern is therefore designed so that only 64 % of the cultivatable area is under full irrigation during the peak months of the year. On that basis the water delivery system is designed to deliver 1.413 liters per second per hectare to 64 % of the arable land during the peak months. These design parameters were used to derive the water constraints for the peak months of the year (April to August).

| CROP NAME | POTENTIAL YIELD KG/HA | NUTRIENT LIMITED YIELD | SOIL NAME (TYPE) | TOTAL IRRIGATION & NUTRIENT REQUIREMENTS | | | |
|---|---|---|---|---|---|---|---|
| | | | | WATER (cm) | N | P | K |
| Barley-dr | 3,000. | 2,741. | C:\ARIS\SOIL\mo-sa | 0.0 | 46. | 78. | 0. |
| | 2,863. | 1,300. | C:\ARIS\SOIL\ag | 0.0 | 150. | 81. | 0. |
| | 2,851. | 2,535. | C:\ARIS\SOIL\mj | 0.0 | 93. | 59. | 0. |
| | 2,807. | 1,777. | C:\ARIS\SOIL\ps | 0.0 | 82. | 91. | 0. |
| | 2,716. | 2,716. | C:\ARIS\SOIL\EB-SA | 0.0 | 0. | 21. | 0. |
| | 2,436. | 2,358. | C:\ARIS\SOIL\ul | 0.0 | 0. | 57. | 0. |
| | 2,279. | 2,013. | C:\ARIS\SOIL\mo | 0.0 | 76. | 51. | 0. |
| | 2,032. | 1,911. | C:\ARIS\SOIL\eb | 0.0 | 60. | 6. | 0. |
| | 1,967. | 1,527. | C:\ARIS\SOIL\sb-sa | 0.0 | 18. | 60. | 0. |
| Barley-ir | 3,906. | 1,512. | C:\ARIS\SOIL\sb-sa | 20.4 | 141. | 143. | 0. |
| | 3,824. | 2,455. | C:\ARIS\SOIL\mo | 28.9 | 173. | 116. | 0. |
| | 3,732. | 2,816. | C:\ARIS\SOIL\ul | 27.8 | 55. | 111. | 0. |
| | 3,700. | 2,668. | C:\ARIS\SOIL\eb | 24.3 | 164. | 76. | 0. |
| | 3,693. | 3,533. | C:\ARIS\SOIL\EB-SA | 36.6 | 0. | 62. | 0. |
| | 3,681. | 1,310. | C:\ARIS\SOIL\ag | 24.5 | 200. | 114. | 0. |
| | 3,628. | 2,856. | C:\ARIS\SOIL\mo-sa | 47.1 | 85. | 104. | 0. |
| | 3,624. | 3,097. | C:\ARIS\SOIL\mj | 32.4 | 140. | 91. | 0. |
| | 3,576. | 1,793. | C:\ARIS\SOIL\ps | 31.0 | 128. | 122. | 0. |
| | 3,321. | 2,477. | C:\ARIS\SOIL\ul-sa | 27.4 | 139. | 93. | 0. |
| Maize | 9,599. | 2,072. | C:\ARIS\SOIL\ul-sa | 58.3 | 567. | 384. | 0. |
| | 9,554. | 2,641. | C:\ARIS\SOIL\mj | 54.1 | 549. | 369. | 0. |
| | 9,512. | 1,273. | C:\ARIS\SOIL\sb-sa | 50.4 | 529. | 400. | 0. |
| | 9,345. | 2,062. | C:\ARIS\SOIL\mo | 51.4 | 554. | 375. | 0. |
| | 9,055. | 2,231. | C:\ARIS\SOIL\eb | 48.3 | 539. | 335. | 0. |
| | 8,942. | 1,484. | C:\ARIS\SOIL\ps | 56.9 | 509. | 377. | 0. |
| | 8,915. | 2,364. | C:\ARIS\SOIL\ul | 58.6 | 428. | 356. | 119. |
| | 8,226. | 1,059. | C:\ARIS\SOIL\ag | 55.6 | 530. | 342. | 0. |
| | 7,424. | 2,290. | C:\ARIS\SOIL\mo-sa | 54.2 | 393. | 310. | 0. |
| | 6,779. | 3,329. | C:\ARIS\SOIL\EB-SA | 39.5 | 263. | 249. | 166. |
| Sugarbeet | 46,267. | 10,800. | C:\ARIS\SOIL\mo | 57.8 | 608. | 406. | 0. |
| | 46,259. | 12,495. | C:\ARIS\SOIL\ul | 58.5 | 491. | 405. | 12. |
| | 46,170. | 5,857. | C:\ARIS\SOIL\ag | 55.5 | 645. | 410. | 0. |
| | 46,138. | 6,677. | C:\ARIS\SOIL\sb-sa | 51.0 | 566. | 428. | 0. |
| | 46,046. | 11,983. | C:\ARIS\SOIL\eb | 53.2 | 604. | 367. | 0. |
| | 45,931. | 7,870. | C:\ARIS\SOIL\ps | 57.2 | 573. | 419. | 0. |
| | 45,756. | 21,309. | C:\ARIS\SOIL\EB-SA | 68.9 | 406. | 351. | 77. |
| | 45,490. | 10,790. | C:\ARIS\SOIL\ul-sa | 46.1 | 597. | 399. | 0. |
| | 45,191. | 12,555. | C:\ARIS\SOIL\mo-sa | 54.1 | 516. | 394. | 0. |
| | 44,217. | 13,918. | C:\ARIS\SOIL\mj | 43.2 | 562. | 372. | 0. |
| Wheat-dr | 4,242. | 2,794. | C:\ARIS\SOIL\mo-sa | 0.0 | 144. | 150. | 0. |
| | 3,956. | 3,019. | C:\ARIS\SOIL\mj | 0.0 | 186. | 123. | 0. |
| | 3,832. | 1,732. | C:\ARIS\SOIL\ps | 0.0 | 170. | 154. | 0. |
| | 3,771. | 1,245. | C:\ARIS\SOIL\ag | 0.0 | 236. | 139. | 0. |
| | 3,659. | 3,348. | C:\ARIS\SOIL\EB-SA | 0.0 | 0. | 76. | 0. |
| | 3,375. | 2,684. | C:\ARIS\SOIL\ul | 0.0 | 45. | 112. | 0. |
| | 3,036. | 2,373. | C:\ARIS\SOIL\mo | 0.0 | 141. | 96. | 0. |
| | 2,760. | 2,450. | C:\ARIS\SOIL\eb | 0.0 | 120. | 45. | 0. |
| | 2,651. | 1,497. | C:\ARIS\SOIL\sb-sa | 0.0 | 72. | 101. | 0. |
| | 2,084. | 1,870. | C:\ARIS\SOIL\ul-sa | 0.0 | 68. | 46. | 0. |
| Wheat-ir | 5,462. | 2,381. | C:\ARIS\SOIL\mo | 29.0 | 312. | 212. | 0. |
| | 5,459. | 1,477. | C:\ARIS\SOIL\sb-sa | 20.4 | 273. | 237. | 0. |
| | 5,403. | 2,719. | C:\ARIS\SOIL\ul | 27.7 | 186. | 208. | 0. |
| | 5,397. | 2,588. | C:\ARIS\SOIL\eb | 24.4 | 305. | 171. | 0. |
| | 5,364. | 4,072. | C:\ARIS\SOIL\EB-SA | 36.6 | 103. | 154. | 31. |
| | 5,268. | 1,273. | C:\ARIS\SOIL\ag | 24.5 | 335. | 206. | 0. |
| | 5,232. | 2,816. | C:\ARIS\SOIL\mo-sa | 46.8 | 211. | 195. | 0. |
| | 5,230. | 3,056. | C:\ARIS\SOIL\mj | 32.5 | 271. | 180. | 0. |
| | 5,097. | 2,423. | C:\ARIS\SOIL\ul-sa | 27.5 | 279. | 190. | 0. |
| | 4,234. | 1,716. | C:\ARIS\SOIL\ps | 25.5 | 201. | 176. | 0. |

**Table 14. Biophysical suitability assessement according to potential yields (climatic data and management coefficient 0.7)**

| CROP NAME | SUITABILITY INDEX | POTENTIAL YIELD (KG/HA) | TOTAL IRRIGATION REQUIREMENTS | SOIL TYPE |
|---|---|---|---|---|
| Barley-dr | 284. | 3,000. | 0.0 | C:\ARIS\SOIL\mo-sa |
| | 270. | 2,863. | 0.0 | C:\ARIS\SOIL\ag |
| | 269. | 2,851. | 0.0 | C:\ARIS\SOIL\mj |
| | 265. | 2,807. | 0.0 | C:\ARIS\SOIL\ps |
| | 258. | 2,716. | 0.0 | C:\ARIS\SOIL\EB-SA |
| | 231. | 2,436. | 0.0 | C:\ARIS\SOIL\ul |
| | 215. | 2,279. | 0.0 | C:\ARIS\SOIL\mo |
| | 192. | 2,032. | 0.0 | C:\ARIS\SOIL\eb |
| | 186. | 1,967. | 0.0 | C:\ARIS\SOIL\sb-sa |
| Barley-ir | 366. | 3,906. | 20.4 | C:\ARIS\SOIL\sb-sa |
| | 357. | 3,824. | 28.9 | C:\ARIS\SOIL\mo |
| | 350. | 3,732. | 27.8 | C:\ARIS\SOIL\ul |
| | 347. | 3,700. | 24.3 | C:\ARIS\SOIL\eb |
| | 346. | 3,693. | 36.6 | C:\ARIS\SOIL\EB-SA |
| | 344. | 3,681. | 24.5 | C:\ARIS\SOIL\ag |
| | 339. | 3,624. | 32.4 | C:\ARIS\SOIL\mj |
| | 338. | 3,628. | 47.1 | C:\ARIS\SOIL\mo-sa |
| | 334. | 3,576. | 31.0 | C:\ARIS\SOIL\ps |
| | 310. | 3,321. | 27.4 | C:\ARIS\SOIL\ul-sa |
| Maize | 1,136. | 9,599. | 58.3 | C:\ARIS\SOIL\ul-sa |
| | 1,131. | 9,554. | 54.1 | C:\ARIS\SOIL\mj |
| | 1,126. | 9,512. | 50.4 | C:\ARIS\SOIL\sb-sa |
| | 1,106. | 9,345. | 51.4 | C:\ARIS\SOIL\mo |
| | 1,072. | 9,055. | 46.3 | C:\ARIS\SOIL\eb |
| | 1,058. | 8,942. | 56.9 | C:\ARIS\SOIL\ps |
| | 1,054. | 8,915. | 58.6 | C:\ARIS\SOIL\ul |
| | 972. | 8,226. | 55.6 | C:\ARIS\SOIL\ag |
| | 878. | 7,424. | 34.2 | C:\ARIS\SOIL\mo-sa |
| | 802. | 6,779. | 39.5 | C:\ARIS\SOIL\EB-SA |
| Sugarbeet | 1,164. | 46,259. | 58.5 | C:\ARIS\SOIL\ul |
| | 1,163. | 46,267. | 57.8 | C:\ARIS\SOIL\mo |
| | 1,161. | 46,138. | 51.0 | C:\ARIS\SOIL\sb-sa |
| | 1,160. | 46,170. | 55.5 | C:\ARIS\SOIL\ag |
| | 1,158. | 46,046. | 53.2 | C:\ARIS\SOIL\eb |
| | 1,155. | 45,931. | 57.2 | C:\ARIS\SOIL\ps |
| | 1,151. | 45,756. | 68.9 | C:\ARIS\SOIL\EB-SA |
| | 1,145. | 45,490. | 46.1 | C:\ARIS\SOIL\ul-sa |
| | 1,137. | 45,191. | 54.1 | C:\ARIS\SOIL\mo-sa |
| | 1,113. | 44,217. | 43.2 | C:\ARIS\SOIL\mj |
| Wheat-dr | 421. | 4,242. | 0.0 | C:\ARIS\SOIL\mo-sa |
| | 392. | 3,956. | 0.0 | C:\ARIS\SOIL\mj |
| | 380. | 3,832. | 0.0 | C:\ARIS\SOIL\ps |
| | 373. | 3,771. | 0.0 | C:\ARIS\SOIL\ag |
| | 365. | 3,659. | 0.0 | C:\ARIS\SOIL\EB-SA |
| | 336. | 3,375. | 0.0 | C:\ARIS\SOIL\ul |
| | 301. | 3,036. | 0.0 | C:\ARIS\SOIL\mo |
| | 274. | 2,760. | 0.0 | C:\ARIS\SOIL\eb |
| | 263. | 2,651. | 0.0 | C:\ARIS\SOIL\sb-sa |
| | 207. | 2,084. | 0.0 | C:\ARIS\SOIL\ul-sa |
| Wheat-ir | 538. | 5,462. | 29.0 | C:\ARIS\SOIL\mo |
| | 538. | 5,459. | 20.4 | C:\ARIS\SOIL\sb-sa |
| | 533. | 5,403. | 27.7 | C:\ARIS\SOIL\ul |
| | 532. | 5,397. | 24.4 | C:\ARIS\SOIL\eb |
| | 530. | 5,364. | 36.6 | C:\ARIS\SOIL\EB-SA |
| | 519. | 5,268. | 24.5 | C:\ARIS\SOIL\ag |
| | 515. | 5,230. | 32.5 | C:\ARIS\SOIL\mj |
| | 514. | 5,232. | 46.8 | C:\ARIS\SOIL\mo-sa |
| | 502. | 5,097. | 27.5 | C:\ARIS\SOIL\ul-sa |
| | 419. | 4,234. | 25.5 | C:\ARIS\SOIL\ps |

**Table 15. Biophysical suitability assessment according to suitability indices, using climatic data and assuming management coefficient 0.7**

| Soil series name | Area (ha) |
|---|---:|
| UL | 69.77 |
| EB | 613.72 |
| MJ | 690.57 |
| AG | 20.98 |
| MO | 98.13 |
| PS | 54.93 |
| SB-SA | 32.37 |
| MO-SA | 379.68 |
| UL-SA | 101.41 |
| EB-SA | 29.36 |
| Total | 2090.92 |

**Table 16. Area of different soil series in the pilot area**

For arable farming in MAIC, different cropping patterns have been suggested by various consulting engineers (e.g., MAIC Master Plan, Absu 1988a; Absu, 1989b), and various cropping patterns are used by the MAIC planning bureau. For the purpose of this experimentation, the cropping pattern planned for MAIC in the period of 1989-1994 (Absu, 1989b) was used as a general guideline (table 17).

| Crop name | Percentages |
|---|---:|
| Wheat | 21.74 |
| Barley | 21.74 |
| Maize | 21.74 |
| Sugarbeet | 21.74 |
| Alfalfa | 8.70 |
| Fallow | 4.34 |
| Total | 100 |

**Table 17 Selected cropping pattern in MAIC**

Data on the crop operation calendar and the variable costs of the various production systems were derived from the farming system analysis of private farmers in the region (Jamee, 1990a and 1990b). On the basis of the crop operation calendar and available norms of operation in the region (standard time to properly execute an operation), the labour requirements for all required operations for cultivation of each crop (such as irrigation, weeding, harvesting and land preparation), together with their requirements for agricultural machinery, were derived. The planning model can accommodate different classes of labour and various types of agricultural machinery. In the present study, however, only one single class of labour was distinguished, and with respect to agricultural equipment only tractor and combine requirements in the critical months of the year were taken into account. For modelling purposes the variable costs exclude the costs of those inputs which are not drawn from the relevant right-hand side or not debited through a purchasing system (Beneke, 1973). In other words, the variable costs comprise those costs of the production system that are not otherwise accounted for in the model, i.e., all costs except labour and fertilizer costs. All costs are expressed in units of 10,000 rials, the Iranian currency (1 rial = +/- US$ 0.015).

### 7.2.2 Validation

Before relying on the planning procedure and the results of the linear programming model, the validity of these results should be carefuly examined to determine if the answers are sensible. The first approach is to examine the optimal solution critically, simply using common sense. If that is satisfactory, the optimal solution should be compared with what might be expected in real practice, to examine the degree of restrictiveness of the model (Williams, 1990).

According to Beneke (1973), a complete interpretation of a farm plan developed through linear programming requires investigation of stability of the plan. Stability is tested by determining the effect of changes in a single coefficient while all the other coefficients are kept constant. According to Hazel and Norton (1986), stability of the solution refers to the degree of variation in a coefficient that can be absorbed by the model without a change in the basis, i.e., before a change in the basis occurs. A change in a basis occurs when a new activity enters the solution, or one previously in the solution is no longer selected. The lower and higher values of the coefficient at which the change in basis occurs are critical turning points, and a difference between them is referred to as the range of the coefficient. Stability therefore depends on the magnitude of the range for each coefficient, assuming the others are fixed.

Following this reasoning, the sensitivity and stability of the optimization model were tested and the results of several runs (different scenarios) were examined to answer the following questions:

- The advantage of activities that were selected compared with those that were not selected.
- The effects of increases or decreases in one or more resources in the value of the program.
- The effects of policy and prices on the final solution.

Useful information on these aspects can be extracted from analysis of the shadow prices of real and disposal activities in the conventional output report. However, the range analysis supplements the information provided by the conventional solution. It facilitates interpretation of the shadow prices by providing an estimate of the range over which they are relevant.

Interpretation and analysis of the various cropping patterns (different scenarios) resulting from the tactical planning process demonstrated the usefulness and effectiveness of the model in deriving the most suitable cropping pattern that suits the natural potential of the land, as well as the management constraints. It also demonstrated how the model could be applied to distribute the slack resources and derive a proper operational calendar for each crop that suits the crop requirements and the available resources.

### 7.2.3 Experimentation

During experimentation, using the relevant data on Section 3 of MAIC, a cropping pattern which maximizes the profit, and in the meantime is suitable to the enterprise environment, was generated. The overall results of such a solution are given in table 18. Since the model incorporates many external and internal variables, such as production policy and prices, crop rotation, availability and seasonality in the use of resources, the introduction of changes in the value of any constraint or coefficient generates a different scenario, for each of which an optimal solution is obtained for the given set of conditions. Post-modelling analysis to select one particular scenario as the most appropriate solution is thus an important aspect of the overall analysis. Beale (1968) claimed that obtaining the first optimal solution to a linear programming problem is of no importance in itself. It is merely a necessary preliminary to the further post-modelling analyses that yield the truly valuable results of an LP study. Therefore, insight into the causal relationships underlying the general pattern of the solution, and the possibilities for improvements, is of prime importance. That insight can be gained by detailed analysis of the solution.

The regular output of the solution consists of a rows and columns section. The rows section indicates the status of each of the constraint rows in the problem. It gives information on the degree of resource utilization by the program, whatever slack is left in the resources, and the shadow prices for all resources that are fully utilized in the

```
TACTICAL PLANNING AT FARM ENTERPRISE LEVEL

THE PLAN HAS AN OPTIMAL (1) SOLUTION

TOTAL VALUE OF THE PROGRAM (IN 1000 TOMANS) IS 100261.

TOTAL AREA OF EACH CROP IN THE PLAN (ha)

TOTAL AREA OF WHEAT-IR                                                          117.
TOTAL AREA OF WHEAT-DR                                                          362.
TOTAL AREA OF BARLE-IR                                                          143.
TOTAL AREA OF BARLE-DR                                                          278.
TOTAL AREA OF MAIZE                                                             432.
TOTAL AREA OF SUGBEET                                                           331.
TOTAL AREA OF ALFAL-1                                                           105.
TOTAL AREA OF ALFAL-2                                                           105.

TOTAL AREA OF EACH CROP IN EACH SOIL TYPE (ha)

SOIL-UL         ALFAL-1                                                          70.
SOIL-MO         MAIZE                                                            98.
SOIL-PS         BARLE-DR                                                         55.
SOIL-AG         BARLE-DR                                                         21.
SOIL-EB         WHEAT-IR                                                        117.
SOIL-EB         BARLE-IR                                                        111.
SOIL-EB         SUGBEET                                                         331.
SOIL-MJ         BARLE-DR                                                        155.
SOIL-MJ         MAIZE                                                           232.
SOIL-MJ         ALFAL-1                                                          35.
SOIL-MJ         ALFAL-2                                                         105.
S-MO-SA         WHEAT-DR                                                        362.
S-MO-SA         BARLE-DR                                                         17.
S-SB-SA         BARLE-IR                                                         32.
S-UL-SA         MAIZE                                                           101.
S-EB-SA         BARLE-DR                                                         29.
S-EB-SA         BARLE-DR                                                         29.

THE TOTAL REQUIREMENTS OF EACH FERTILIZER (kg)

TOTAL NITROGEN REQUIREMENTS = 654839.
TOTAL PHOSPHATE REQUIREMENTS = 461579.
TOTAL POTASSIUM REQUIREMENTS = 0.

TOTAL REQUIREMENTS FROM EACH EQUIPMENT (hours)

TOTAL REQUIREMENTS OF   TRACTOR  JAN                                           1728.
TOTAL REQUIREMENTS OF   TRACTOR  FEB                                            864.
TOTAL REQUIREMENTS OF   TRACTOR  MAR                                           6000.
TOTAL REQUIREMENTS OF   TRACTOR  APR                                           3709.
TOTAL REQUIREMENTS OF   TRACTOR  MAY                                           4119.
TOTAL REQUIREMENTS OF   TRACTOR  JUN                                           2368.
TOTAL REQUIREMENTS OF   TRACTOR  JUL                                           6000.
TOTAL REQUIREMENTS OF   TRACTOR  AUG                                           2394.
TOTAL REQUIREMENTS OF   TRACTOR  SEP                                           4334.
TOTAL REQUIREMENTS OF   TRACTOR  OCT                                           2883.
TOTAL REQUIREMENTS OF   TRACTOR  NOV                                           5200.
TOTAL REQUIREMENTS OF   TRACTOR  DEC                                           1653.
TOTAL REQUIREMENTS OF   COMBINE  JUN                                            650.
TOTAL REQUIREMENTS OF   COMBINE  JUL                                           1400.
TOTAL REQUIREMENTS OF   COMBINE  SEP                                           2339.
TOTAL REQUIREMENTS OF   COMBINE  OCT                                            827.
```

**Table 18. Overall results of the tactical planning process (comupter output)**

```
 NR    ..ROW..    AT      ..ACTIVITY..   SLACK ACTIVITY   DUAL ACTIVITY

  1    GROS...    BS      100261.50000   -100261.50000        -1.00000
  2    XP1..01.   BS         627.04560      -127.04560          .00000
  3    XP2..02.   BS        1709.61500     -1209.61500          .00000
  4    XP1..03.   LL         500.00000          .00000          .65627
  5    XP2..04.   BS         830.04900      -330.04900          .00000
  6    XP1..05.   BS        4253.37200     -1753.37100          .00000
  7    XP1..06.   LL       16000.00000          .00000          .65580
  8    XP1..07.   BS         630.00000      -330.00000          .00000
  9    RO...01.   BS         117.00790       344.99210          .00000
 10    RO...02.   BS         362.28340        99.71664          .00000
 11    RO...03.   BS         143.08660       318.91340          .00000
 12    RO...04.   BS         277.71660       184.28340          .00000
 13    RO...05.   BS         432.00790        29.99206          .00000
 14    RO...06.   BS         330.66050       131.33950          .00000
→15    RO...07.   UL         105.00000          .00000       -16.81944
 16    RO...08.   UL         105.00000          .00000       -20.01474
 17    WA....03   BS        2954.24600     46269.70000          .00000
 18    WA....04   BS        8702.35500     40521.59000          .00000
 19    WA....05   BS        7977.77300     41246.18000          .00000
 20    WA....06   BS       14061.54000     35162.41000          .00000
 21    WA....07   BS       14241.84000     34982.11000          .00000
 22    WA....08   BS        5196.45300     44037.50000          .00000
 23    WA....09   BS        1050.00000     48173.95000          .00000
 24    EM1..01.   BS        1728.03200      3071.96800          .00000
 25    EM1..02.   BS         864.01590      3935.98400          .00000
 26    EM1..03.   UL        6000.00000          .00000       -10.80189
 27    EM1..04.   BS        3709.44700      1090.55300          .00000
 28    EM1..05.   BS        4119.44700       680.55270          .00000
 29    EM1..06.   BS        2267.64200      2532.35800          .00000
 30    EM2..06.   BS         650.23650       949.76350          .00000
 31    EM1..07.   UL        6000.00000          .00000        -3.01757
 32    EM2..07.   UL        1600.00000          .00000        -7.22452
 33    EM1..08.   BS        2394.13400      2405.86600          .00000
 34    EM1..09.   BS        4333.80800       466.19240          .00000
 35    EM2..09.   BS        2338.67900       661.32100          .00000
 36    EM1..10.   BS        2883.06000      1916.94000          .00000
 37    EM2..10.   BS         826.65110      2173.34900          .00000
 38    EM1..11.   UL        5200.00000          .00000        -2.19604
 39    EM1..12.   BS        1653.30200      3146.69800          .00000
 40    SCO1....   BS          69.77000          .00000          .00000
 41    SCO2....   UL          98.13000          .00000         -.83780
 42    SCO3....   UL          54.93000          .00000         -.75880
 43    SCO4....   UL          20.98000          .00000         -.32290
 44    SCO5....   BS         558.38510        55.33490          .00000
 45    SCO6....   BS         527.74790       162.82210          .00000
 46    SCO7....   UL         379.68000          .00000        -1.23290
```

**Table 19. Status of rows in the optimal solution (a part of the computer output)**

solution (table 19). The shadow price is defined as the change in the value of the goal variables (objective) at a relaxation of the restriction by one unit (Veenekleas et al., 1991).

As an example, in table 19 we see that the maximum permitted area of alfalfa-1 (105 hectares) has been fully utilized, and that its shadow price, which in fact represents its economic value, is -16.819. This implies that if we increase the area of alfalfa-1 in the program by one hectare, its value will increase by 16.819.

Similar analyses can be made for all resources that are fully utilized. From analysis of the slack resources, more efficient plans for distribution of resources can be generated, e.g., as seen from the table, "available tractor hours in July" is at its upper level (binding constraint). Hence, if its availability increases or its requirement in the plan is reduced, the benefits of the plan may be increased. This could be achieved by rescheduling time-flexible operations that require tractors for other periods in which tractor hour is a slack resource, e.g., the first plough operation for cereal cultivation could be shifted from July to August.

The output also provides information about the optimal cropping pattern, i.e., the intensity at which the various activities are selected in the optimal solution, the input requirements as well as the input profit of each activity (cropping system) and the reduced cost of each activity which appears in the final solution. The reduced costs of an activity are comparable to the shadow prices for the resource constraint, i.e., expressing the changes in the value of the objective function if a unit of that activity were forced into the solution. Similarly, the negative sign indicates the required increase in gross margin per hectare to make an activity profitable enough to be included in the optimal plan, e.g., the gross margin for irrigated and fertilized wheat in soil series SB-SA should increase by 20.94 per hectare before it is included in the optimal solution. As shown in the solution table, the program assigns to each soil type a crop giving the highest input profit to the value of the program.

To obtain further information on the stability and sensitivity of the solution (post-modelling analysis), a range analysis was performed. The range analysis basically contained four sections.

(1) Rows at limit level: reports on the constraint rows where the resources are fully utilized and which are thus binding. This provides information on the following:

  - The range of changes in each constraint over which the shadow price holds. From the analysis of the rows at limits (table 20), it follows that under the given conditions an increase in the area of alfalfa-2 from 105 to 113 hectares in the cropping pattern would increase the value of the program by 20.01 per unit.

SECTION 1- ROWS AT LIMIT LEVEL

```
       NR.  ..ROW..    AT      ..ACTIVITY..   LOWER ACTIVITY  ..UNIT PROFIT..   LIMITING  AT
                                              UPPER ACTIVITY  ..UNIT PROFIT..    PROCESS  AT

         4  XP1..03.   LL        500.000000       435.794800          .656267   XA070421  LL
                                                  691.458700         -.656267    YL05....  UL
         7  XP1..06.   LL       1600.000000     14871.250000          .655799    RO...05.  UL
                                                16498.840000         -.655799   XA070421  LL
  --->  15  RO...07.   UL        105.000000        69.770000       -16.819440   XA060711  LL
                                                  113.836400        16.819440   XA070421  LL
        16  RO...08.   UL        105.000000        68.110060       -20.014740    YL05....  UL
                                                  113.826400        20.014740   XA070421  LL
        26  EM1..03.   UL       6000.000000      5709.492000       -10.801890    YL05....  UL
                                                 6069.586000        10.801890   XA070421  LL
        31  EM1..07.   UL       6000.000000      5960.236000        -3.017569   XA070421  LL
                                                 6166.005000         3.017569    SC05....  UL
        32  EM2..07.   UL       1600.000000      1299.956000        -7.224520    XP2..04.  LL
                                                 2007.055000         7.224520    SC06....  UL
        38  EM1..11.   UL       5200.000000      3725.733000        -2.196038    RO...04.  UL
                                                 5339.173000         2.196038   XA070421  LL
        41  5002....   UL         98.130000          .000000         -.837799   XA020511  LL
                                                   98.130000          .837799    YL02....  UL
        42  5003....   UL         54.930000          .000000         -.758800   XA030421  LL
                                                  209.980000          .758800   XA060421  UL
        43  5004....   UL         20.980000          .000000         -.322901   XA040421  LL
                                                  176.030000          .322901   XA060421  LL
        46  5007....   UL        379.680000       362.283400        -1.232901   XA070421  LL
                                                  534.730000         1.232901   XA060421  LL
        48  5009....   UL        101.410000          .000000        -1.134610   XA090511  LL
                                                  101.410000         1.134610    YL09....  UL
        49  5010....   UL         29.360000          .000000       -19.090000   XA100421  LL
                                                  184.410000        19.090000   XA060421  LL
        50  YL01....   UL         69.770000          .000000          .000000   XA010711  LL
                                                   69.770000          .000000    SC01....  UL
        57  YL08....   UL         32.370000          .000000        -1.394152   XA080311  LL
                                                   32.370000         1.391452    SC08....  UL
        60  FI1.....   UL           .000000        -INFINITY         -.001000       NONE
                                               654838.600000          .001000    X1.....1  LL
        61  FI2.....   UL           .000000        -INFINITY         -.001200       NONE
                                               461579.500000          .001200    X1.....2  LL
```

Table 20. Rows at limit level (a part of the computer output)

Similarly, increasing the availability of tractor hours in March from 6000 to 6069 hours would increase the value of the program by 10.8 units per tractor hour; increasing the availability of combine hours in July from 1600 to 2007 would increase its value by 7.22 units per hour. This in fact defines the ranges over which the profitability of each binding constraint is equal to the shadow prices derived in the program.

  - Information about activities that would no longer be selected in the optimal solution at the critical turning point for each limiting resource (limiting processes in LP terms), e.g., increasing the area of alfalfa-2 to 113 hectares will result in exclusion of "rain-fed barley on soil series MO-SA" from the optimal solution. Similarly, increasing available combine hours in July to 2007 will cause the area of soil series MJ to become a limiting factor.

(2) Columns at limit level: provide information on the stability of those activities that appear at their limit levels in the optimal solution, and include the following:

  - The required gross margin and the level at which an activity would enter the optimal solution if its input profit (gross margin) were increased by the required reduced cost. This shows that the area of irrigated wheat on soil series MJ would increase from zero to 117 hectares if its gross margin increased from 30.99 to 32.62.
  - Information about activities that would no longer be selected in the optimal solution as a result of new activities entering the solution, e.g., as a result of the above change (increasing the gross margin to 32.62), the activity "irrigated wheat on soil series EB" would be forced out of the optimal solution.

(3) Columns and (4) rows at intermediate levels, which provide information on the ranges that the shadow prices and gross margins can vary without affecting the optimal solution. In each case it also indicates the related levels of activities in the final solution and the new limiting processes.

Post-modelling analysis of the generated tactical plan, using the range analysis, provides opportunities to analyze the economic value of different resources and various production systems as a basis for derivation of an alternative tactical plan more suitable to the enterprise environment. The following considerations resulted in a number of modifications:

- Rescheduling of the time-flexible operations to alleviate some of the binding constraints, such as that on land preparation for different cropping systems to the period in which agricultural machinery is slack.
- Increasing the availability of some of the binding resources, i.e., the availability of

tractor hours in March and July from 4800 to 5600 and 5500 hours, respectively.

- Analyze the validity of the production policy and make the necessary changes for improvements. In the given situation, maize and sugar beet have the highest input profit and alfalfa and barley the lowest. To maximize profit when different cropping systems are competing for limiting resources, the model always gives priority on the basis of gross margin. Therefore, crops with low gross margin do not appear in the solution unless their production follows from production policy, e.g., alfalfa-2 did not appear in the first solution (table 18). The recommended area for alfalfa in the approved cropping pattern (table 17) was around 180 hectares, so a minimum level of production for alfalfa was included in the production policy. Alfalfa is a four-year crop; thus the minimum production levels of alfalfa for the first year's cultivation and the other three years of cultivation were set at 270 and 810 tons, respectively.
- Analyze the profitability and suitability of the different cropping systems and make the necessary modifications to the approved cropping pattern.

These modifications resulted in a new cropping pattern as given in table 21. Comparison of the two solutions (tables 18 and 21) shows:

- The first solution allocates around 90 % of the available land, whereas the second solution allocates all.
- The value of the program in the second solution is around 12 % higher.
- The cropping pattern recommended by the second solution matches well with the approved cropping pattern.

The improved tactical plan was therefore selected to be used for generation of the operational plan.

## 7.3 Operational planning

Operational planning is a multi-objective problem that translates the tactical plan into an operational plan. The allocation process, which uses mainly a spatial decision model, is an iterative, sequential and interactive process. In each iteration based on the tactical plan, the suitable parcels are assigned to specific crops. The process is interactive, i.e., the user in the course of planning can change the relative importance of different objectives, the order of crop assignments and the location of the stores for each crop. Experimentation with the model included:

- Data collection and preparation
- Decisions on the order of crop assignment and the relative importance of the different objectives
- The actual experimentation.

```
TACTICAL PLANNING AT FARM ENTERPRISE LEVEL
THE PLAN HAS AN OPTIMAL (1) SOLUTION
TOTAL VALUE OF THE PROGRAM (IN 1000 TOMANS) IS                          111517.

TOTAL AREA OF EACH CROP IN THE PLAN (ha)
TOTAL AREA OF WHEAT-IR                                                     263.
TOTAL AREA OF WHEAT-DR                                                     400.
TOTAL AREA OF BARLE-IR                                                     143.
TOTAL AREA OF BARLE-DR                                                     181.
TOTAL AREA OF MAIZE                                                        462.
TOTAL AREA OF SUGBEET                                                      462.
TOTAL AREA OF ALFAL-1                                                       45.
TOTAL AREA OF ALFAL-2                                                      135.

TOTAL AREA OF EACH CROP IN EACH SOIL TYPE (ha)
SOIL-UL    SUGBEET                                                          70.
SOIL-MO     SUGBEET                                                         98.
SOIL-PS    BARLE-DR                                                         22.
SOIL-PS    SUGBEET                                                          33.
SOIL-AG     BARLE-IR                                                        21.
SOIL-EB    WHEAT-IR                                                        263.
SOIL-EB    BARLE-IR                                                         90.
SOIL-EB    SUGBEET                                                         261.
SOIL-MJ    WHEAT-DR                                                         20.
SOIL-MJ    BARLE-DR                                                        159.
SOIL-MJ    MAIZE                                                           361.
SOIL-MJ    ALFAL-1                                                          45.
SOIL-MJ    ALFAL-2                                                         106.
S-MO-SA     WHEAT-DR                                                       380.
S-SB-SA    BARLE-IR                                                         32.
S-UL-SA    MAIZE                                                           101.
S-EB-SA    ALFAL-2                                                          29.

THE TOTAL REQUIREMENTS OF EACH FERTILIZER (kg)
TOTAL NITROGEN REQUIREMENTS = 785300.
TOTAL PHOSPHATE REQUIREMENTS = 544490.
TOTAL POTASSIUM REQUIREMENTS = 1116.

TOTAL REQUIREMENTS FROM EACH EQUIPMENT (hours)
TOTAL REQUIREMENTS OF          TRACTOR  JAN                               1848.
TOTAL REQUIREMENTS OF          TRACTOR  FEB                               2772.
TOTAL REQUIREMENTS OF          TRACTOR  MAR                               5344.
TOTAL REQUIREMENTS OF          TRACTOR  APR                               4216.
TOTAL REQUIREMENTS OF          TRACTOR  MAY                               4367.
TOTAL REQUIREMENTS OF          TRACTOR  JUN                               2658.
TOTAL REQUIREMENTS OF          TRACTOR  JUL                               5430.
TOTAL REQUIREMENTS OF          TRACTOR  AUG                               4584.
TOTAL REQUIREMENTS OF          TRACTOR  SEP                               4168.
TOTAL REQUIREMENTS OF          TRACTOR  OCT                               4641.
TOTAL REQUIREMENTS OF          TRACTOR  NOV                               4435.
TOTAL REQUIREMENTS OF          TRACTOR  DEC                               2524.
TOTAL REQUIREMENTS OF          COMBINE  JUN                               1152.
TOTAL REQUIREMENTS OF          COMBINE  JUL                               1316.
TOTAL REQUIREMENTS OF          COMBINE  SEP                               2772.
TOTAL REQUIREMENTS OF          COMBINE  OCT                               1153.

TOTAL LABOUR REQUIREMENTS (days)
TOTAL LABOUR REQUIREMENTS FEB                                             1014.
TOTAL LABOUR REQUIREMENTS MAR                                             1306.
TOTAL LABOUR REQUIREMENTS APR                                             5712.
TOTAL LABOUR REQUIREMENTS MAY                                            10332.
TOTAL LABOUR REQUIREMENTS JUN                                             9318.
TOTAL LABOUR REQUIREMENTS JUL                                             4698.
TOTAL LABOUR REQUIREMENTS AUG                                             4698.
TOTAL LABOUR REQUIREMENTS SEP                                              405.
TOTAL LABOUR REQUIREMENTS OCT                                              540.
TOTAL LABOUR REQUIREMENTS NOV                                             1014.
```

**Table 21. Overall results of the final tactical plan, after post-optimal modelling (computer output)**

### 7.3.1 Data collection and preparation

The allocation process requires two types of data, i.e., site specific and crop specific. The site specific data are attributes of a location and are the same for all crops. These are:

- Soil type map, including the soil classification and information on each class.
- Map of the road network, including road type and related impedance.
- Map of the canal network, including canal type and related flow rates and corresponding conveyance losses.
- Administrative boundary map, identifying the parcel boundaries and their areas.
- The crop rotation history of each parcel.

To prepare data for experimentation, all required maps with relevant attributes were collected, digitized and stored as separate map layers in the system (figure 37). In the same way, the cropping history of each parcel was collected and stored in the relevant data file.

The conveyance losses in the irrigation canals within the pilot area have been measured by various consulting engineers, i.e., Yekom (1984) reported a percolation rate of 0.1 l/m/s in the main canal; MAIC (1987) reported 0.04 l/m/s in the secondary canals and Absu (1988a) reported 0.06 l/m/s in the tertiary canals. According to the standards given by Deridder and Erez (1977) the conveyance losses in the main, secondary and tertiary canals are around 5 per 1000,000, 1 per 100,000 and 2 per 1000 of the flow rates respectively. Application of these standards gives 0.15 and 0.01 l/m/s for the main and secondary canals, respectively. These figures do not quite match those reported by the consulting engineers. In the present experiment, the data reported by the consulting engineers were used to assign a loss rate to every link in the canal network and calculate the total loss rate at each field inlet.

The crop related data are the biophysical suitability index, total conveyance water losses in the irrigation network and the transportation costs of each crop from its parcel to its delivery points. The biophysical suitability index and the crop irrigation requirements of each crop on a specific soil type were derived through the biophysical land evaluation process. By using overlay processing in the GIS, the biophysical suitability index of each parcel and the related total conveyance losses in the irrigation network for irrigating the parcel were calculated.

### 7.3.2 Decisions on the order of crop assignment and the relative importance of the different objectives

In operational planning, one crop is assigned to the most suitable parcels in each iteration. The order of crop assignment is therefore very important, because the process assigns the best land first. In reality, the planner should study the importance of the cropping systems from different aspects and on that basis decide on their order. In this experiment, the order maize, sugar beet, wheat-irrigated, barley-irrigated, alfalfa, wheat-rainfed and barley-rainfed was assumed.

Operational planning includes three objectives, i.e., optimum allocation of crop to a parcel, minimizing conveyance losses in the irrigation network and minimizing the transportation costs. In the model, these objectives are combined into a single objective by assigning a priority weight to each in a composite objective function. The choice of relative weights is thus critical for the problem solution. A straight-forward weighting method is to define the objectives in financial terms. However, in many cases, because of government policies, the prices may not reflect the importance of different objectives.

The impedance in the road network can be defined in terms of distance, travelling time or transportation costs, which are related to the length of the road. In the present experiment, in the absence of any quantitative information on the relative costs of transportation on different types of roads, the transportation time was used as a criterion to define road impedance. It was further assumed that transportation speed (impedance of each link) on the primary, secondary and tertiary roads is around 60, 40 and 20 kilometers per hour, respectively. This resulted in impedance values of 0.06, 0.09 and 0.2 s/m in the primary, secondary and tertiary roads, respectively.

The biophysical suitability index of each soil type is defined in terms of thousands of rials. The total conveyance losses are expressed in thousands of cubic meters of water, and the road impedance is expressed in seconds. These criteria were combined into a single decision variable using a composite weighted linear function. In this function, the relative importance of the various objectives are expressed by assigning different weighting factors. Hence, if some of the decision variables are not relevant, a weighting factor of zero can be assigned. In this experiment the assigned weights were 4, 1 and 0.1 for the total conveyance losses, biophysical suitability index and travelling time, respectively. These assumptions for maize, established an order of 802-1136 for biophysical suitabilities, 4-190 for conveyance irrigation losses and 132-245 for the compound impedances resulting from combinning the biophysical suitabilities and conveyance irrigation losses and 9-27 units for the road impedances.

### 7.3.3 Experimentation

Using the operational planning process and on the basis of the above crop allocation order and the priority weights of various objectives, the final cropping pattern derived in the course of tactical planning (table 21) was allocated to the most suitable parcels. The location and capacity of each store for different crops were determined interactively. For each crop, one store with the capacity equal to the required area (derived in tactical planning) times the average yield was assumed. A flexible method was employed to satisfy the crop rotation constraint in which there was no explicit crop sequence. This was implemented by using the crop rotation rule expressed in table 22 and using relational database operations to select the suitable parcels which can be allocated to the specified crop. The results are illustrated in table 23 and figure 42.

| **Alfalfa** | **Barley** | **Maize** | **Sugarbeet** | **Wheat** |
|---|---|---|---|---|
| Alfalfa | Alfalfa | Barley | Barley | Alfalfa |
| Barley | Maize | Sugarbeet | Maize | Barley |
|  | Sugarbeet | Wheat | Wheat | Maize |
|  | Wheat |  |  | Sugarbeet |

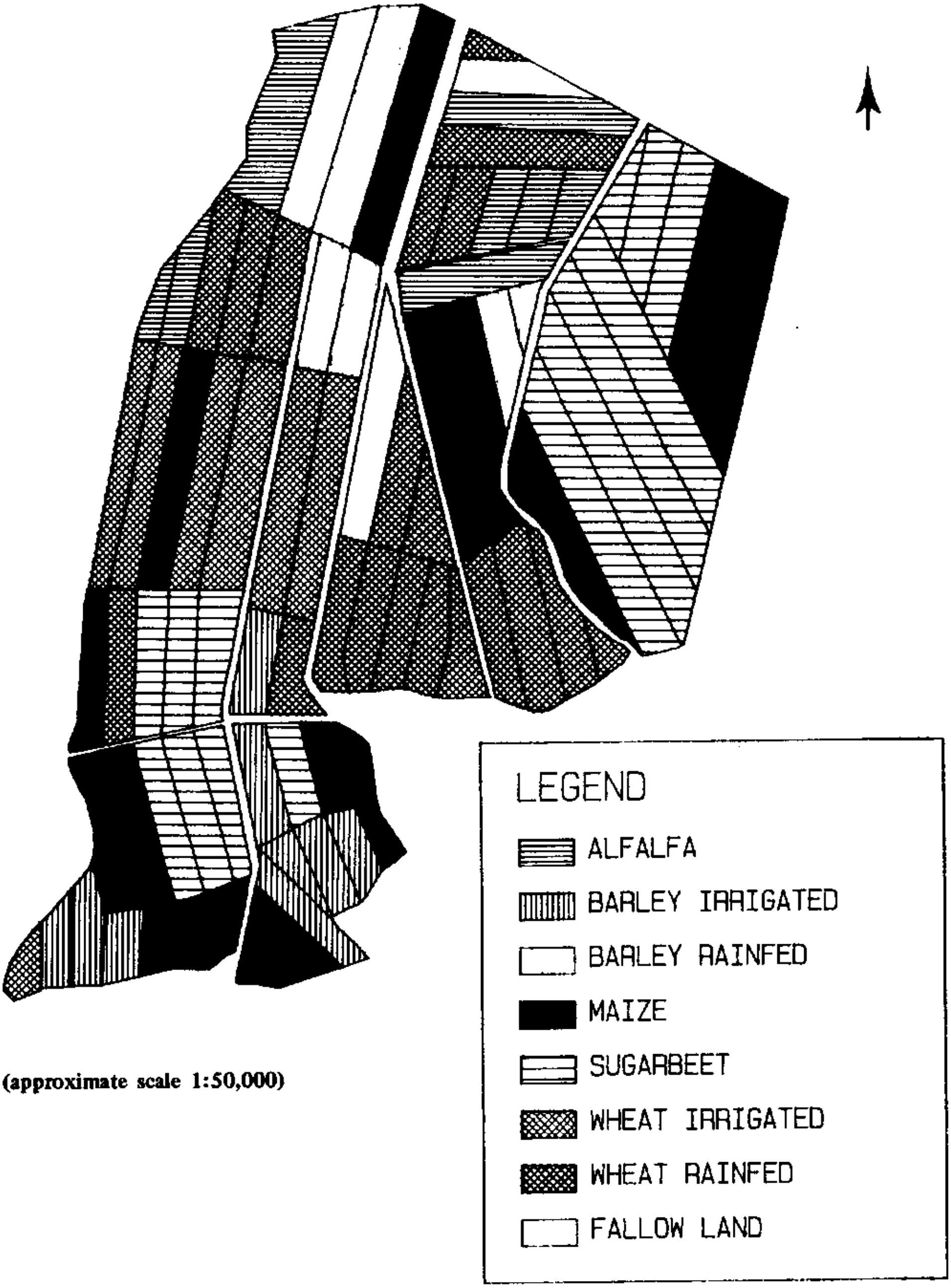
**Table 22 Crop rotation rules (the first crop in each column can be followed by any of the other crop in that column)**

## 7.4 Supportive planning

All supporting plans were derived from the actual land use plan. This included the logistics requirements of the plan, such as fertilizer, labour and various type of agricultural machinery requirements, together with their timing. On the basis of the actual plan and the required crop husbandry operations, the detailed plan of operation was derived. Estimates of the production of various crops can also be derived to help plan marketing, transportation and other related types of activity.

| Crop | Cropping pattern based on | | | Final plan and tactical planning (%) |
|---|---|---|---|---|
| | MAIC policy | Tactical planning | Operational planning | |
| Maize | 454.6 | 462 | 460.8 | 99.70 |
| Sugarbeet | 454.6 | 462 | 459.5 | 99.46 |
| Wheat-ir | 454.6 * | 263 | 258.3 | 98.2 |
| Barley-ir | 454.6 * | 143 | 137.9 | 96.4 |
| Wheat-dr | * | 400 | 393.1 | 98.3 |
| Barley-dr | * | 181 | 154.5 | 85.3 |
| Alfalfa | 181.9 | 180 | 172.7 | 95.5 |
| Fallow | 90.7 | 0 | 53.9 | -- |
| Sum | 2091 | 2091 | 2090.7 | -- |
| Average | -- | -- | -- | 96.1 |

**Table 23** Comparisons of the final land use plan with the MAIC general plan and the tactical plan. (*, in master plan, rainfed and irrigated cultivations are expressed by one figure)



(approximate scale 1:50,000)

**Figure 42 Final land use plan**

# CHAPTER 8

## SUMMARY AND RECOMMENDATIONS

### 8.1 Summary

The dynamics of agricultural systems include complex biological, social and economic processes, their future possibilities are affected by many different factors that influence their biological and economic efficiency. Successful management of these systems can be greatly facilitated by a proper tool to support rational decision making. Such a tool should follow the logic of the decision making process, and include the capacity to support land use planning, monitoring and evaluation activities.

The major purpose of the present study was to develop an appropriate resource information system which would improve decision making processes in farm management. The system was designed to provide support for land use planning and the means to monitor and evaluate agricultural activities, and to alleviate the information-related constraints in farm management. These constraints are basically:

- Methodological constraints that prevent full integration of existing technical and management data into the management decisions.
- Lack of a proper framework for data collection, which has resulted in gathering vast amounts of data regarding various aspects of the agricultural system, i.e. technical, physical and economic, but without a coherent structure.
- Lack of an appropriate tool for organizing the data in a form suitable for updating, processing, retrieval, and for exchnge of data and information between various processes and users.

In the present study, a prototype of such a system was developed (ARIS) for application at farm enterprise level. It includes two basic functional sub-systems: the land use planning sub-system and the monitoring and evaluation sub-system. The monitoring and evaluation sub-system is tailored to the Moghan Agro-Industrial Complex (MAIC) in Iran, whereas the land use planning sub-system is general. It includes an integrated land use planning model that, after proper calibration and validation, can be applied elsewhere. Moreover, the method that was devised and used to develop the information system also could be used elsewhere.

The monitoring and evaluation sub-system has been implemented in MAIC. The existing data were organized properly by establishing appropriate databases. A preliminary evaluation showed that data required for planning, monitoring and evaluation were satisfactorily organized, resulting in changes in the information flow and power distribution within the enterprise which has improved the quality and efficiency of the monitoring and evaluation processes. Final conclusions can be drawn, however, only after a systematic evaluation of the performance of this sub-system in the future.

Planning is a dynamic process that should result in plans at different levels: strategic, tactical and operational. An appropriate planning tool should provide strong links, interfaces and feed-backs among these different levels. As existing methods in land use planning (such as land evaluation and farming systems analysis) appear inadequate for the integration of all relevant features of the agricultural production system (Van Diepen et al., 1991; Fresco et al., 1990), an integrated land use planning model was developed, with all the characteristics of a comprehensive planning tool. In this system, land use planning consists of three phases:

(1) The biophysical land evaluation process provides a capacity for resource analysis and estimating the productivity of the land for any feasible type of land use at different levels of inputs. The model is based on a quantitative estimate of the growth and yield of each prospective agricultural crop on each tract of land. These estimates are derived from a dynamic crop growth simulation model, and corrected for management efficiencies. The model can simulate the growth of all prospective annual crops with specified properties under a wide range of weather and soil conditions, and provides realistic input/output response relations between yields and major factors of the agricultural environment. It also provides reliable estimates of the irrigation and macro-nutrient requirements of each prospective crop on each tract of land for a given production level.

(2) The tactical planning model integrates the physical and socio- economic information and produces an overall land use plan. The planning model is based on profit maximization and uses a single objective linear programming model to determine economically optimal cropping patterns and the associated combination of inputs for an enterprise with a given set of resources and specified constraints. Using this model, different scenarios can be generated and cosequences of alternative decisions can be analyzed by varying the constraints, coefficients and fixed resources.

(3) The operational planning model translates the tactical plan into an operational plan on the basis of the suitability of the land, conveyance irrigation losses, the transportation costs associated with each prospective crop and crop rotation requirements. Operational planning, as defined here, is a multiple objective problem and uses a spatial decision model to derive the final land use plan. This process arrives at the optimal operational plan that satisfies the tactical plan, the

biophysical land suitability and the management priorities. All supportive plans are generated on the basis of the established operational plan .

The land use planning sub-system was tested in an area of 2091 ha (Section 3 of MAIC). Analysis of the results showed the following:

- The biophysical land evaluation model with limited calibration effort, produces results that are in reasonable agreement with the experimental data. This included comparison of the simulated results (using actual weather data) with the relevant experimental data and the simulated results using average climatic data with the average yield obtained in well-managed farms in the region and attainable yields estimated by Jamee (1990a and 1990b).

- Interpretation and analysis of the various cropping patterns (scenarios) generated by the tactical planning model proved it to be effective in deriving the optimal cropping pattern suitable to the natural potentials of the land, as well as the management constraints (finding the first feasible solution). It also demonstrated how post-model analysis could be used to analyze the economic value of the required resources in the production system. This could be used to derive a proper production policy, an optimal cropping pattern and a well organized operational plan.

- In the course of operational planning the planner can decide on the order of crops in land allocation, the relative importance of the optimum allocation of a crop to a parcel based on its biophysical suitability index, the conveyance irrigation losses in the irrigation network and the transportation costs of crop produce to the respective delivery points. On the basis of those decisions and by considering crop rotation constraints, the model finds a cropping pattern that satisfies all the constraints. Results of experimentation showed an average of 96 % match between the cropping pattern derived in tactical planning and that in operational planning (table 23).

Analysis of the results showed an overall methodological improvement in land use planning and the elimination of the constraints that severely limited the use of existing information in management decisions. Moreover, the system provides a framework for defining the required data in various related disciplines, defining data requirements, designing data collection and their related organization, processing data into information and finally their integration into the management decisions. Based on the existing information (Baker and Hanson 1991) the system is unique among agricultural-system models, in the sense, that it integrates three class of models i.e. crop growth simulation, optimization and spatial models to form a decision support system for sustainable agricultural development.

## 8.2 Major advantages of the system

ARIS is a decision support system for management at farm enterprise. It assists decision makers in the assessment and evaluation of alternative strategies for tactical and operational land use planning, as well as providing facilities for monitoring and evaluation that allow feed-back for correction of unsuccessful operations and feed-forward for promoting promising activities (achievements). Major advantages of the system include the following:

- Existing biophysical land evaluation methods are improved by replacing the subjective rating, sub-rating and matching procedures of land use requirements and land qualities by a dynamic crop growth simulation model. This model--developed on the basis of insights in the basic causal relationships between crop performance and its environment (soil and weather)--improves the consistency and reliability of the production estimates and the applicability (operational aspects) of the biophysical land evaluation procedures (Fresco et al., 1990).

- In current land evaluation practices, integration of information from biophysical, technological, social and economic disciplines still relies heavily on subjective judgment, and is weakly articulated in operational land use planning (Van Diepen et al., 1991). Here the subjective judgments are replaced by a linear programming model, that integrates the information from various disciplines and provides an appropriate link between land evaluation and the land use planning process.

- The system complies with the definitions of planning as given by Davis and Olson (1985) and of land use planning as given by Dent (1988), and provides support for planning at different levels, i.e. strategic, tactical and operational. The system allows the decision maker to examine the environment in order to quantify the expectations, opportunities and constraints, use appropriate planning models to generate plans, and test the feasibility of alternative plans in the course of the decision making process.

- The system provides support for different phases of the decision making process in land use planning. In each phase, part of the analysis is systematized for the computer, and where the decision maker's insight and judgment are needed, the system allows him to interact and control the process. It also allow him to impose his/her priorities among different objectives.

- The models used in different phases of planning are complementary; in combination, they form an integrated system for land use planning at different levels. For example, in developing a linear programming model, the critical and difficult tasks which in most cases appear to be limiting, are estimating realistic resource-to-product relationships, deriving reliable technical coefficients, defining meaningful constraints, and estimating reliable benefit expectations. In ARIS, the biophysical land evaluation model and the implementation of the monitoring and evaluation sub-system remove most of these constraints.

- In an agricultural environment, manual data collection, developing planning models and producing alternative plans are very costly, time-consuming, difficult and tedious tasks. They place a severe limitation on planning activities, to the extent that they are frequently neglected, or a plan is generated but not used. That is one of the major factors affecting agricultural management, which is directly related to land degradation and mis-use of resources. The use of planning support systems can remove some of these constraints and improve the planning function as a basis for better management of agricultural systems.

- The important physical, socio-economic features of the agricultural system are modelled. These models incorporate the relevant aspects of theory and information on agronomy, crop physiology, soil science, meteorology and economics. All models are integrated into one system which allows integration of various data from different sources and disciplines into the management decisions.

- Each model is developed on the basis of insight in the fundamental relationships between major factors affecting the behaviour of the agricultural system. This has a very important operational impact, because it provides a rational framework for data collection which allows restriction of collection and organization of data to only those factors that have a considerable impact on the system.

- According to Unger (1977), improvements in water application practices such as, irrigation scheduling, differentiation of timing and amount of irrigation on alternative crops and soils, are expected to have the greatest environmental implications in the future (rank 1). These improvements are achieved using ARIS with real-time weather data.

- Methodological suggestions have been put forward by many authors to explicitly include crop rotation considerations in land use planning. Talaat and McMarl (1986) reviewed the background of rotation modelling and concluded that virtually all of the suggested methods limit the choice of rotations to pre-selected combinations. To improve the situation they propose a method to develop a countinuously repeatable optimum crop rotation. All these models explicitly consider crop rotation as the only objective. The ARIS land use planning approach, allows free selection of the optimum rotation, as well as considering other objectives affecting the land use plan.

- Much of the existing knowledge about the basic principles underlying the major processes involved in an agricultural production system are formulated and integrated in the various models. This will reduce the need for high-quality experts of different disciplines required for the interpretation of data and their integration into management decisions.

- In the course of the planning, monitoring and evaluation activities, various related data sets-such as resource inventories, inputs, outputs, cost accounting and crop calendars--are collected and organized in the respective databases. This allows systematic updating, and easy data access, retrieval and processing. Although the system starts from available data sets that may not be very reliable, they are updated and improved in the course of routine operations, thus, providing eventually the reliable data required for other processes, and for calibration and validation of the different models.

- The concept of geographic information system (GIS) is employed to support spatial information management, analysis of spatial data combined with related thematic data to support decision making processes, and finally to allow the transfer and presentation of the results of various processes to the decision makers in a manageable, communicable and easily understandable form. Spatial presentation is a natural way of approaching any spatial problem. Visualization of results using GIS technology is one of the most comprehensive and effective forms of presentation and communication.

- Using the geographic information concept has created a capability to combine various forms of information from many different sources and relate them through a common spatial location.

- GIS technology is applied to find a proper solution for a multiple objective problem that could not have been easily addressed otherwise; even if it were possible, it would not have been as flexible and widely applicable.

- The integration of different decision models with the capability of visual presentation of the results of each analysis makes it possible to judge the performance of the models and interactively control the processes.

- The integration of land use planning, monitoring and evaluation functions in a single system, that is both comprehensive and easy to use, has improved the functionality, operationality and performance of those management functions.

## 8.3 Recommendations for further development

Development of a comprehensive resource information system which covers every aspect of the complex agricultural system is an enormous task which is far beyond the framework of a PhD thesis. However, the system developed in the course of this study (ARIS) is unique among agricultural information systems; it integrates crop growth simulation, optimization and spatial models to form a decision system. It is a powerful system in support of agricultural development at farm enterprise level, with a potential applicability at regional level. It is by no means complete; there is ample room for improvement in the formalization and integration of processes of related disciplines into the management decisions. However, the following areas of research and development should receive priority:

- Integration of groundwater model: the inevitable water losses of irrigation schemes in many arid and semi-arid areas of the world have caused serious land degradation by raising groundwater tables, waterlogging and salinization. The present state of ARIS allows estimation of the water losses for irrigation of every cropping pattern that percolate into the groundwater. Integration of a proper groundwater model with ARIS to allow simulating and monitoring the effects of various cropping pattern in the ground- water table will increase considerably the potential of the system for planning sustainable agricultural development.

- Integration of other models that simulate major pollutants from agricultural practices, such as sediment, plant nutrients, and pesticides (Canter, 1986), in the planning model will allow consideration of the potential environmental effects of pollutants from various agricultural activities in the planning process.

- Some of the major crop growth variables such as leaf-area-index (LAI), canopy structure, canopy biomass and canopy water may be efficiently estimated using remote sensing techniques (Bouman, 1991). Integration of these techniques into the system will improve the performance of the crop growth simulation model either by controlling the behaviour of the model in the course of growing period or by replacing some of the growth variables.

- Improvement of nutrient model: calculation of the nutrient requirements in ARIS is based on the QUEFTS approach (Janssen et al., 1990), which has been developed for evaluating fertility of tropical soils. This should be further developed to allow evaluation of soil fertility in arid and semi-arid areas.

- Spatial interpolation: in the present study, the land mapping unit (LMU) concept (FAO, 1983) has been used to divide the area of interest into some areal units. Each unit is assumed to be homogeneous in terms of climate, physiography, soil chemical and physical properties, and defined by different areal attributes (tags), describing each unit as a whole on the basis of the dominant attributes within the unit (Gersmehl et al., 1987). However, it is clear that, in different land units and different scales of investigation, this assumption is not practical. To improve the situation the following research topics are recommended:

- Climatic and weather variables are usually measured at a point. The gauging network is highly irregular and the sampling density is not uniform and often sparse. The biophysical land evaluation model requires daily weather data of each geographic location, on which only monthly data of some points (weather stations) are commonly available. To alleviate this problem, a stochastic weather generator should be developed and used in combination with a proper spatial interpolation method to generate the required sequence of daily weather data at any geographic location as a function of the statistical moments of the historical data (e.g. bi-monthly) and the geographic position with respect to the existing weather stations.

- Soil physical and chemical data of the area of interest are extracted from the respective existing soil survey reports and corresponding maps. A soil map shows the boundaries between map units, which infers homogeneity within those units. However, the inferred homogeneity does not exist for many of the physical and chemical attributes needed for a biophysical land evaluation model. Soil maps are the product of spatial interpolation of point data (soil profiles, auger holes) using mainly qualitative methods based on transfer by analogy which is not proper for quantitative modelling (Moore et al., 1991). Research leading to parametric methods of estimating specific soil properties using the point data (pedons) in combination with digital terrain models (DTM), and proper spatial interpolation techniques integrated into a GIS or a geoscientific information systems (GSIS) (Turner, 1991, 1990) and remote sensing can improve the situation.

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# Samenvatting

Landbouwsystemen zijn aan voortdurende veranderingen onderhevig, waarbij hun dynamisch gedrag wordt bepaald door complexe biologische, sociale en economische processen. Het optimale landgebruik zowel in biologische als in economische zin wordt door vele factoren bepaald. Computer-ondersteunde 'decision support' systemen kunnen daarom een belangrijke rol spelen bij de planning, bewaking en evaluatie van het landgebruik.

De belangrijkste knelpunten voor toepassing van dergelijke systemen in de huidige situatie zijn:

- Onvoldoende toepassing van bestaande technische- en beheersgegevens bij de totstandkoming van beheersbeslissingen.
- Het ontbreken van een op het doel toegesneden systeem voor het op gestructureerde wijze verzamelen van grote hoeveelheden gegevens met betrekking tot technische, natuurwetenschappelijke en economische aspecten van het landbouwsysteem.
- Het ontbreken van een geeigend instrument om die gegevens te beheren in een vorm die geschikt is voor het actualiseren, verwerken en terugvinden en voor het uitwisselen van gegevens en informatie tussen verschillende processen en gebruikers.

In deze studie is een prototype van een dergelijk systeem ontwikkeld (ARIS), voor toepassing op het niveau van een landbouwbedrijf. Het bestaat uit twee deelsystemen: een deelsysteem voor landgebruiksplanning en een voor bewaking en evaluatie. Het deelsysteem voor bewaking en evaluatie werd speciaal ontwikkeld voor het Moghan Agro-Industrial Complex (MAIC) in Iran, terwijl het deelsysteem voor landgebruiksplanning meer algemeen toepasbaar is. Het laatste bestaat uit een geintegreerd planningmodel voor landgebruik, dat na calibratie en validatie elders kan worden toegepast. Bovendien is de gepresenteerde methode voor het ontwikkelen van een informatiesysteem ook in andere situaties toepasbaar.

Het deelsysteem voor bewaking en evaluatie is geinstalleerd op MAIC. De beschikbare gegevens werden daarbij ingevoerd in de daarvoor ontworpen databases. Een voorlopige evaluatie heeft aangetoond dat de gegevens, nodig voor planning, bewaking en evaluatie op bevredigende wijze worden verwerkt, en resulteerden in veranderingen in de informatiestroom, en als gevolg daarvan ook in de machtsverhoudingen binnen het bedrijf. Dit heeft geresulteerd in verbetering van de efficientie en de kwaliteit van de bewakings- en evaluatieprocedures.

Planning is een dynamisch proces, dat moet resulteren in plannen op zowel strategisch, taktisch als operationeel niveau. Een operationeel planninginstrument moet de mogelijkheid bieden tot een effectieve interactie tussen de verschillende niveau's. Daar bestaande methoden voor landgebruiksplanning, zoals landevaluatie en 'farming systems analysis' onvoldoende mogelijkheden boden voor de integratie van alle relevante kenmerken van landbouwproduktiesystemen (van Diepen et al., 1991, Fresco et al., 1990) werd een geintegreerd systeem voor landgebruiksplanning ontwikkeld, dat als planninginstrument dienst kan doen. In dit systeem bestaat landgebruiksplanning uit drie fasen:

1. In de bio-fysische landevaluatie wordt een kwantitatieve schatting gemaakt van de produktiemogelijkheden (opbrengsten) van iedere relevante vorm van landgebruik bij verschillende niveau's van input van externe produktiemiddelen. Hierbij wordt gebruik gemaakt van een dynamisch gewasgroeimodel dat groei en opbrengst van gewassen simuleert op basis van de kenmerken van bodem, weer (klimaat) en gewas (of varieteit). Voor invoering in het landgebruikssysteem worden de gesimuleerde opbrengsten gecorrigeerd voor de efficientie van beheer.

   Het model simuleert groei en opbrengst van eenjarige gewassen met expliciet gedefinieerde fenologische, physiologische en fysische eigenschappen onder gegeven omstandigheden in de omgeving (bodem en klimaat). Op grond hiervan kunnen realistische input/output verhoudingen worden berekend als functie van de voornaamste produktiefactoren.

2. Toepassing van een taktisch planningmodel, waarin de agro-technische en de economische informatie wordt geintegreerd, en dat leidt tot een overall landgebruiksplan. Het betreft een lineair programmeringsmodel, dat een enkele doelstelling, namelijk winst, maximaliseert bij een gegeven combinatie van hulpmiddelen en beperkingen op bedrijfsniveau. Het resultaat van het model is een economisch optimale combinatie van gewassen met de daarbij behorende combinatie van de inzet van externe middelen. Het model biedt de mogelijkheid verschillende scenario's te verkennen, door bestaande beperkingen opgeheven te veronderstellen, alternatieve beslissingen te analyseren en aanwezige hulpmiddelen te varieren.

3. Toepassing van een operationeel planningmodel, dat het taktische plan vertaalt in een operationeel plan, op basis van de geschiktheid van het land voor de verschillende gewassen, de kosten voor vervoer van de produkten, de waterverliezen tijdens irrigatie van de gewassen en rekening houdend met de vereisten voor gewasrotaties. Operationele planning, zoals hier gedefinieerd, is een probleem met meervoudige doelstellingen, en vereist een ruimtelijk beslismodel om een ruimtelijk gespecificeerd landgebruiksplan te ontwerpen. Deze fase resulteert in een operationeel plan, dat in overeenstemming is met het taktische plan, en rekening houdt met de bio-fysische geschiktheid van het land en de doelstellingen van het management. Alle

ondersteunende plannen worden afgeleid van het operationele plan.

Het deelsysteem voor landgebruiksplanning is getest op een areaal van 2091 ha (Sectie 3 van MAIC). Analyse van de resultaten toonde aan, dat:

Het model voor bio-fysische landevaluatie, na calibratie, opbrengsten reproduceert, die redelijk overeenkomen met experimentele resultaten. Dit betreft zowel vergelijking van gesimuleerde opbrengsten (met gebruik van aktuele dagelijkse weersgegevens) met beschikbare proefgegevens, als vergelijking van gesimuleerde opbrengsten (met gebruik van langjarig gemiddelde weersgegevens) met gemiddelde opbrengsten in de streek op goed geleide bedrijven, als gerapporteerd door Jamee (1990a; 1990b).

Het taktische planningmodel in staat is optimale bouwplannen (scenario's) te genereren, op basis van de bio-fysische potenties van het land, en rekening houdend met knelpunten op beheersniveau (best haalbare oplossing). Tevens werd geillustreerd, hoe op basis van deze resultaten in een 'post-model' analyse de economische waarde van de verschillende produktiemiddelen kan worden gekwantificeerd. Deze uitkomsten kunnen worden gebruikt om een optimaal bedrijfsbeleid af te leiden, op basis van het gegenereerde operationele plan.

In de loop van de operationele planningsprocedure kan de planner beslissen over de volgorde waarin de verschillende gewassen aan de verschillende percelen worden toegewezen. Deze toewijzing is gebaseerd op de bio-fysische geschiktheid, de waterverliezen tijdens irrigatie en de transportkosten van de produkten naar de afleveringspunten. Op basis van deze criteria, en daarnaast rekening houdend met rotatieeisen, genereert het model een optimaal bouwplan.
Analyses hebben aangetoond, dat de bouwplannen afgeleid uit het taktische planningmodel en die afgeleid uit het operationele planningmodel, gemiddeld voor 96 % overeenkwamen.

De ontwikkelde procedure een verbetering inhoudt van de gebruikte methoden voor landgebruiksplanning, waarbij belemmeringen, die het gebruik van bestaande informatie in beheersbeslissingen beperken, voor een groot bleken te zijn opgeheven. Daarnaast biedt het systeem een raamwerk voor identificatie van de benodigde gegevens uit verschillende disciplines, ontwerp van de relevante databases en de daarmee samenhangende organisatie, de omzetting van gegevens in informatie en tenslotte de integratie ten behoeve van beheersbeslissingen.

Het hier gepresenteerde informatiesysteem is een verbetering ten opzichte van bestaande systemen, in de zin dat het drie typen modellen integreert, namelijk gewasgroeisimulatie, optimalisatie en ruimtelijke allocatie, ten behoeve van landgebruiksplanning.

# Biography

Mohammad Ali Sharifi was born in Towiserkan, Iran, on 30 December 1944. In 1967, he obtained his MSc degree in forestry from the Agricultural College of the University of Tehran. He then received a postgraduate diploma and MSc degree in photogrammetric engineering from ITC in the Netherlands in 1972 and 1973. His MSc thesis at ITC was one of the first research projects in Europe on data compression of remotely sensed data. He has followed a number of courses in various countries in computer systems and application software, remote sensing hardware and software, information system development and intellectual property systems. He has also taught courses in photogrammetry and remote sensing applications at university level in Iran. He has contributed to many national, regional and international workshops, seminars and conferences related to the application of remote sensing and geographic information systems. He has been author and co-author of more than thirty professional papers, articles, lecture notes and books.

In his career, he has served in various capacities, e.g., remote sensing specialist, director general of the informatics and remote sensing department, and excutive manager of satellite application projects in the Ministry of Agriculture and Natural Resources of Iran, and scientific deputy of the Iranian Research Organization for Science and Technology. He has been involved in the design and implementation of large forest inventory projects, development of remote sensing hardware and software, application of remote sensing in the management of agricultural resources, land use planning, macro-planning of the agricultural sector, definition of research priorities in the field of agriculture and information system development.