

AEZWIN

An interactive multiple-criteria analysis tool for land resources appraisal



**International Institute for
Applied Systems Analysis**



**Food
and
Agriculture
Organization
of
the
United
Nations**

AEZWIN
**An interactive multiple-criteria analysis tool
for land resources appraisal**

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Preface

Since the early 1980s the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA) have been collaborating on expanding FAO's agro-ecological zones (AEZ) methodology of land resources appraisal by incorporating decision support tools for optimizing the use of land resources. Agro-ecological zoning involves the inventory, characterization and classification of land resources for assessment of their potential for agricultural production systems.

This effort culminated in the publication in 1994 of the Kenya AEZ software for MS-DOS PCs for application in national and sub-national level AEZ studies. The decision support tools included in the software consisted of the application of linear optimization techniques for analysing land use scenarios with regard to single objective functions, such as maximizing agricultural production or minimizing the cost of production under specific physical environmental and socio-economic conditions and constraints.

The software package documented in this report is an upgraded version for WINDOWS 95 and NT of the Kenya AEZ software. It has been developed in continuation of collaborative AEZ work between FAO and two projects of IIASA, namely, the Land Use Change and the Risk, Modelling and Policy (formerly Methodology of Decision Analysis) projects. When evaluating the performance of alternative land utilization types, often the specification of a single objective function does not adequately reflect the preferences of decision-makers, which are of a multi-objective nature in many practical problems dealing with resources. Therefore interactive multi-criteria model analysis (MCMA) has been introduced and applied to the analysis of AEZ models.

This new computer program features modules for data management, land suitability and land productivity assessment and multiple-criteria model analysis (MCMA) tools for land use optimization. The software makes it possible to interactively generate models corresponding to various scenarios of land use and then to analyse these models using the MCMA software tools. A user-friendly interface with on-line tutorial has been implemented in order to permit use of the software also by persons with only very basic computing experience.

The software package is a specialized tool meant primarily for two kinds of use:

- land resources appraisal studies for land use planning and management. Potential users include land resources and land use specialists, agricultural and environmental planners in government ministries and research institutions. Capability to adapt the system to the user's own needs and to develop the required databases and scenarios is a prerequisite to use the software in projects and studies.
- to teach and research the AEZ methodology of land resources appraisal. Users are University teachers, students and postgraduate researchers. This manual is for the above mentioned technicians and not for casual users.

Good knowledge of the FAO AEZ methodology, as described in the Kenya AEZ study, is required in order to use the system. The full documentation of the Kenya AEZ study is available from FAO.

Acknowledgements

This software package was prepared under the guidance and supervision of Mr. J. Antoine, Senior Officer, Soil Resources, Management and Conservation Service (AGLS) of the Land and Water Development Division of FAO.

This collaborative effort between IIASA and FAO would not have been possible without the foresight and willingness of the concerned directing staff. In particular the active support provided during the period of the preparation and testing of the software by Mr P Koohafkan (Chief, AGLS, FAO) and Mr R. Brinkman (former Director of the Land and Water Development Division), FAO) is acknowledged.

The three main developers of the AEZWIN software package acknowledge and appreciate the contributions of the following staff of the Warsaw University of Technology:

- Mr Pawel Białoń who developed the lpgen2 program and several dialogs in AEZWIN.
- Mr Grzegorz Wójcik who developed a tool for converting a single source documentation in the form of L A T E X (with additional styles) into three types of documents, namely a standard L A T E X document, the HTML files, and the restricted HTML files accepted by a portable zHelp utility. The tool also generates a dictionary that makes it possible to implement a context sensitive help in a C++ program.

The authors would also like to thank Messrs Jacques Antoine and Wolfgang Prante of FAO and Mr Ponce Hernandez, Trent University, for their detailed comments on both the software and the manual. Their suggestions have helped to improve the documentation, user interface and organization of the software distribution.

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Acronyms

| | | |
|--------|---|---|
| AEC | : | Agro-ecological cell |
| AEZ | : | Agro-ecological zone |
| AEZCCS | : | Agro-ecological zone country case study |
| AEZWIN | : | AEZ for Windows |
| DSS | : | Decision support system |
| FAO | : | Food and Agriculture Organization of the United Nations |
| GIS | : | Geographic information system |
| GUI | : | Graphical user interface |
| IIASA | : | International Institute for Applied Systems Analysis |
| LGP | : | Length of growing period |
| LP | : | Linear programming |
| LRI | : | Land resource inventory |
| LUAM | : | Land use allocation model |
| LUT | : | Land utilization type |
| MCMA | : | Multiple criteria model analysis |
| ISAAP | : | Interactive specifications and analysis of adjunction-based preferences |
| UNFPA | : | United Nations Funds for Population Activities |
| USLE | : | Universal soil loss equation |

Chapter 1

Introduction

The purpose of this document is to describe the Decision Support System (DSS) called AEZWIN, which has been designed and implemented for the interactive multiple criteria analysis of agro-ecological land resources assessment for agricultural development planning. AEZWIN stands for **AEZ** for Windows, where AEZ is traditionally used for the applied methodology of land resources assessment described in Fischer and Antoine (1994a).

Agro-ecological zoning involves the inventory, characterization and classification of the land resources that are meaningful for assessments of the potential of agricultural production systems. This characterization of land resources includes components of climate, soils and landform, basic for the supply of water, energy, nutrients and physical support to plants.

Since the early 1980s, the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA) have been collaborating on expanding FAO's agro-ecological zones (AEZ) methodology of land resources appraisal by incorporating decision support tools for optimizing the use of land resources. Initially these tools consisted in the application of linear programming techniques for analysing land-use scenarios with regard to single objective functions, such as maximizing agricultural production or minimizing the cost of production under specific physical environmental and socio-economic conditions and constraints. Often the specification of a single objective function does not adequately reflect the preferences of decision-makers, which are of a multi-objective nature in many practical problems dealing with resources.

The objectives of developing AEZWIN are twofold:

- First, to provide a user-friendly interface to the software documented in Fischer and Antoine (1994b). For the sake of brevity the abbreviation AEZWIN is used to label this software.
- Second, to allow for Multiple-Criteria Model Analysis (MCMA) integrated with the AEZWIN on a PC computer. The methodology and software used for MCMA are documented in a paper by Granat and Makowski (1998).

AEZWIN is aimed at supporting interactive analysis of agricultural land-use options. An example of such analysis is documented in two papers by Antoine, Fischer and Makowski (1996), and Antoine, Fischer and Makowski (1997). However, the analysis presented in these papers required a cumbersome procedure that consisted of the generation of a core model using the AEZ software on a PC, then converting the core model into the LP DIT format on a Unix workstation. Interactive analysis of the model required also a Unix workstation. AEZWIN supports all of the functionality of the AEZ and it replaces the traditional batch mode type use of the AEZ by the MS-Windows user interface and allows for integrated generation and multiple criteria analysis of land resources models.

Because of the current software distribution policy (AEZWIN is available only directly from FAO whereas MCMA is distributed both by FAO and by IIASA) the description and documentation of the software has been split into two separate papers. First, this paper documents the AEZWIN. Second, MCMA is documented in a IIASA paper prepared by Granat and Makowski (1998), which contains also a detailed tutorial guide to MCMA based on the AEZ model. Therefore both papers should be consulted by users of AEZWIN. The papers can be obtained from IIASA.

This document is organized in the following way. Chapter 2 gives some methodological background of AEZ. The structure of the entire AEZWIN DSS is described in Chapter 3. Chapter 4 provides technical details about the hardware requirements and installation procedure. Chapter 5 briefly summarizes the use of AEZWIN. Chapter 6 provides some examples of AEZ use. The core model utilized in AEZ is described in Chapter 7. Chapter 8 contains a detailed tutorial for using AEZWIN and MCMA. Some trouble-shooting procedures can be found in Section 9. Section 10 contains information about the availability of the software and about guidelines for coping with problems. Appendix A documents coding schemes for the Kenya example.

Chapter 2

Methodological background

The potential for sustainable food production, including meat and milk, is determined, on one hand, by environmental factors, primarily by soil and climatic conditions, and, on the other hand by a complex interplay of socio-economic, cultural and technological factors, such as farm sizes, level of farming and livestock inputs, management practices including soil conservation and enhancement, veterinary services, economic factors like market prices and access, credit availability, education and extension services. At any given point in time¹, there are limits to the sustainable levels of crop and livestock production obtainable from a plot of land, and hence limits to the human and livestock population that can be supported from any area.

Development of land resources to meet food needs of growing populations should be based on an integral assessment and consideration of environmental, social and economic factors. Development policies in the past, while focusing on economic and social considerations, have largely ignored the environmental issues. Recognizing the critical importance of resource literacy, the FAO, with the collaboration of IIASA, developed a land resources database and the agro-ecological zoning (AEZ) methodological framework to assess food production and population supporting potentials in developing countries.

This involves linking land-use options with other development goals in such areas as food production, food self-sufficiency, cash-crop requirements, population supporting capacity, issues of soil fertility constraints, soil erosion risks and land degradation. The AEZ approach was first applied in a global study of Land Resources for Populations of the Future (FAO/IIASA/UNFPA, 1983), which focused on the determination of ecological potential of land resources for food production and the appropriate policies for their management. Subsequently, the AEZ methodology has been extended, refined and utilized in national and sub-national assessments of land productivity and population supporting capacity in various countries, such as Bangladesh, China, Mozambique, Nigeria, the Philippines, and Thailand.

The AEZ methodology to assess the crop and livestock production potential includes the following principles that are fundamental to any sound evaluation of land resources:

- application of an inter-disciplinary approach, based on inputs from crop ecologists, pedologists, agronomists, climatologists, livestock specialists, nutritionists, economists, GIS specialists and sociologists;
- land evaluation is only meaningful in relation to specific land uses;
- land suitability refers to use on a sustained basis, i.e., the envisaged use of land must take account of degradation, e.g. through wind erosion, water erosion, salinization or other degradation processes. Soil regeneration, especially at the low input level, is assumed to be

¹ The capacity of land to support people and livestock, sometimes termed carrying capacity, is understood as a dynamic concept. At any given point in time, however, the available technology, capital stock, human and natural resources define an upper limit to that supporting capacity.

achieved by means of fallowing land, appropriate crop rotations and soil conservation measures;

- evaluation of production potential with respect to specified levels of inputs, e.g., whether fertilizers are applied, if pest control is effected, if machinery or hand tools are used (agricultural inputs and farming technology);
- different kinds of land use must be considered in the context of meeting national or regional food crop-mix and livestock products demand;
- different kinds of livestock feed resources must be considered, e.g., natural pastures and browse, sown pastures, crop residues and by-products and feed concentrates, in the context of meeting seasonal and spatial feed requirements.
- land-use patterns must be constructed so as to optimize land productivity in relation to political and social objectives taking into account physical, socioeconomic and technological constraints.

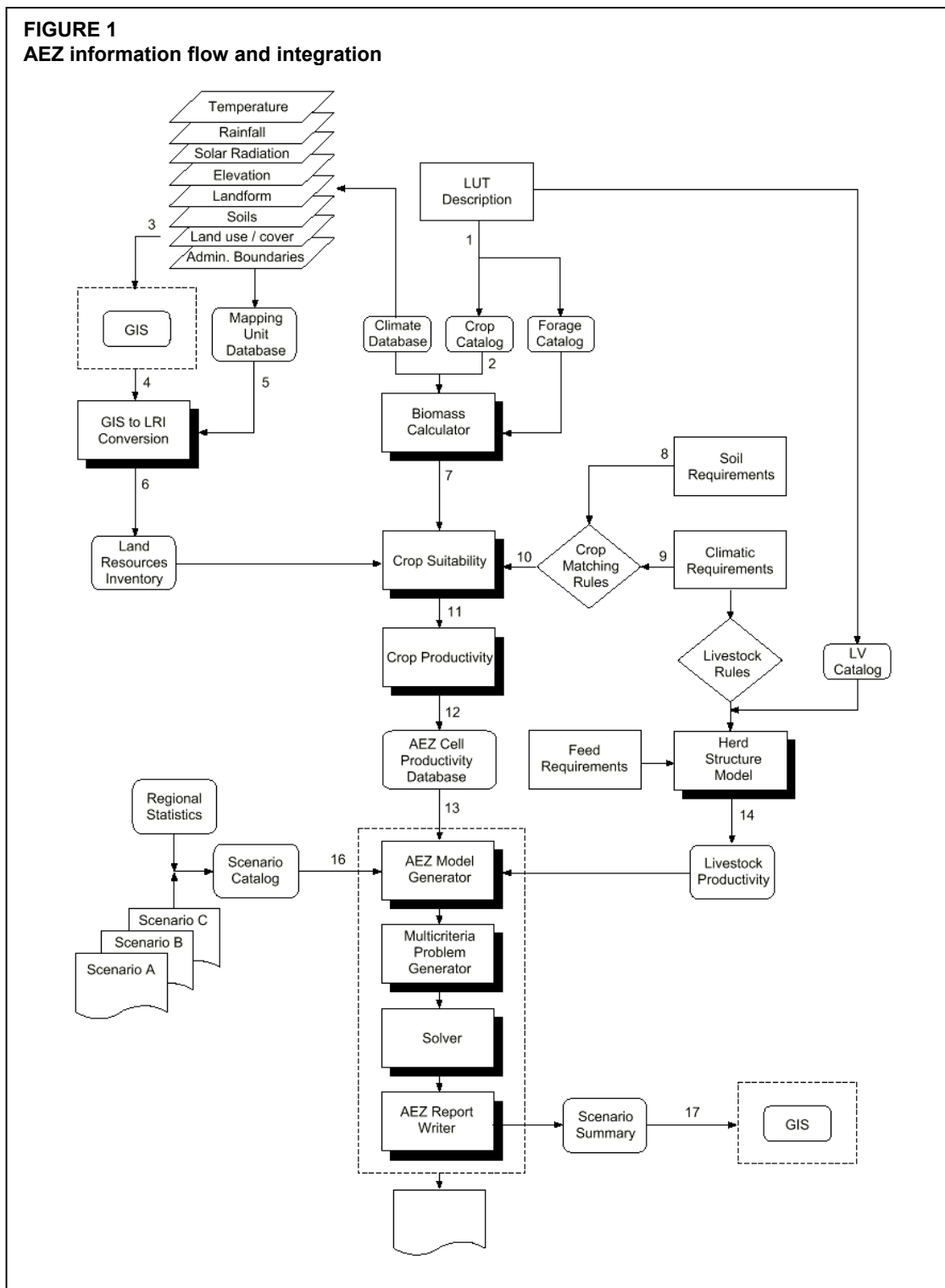
AEZ INFORMATION FLOW

Figure 1 gives a general overview of the flow and integration of information as implemented in the AEZ Kenya case study. In the following explanations the numbers in brackets relate to the numbering used in Figure 1.

- (1) LUT descriptions: These define the fundamental objects of analysis that comprise the set of alternative activities available to achieve specified objectives. The first step in an AEZ application is the selection and description of land utilization types (LUT) to be considered in the study. FAO (1984) characterizes a LUT as follows: *"A Land Utilization Type consists of a set of technical specifications within a socio-economic setting. As a minimum requirement, both the nature of the produce and the setting must be specified"*. It is suggested that the description of LUTs is prepared according to a hierarchical structure that defines, for example,
 - elements common to all land utilization types: typically such elements would include the socio-economic setting of a (fairly homogeneous) region for which a number of land utilization types may be defined (Level 1);
 - elements common to certain groups of land utilization types: e.g. several land utilization types could be defined for a particular farming system. Holding size, farm resources, etc., could be recorded at this level of LUT description (Level 2);
 - elements specific to particular land utilization types: crop specific information such as cultivation practices, input requirements, cropping calendar, utilization of main produce, crop residues and by-products are to be described at this level (Level 3).

The specific aspects that can be meaningfully included in the description and the amount and detail of quantitative information provided, must match the needs and scale of the application. For example, the AEZ Kenya study distinguishes 64 crop LUTs, 31 fuelwood LUTs and a synthetic² grassland LUT, each at three levels of input. Also, 10 representative livestock systems are considered per input level.

² Twenty-four grass and eight legume pasture species were rated in relation to temperature regime and moisture availability, and combined into a generalized grassland productivity assessment, assuming that for different ranges of environmental conditions respectively the most suitable and productive species would dominate, depending on level of inputs.



- (2) The term 'Crop Catalogue' refers to a computer representation of the quantitative aspects of the LUT description in a database format. At minimum, the parameterization will contain information on the photosynthetic pathway, crop adaptability group, crop cycle length, temperature thresholds, harvest index, etc.

- (3) The assessment of alternative land utilization types is performed for a set of land units, i.e., areas of land with specific and distinguished characteristics. In the modeling, the defined land units represent unique and homogeneous land management units. In practice, land units are often obtained by superimposing various thematic maps (in raster or vector format) regarding aspects such as different attributes of climate, soils, landform, slope, vegetation, present land use, and administrative boundaries.
- (4) For storage and manipulation of complex spatial information, the geographic datasets are best entered into a geographic information system (GIS).
- (5) Additional attribute data related to the mapped information, e.g., a description of soil mapping units in terms of soil associations, soil phases and texture classes, landform, slope, etc., is linked to the polygon geometry or grid-cells of the digital maps in the form of attribute tables.
- (6) Combining overlaid spatial information with the contents of relevant attribute files results in the creation of unique (in terms of a set of selected attributes such as thermal regime, moisture regime, soil type, slope class, etc.) georeferenced extents of land units, termed agro-ecological cells (AEC), which form the basic unit of analysis used in AEZ applications at the highest level of resolution. The groupings of AEC form Agro-ecological zones. The collection of all agro-ecological cells constitutes the land resources inventory (LRI). The fairly detailed land resources inventory (compiled at scale 1:1 million) used in the Kenya study distinguishes some 90000 agro-ecological cells.
- (7) The methodology used in regional or national AEZ applications for determination of agronomically attainable yields in an agro-ecological cell proceeds in three steps: it starts out from estimation of maximum agro-climatic yield potential as dictated by climatic conditions. Biomass accumulation is described in terms of photosynthetic characteristics and phenological requirements, to calculate a site-specific constraint-free maximum yield. Then agro-climatic constraints are assessed to derive agronomically attainable yields taking into account yield losses occurring due to temperature limitations, moisture stress, pests and diseases, and workability constraints. Attainable yields are estimated for different levels of management and inputs.¹
- (8) Crops, grasses and fuelwood species, as well as livestock species have climatic requirements that must be known for suitability assessment. These include, for instance, temperature limitations for cultivation, tolerance to drought or frost, optimal and marginal temperature ranges for cultivation, and, for some crops, specific requirements at different phenological stages.
- (9) To match soils to the requirements of particular land utilization types, soil requirements of crops must be known. These requirements must be understood within the context of limitations imposed by landform and other features which, perhaps, do not form a part of soil but may have a significant influence on the use that can be made of the soil. Distinction is made between internal soil requirements of crops, such as soil temperature regime, soil moisture regime, soil fertility, effective soil depth for root development, and chemical soil

¹ For in-depth agronomic assessments, when available data permits, crop growth simulation models, such as the WOFOST (van Diepen, Rappoldt, Wolf and van Keulen, 1988) and CERES (Jones and Kinioy, 1986; Ritchie, Godwin and Otter-Nacke, 1988) models could be used to derive attainable LUT crop yields.

properties, and external requirements related to soil slope, occurrence of flooding and soil accessibility.

- (10) Matching rules for comparing requirements of crops, forage and livestock to the attributes of a particular agro-ecological cell are devised by experts (or modelling) and stored in a database.
- (11) As a result of the agro-climatic and agro-edaphic matching procedures, each agro-ecological cell is characterized in terms of several suitability classes for all land utilization types relevant in that location.
- (12) Based on crop suitability, the productivity assessment considers important factors that impact upon the production levels that can be attained as average on an annual basis: (i) production increases due to multiple cropping resulting from intensification of cultivation in space and time, (ii) productivity losses due to soil erosion. (iii) Since the productivity estimates relate to production on a sustainable basis, fallow requirements, to maintain soil fertility and structure and to counteract soil degradation caused by crop cultivation, are imposed depending on climatic conditions, soil type, crop group, and level of inputs and management.
- (13) The productivity assessment records input level specific production of relevant and agro-ecologically feasible cropping activities; the information stored includes amounts of main produce and by-products, input requirements, and estimated soil erosion. The algorithms applied impose a filter which eliminates activities that are ecologically unsuitable in the agro-ecological cell under consideration, too risky with respect to climatic uncertainties, environmentally unacceptable, (i.e., too high erosion) or much inferior to other possible activities in this land unit in terms of both expected economic benefit and nutritional value. At this stage of the analysis a database is created that contains for each agro-ecological cell quantified information on all feasible land utilization types. This database can be used to tabulate or map potential arable land by crop or zone; but more important, the database contains the necessary geo-referenced agronomic data for district or national planning scenarios.
- (14) The performance of livestock systems is estimated in two steps: (i) describing a representative herd composition, by age and sex, fertility rates and mortality, and (ii) quantifying production of meat, milk and other outputs in relation to different management levels and feed quality. Input to output relationships of livestock systems, expressed per reference livestock unit, are recorded in a livestock systems productivity database, as feed requirements and resulting production of the total herd for use in the planning model.
- (15) Planning scenarios in the AEZ application are specified by selecting and quantifying objectives and constraints related to various aspects such as demand preferences, production targets, nutritional requirements, input constraints, feed balances, crop-mix constraints, and tolerable environmental impacts (i.e., tolerable soil loss). Given the large number of agro-ecological cells and variety of LUTs to be taken into consideration, the objective function and the constraint set of the district planning model have been defined by linear relationships to allow for application of standard linear programming techniques in the interactive decision support system.

- (16) Different sets of assumptions, e.g. regarding population growth, availability and level of inputs, consumer demand, etc., are stored in the scenario catalogue, a database used by the application programs.
- (17) Output from the AEZ application report writer is kept in a scenario summary database and can be passed to a geographical information system (GIS) for visualization of the results.

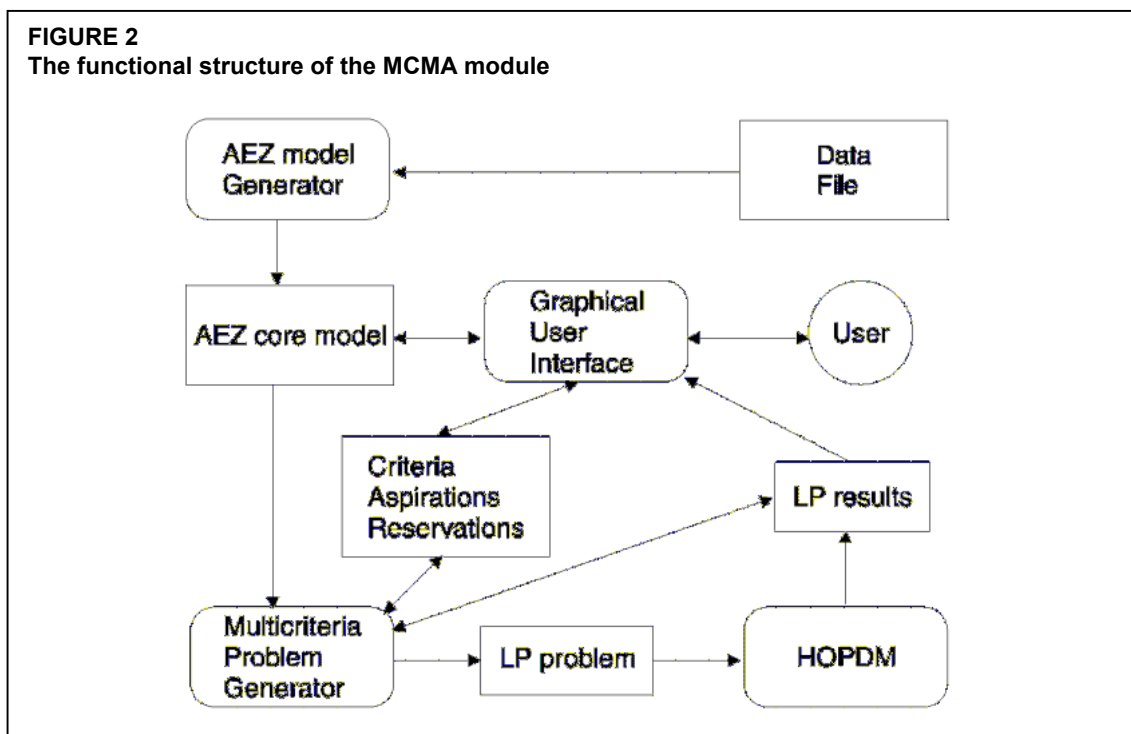
Several of the steps sketched above will be illustrated and further explained in the AEZ Tutorial. Before doing so, however, it is recommended to install the software system for hands-on practicing.

Chapter 3

Structure of the DSS

A user-friendly graphical user interface (GUI) implemented in most interactive decision support systems (DSS) makes it easy to use a DSS. However, for effective application of a DSS for actual decision support it is necessary to understand the structure and the functionality of each component. The purpose of this section is to provide this background.

The general structure of the Decision Support System that can be applied also to other problems is illustrated in Figure 2. An important and problem specific component of this structure is a core model generator. In order to provide the user with a uniform interface for the generation and analysis of a scenario of the AEZ model, a specialized application, called AEZWIN, has been developed. The components of the AEZWIN DSS are illustrated in Figure 3.



A pilot implementation of the Multiple-Criteria Model Analysis (MCMA) to the analysis of AEZ is described in Antoine et al. (1996). Its functional structure is illustrated in Figure 2. The functional structure of the DSS presented in this paper resembles the one illustrated in Figure 3.¹

¹ Note, that for the sake of keeping the presentation simple the MCMA part is presented in more detail only in Figure 2

The main difference between the pilot and the current implementation is the direct link between the Graphical User Interface (GUI) and the AEZ model generator. The AEZ model generator is part of a system of programs and data files as documented in detail in (Fischer and Antoine, 1994b).

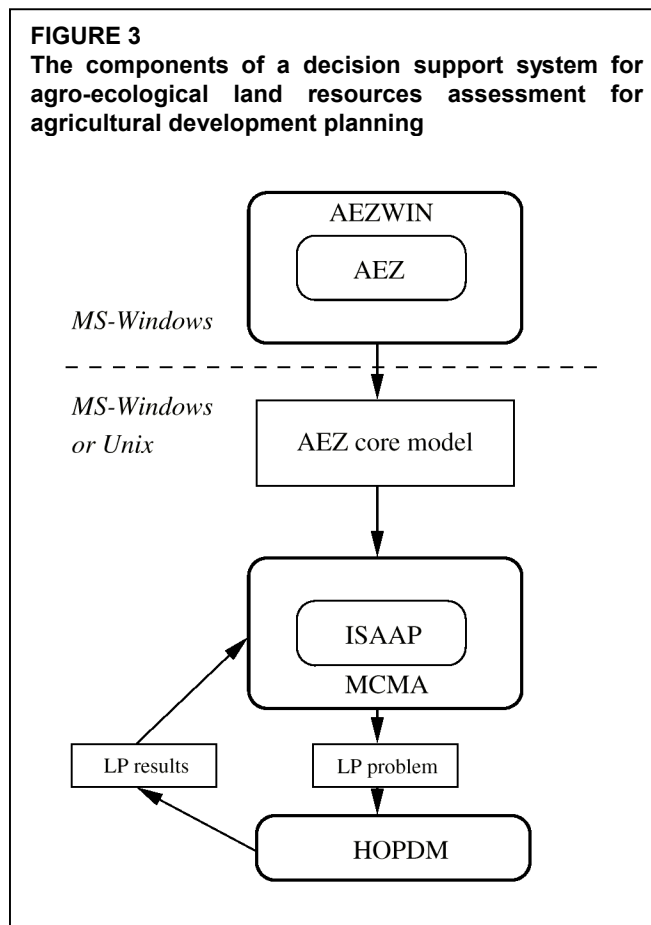
First, a user must generate the AEZ core model (which is an instance of the AEZ core model for a specific region and for selected scenario assumptions). Selection of a scenario and its basic parameters is achieved interactively (see Chapter 5 for details). The scenario-specific core model generation must currently be done on a PC. However, the remaining part of the analysis can be done either on a PC or on a Unix Workstation (the latter might be preferable for large problems). After generating an instance of the AEZ core model, the user can start the interactive multiple-criteria analysis (MCMA) of this model. The MCMA implemented with AEZWIN is based on aspiration-reservation led multiple-criteria model

analysis and the Interactive Specifications and Analysis of Adjunction-Based Preferences (ISAAP) modular tool documented in Granat and Makowski (1998). The aspiration-reservation based multiple-criteria optimization uses a natural way for specifying user preferences in terms of desired values of criteria, and its implementation in ISAAP is intuitive. Nevertheless, multi-criteria model analysis will be a new tool for many users. Therefore a detailed tutorial (based on an instance of the AEZ core model) of using MCMA is provided in Granat and Makowski (1998). The use of the remaining parts of the AEZWIN DSS illustrated in Figure 2 and 3 is transparent to the user, the sequence is as follows:

- The multiple-criteria problem is generated and is converted into a single-criterion parametric problem (see Makowski (1994b) for details).
- The corresponding single-criterion model is generated in the LP DIT format (see Makowski, (1994a); Makowski, (1998)) for the background and documentation).
- A robust and fast LP solver is provided for computing Pareto efficient solutions. The solver, called HOPDM, based on the Interior Point Method (see Gondzio and Makowski (1995) for details) makes it possible to interactively solve medium size LP problems on a PC.
- The resulting Pareto-optimal solution is provided in two forms: graphical and numerical.

Hence, from the user point of view, one instance of a multi-criteria problem is generated and solved automatically.

The AEZWIN allows to generate the core model and to perform its analysis on a PC running Windows 95/NT (see Chapter 4 for details).



Chapter 4

Software installation

HARDWARE REQUIREMENTS

The recommended hardware for using the AEZWIN DSS described in this document should include:

- a personal computer (PC) with a Pentium processor,
- 32 MB RAM,
- 100 MB disk space.

The minimum hardware requirements are as follows:

- 486 PC (min. 486DX because a mathematical co-processor is required),
- 16 MB RAM,
- 50MB disk space.

Both AEZWIN and MCMA require 32 bit MS-Windows; the current software has been developed and tested with MS-Windows 95 and MS-Windows NT. To obtain the dialogs in the same form as reproduced in this tutorial a 15 inch display supporting a resolution of 1024 x 768 should be used.

INSTALLATION PROCEDURE

The software is being distributed by file transfer protocol (ftp) in the form of a self-extracting archive named install.exe and on CD-ROM. The software must be installed in the root directory of a hard disk drive. It is recommended to install AEZWIN on a local hard disk (rather than a network drive) because the software may run much slower¹ (due to heavy use of input/output functions) on a networked drive.

The following procedure is recommended for installing the AEZWIN software:

1. Go to the root directory of the hard disk where the software will be installed.
2. Rename (or remove) aez or/and aezwin directory(ies) if already existing in the root directory on the selected drive.
3. Copy the self-extracting archive named install.exe to the root directory of the selected drive.
4. Run: install

Note: After executing install you will see a dialog entitled:
WinZip Self-Extractor [install.exe].

¹ Some functions have been measured to execute more than 10 times slower on a networked hard disk.

Please make sure that the folder to which you unzip all the files will be defined as C:\ (where C: can be replaced by any other valid drive letter corresponding to your hard disk) and click on the button Unzip.

5. Move the install.exe file to a place where software back-up copies are kept.
6. Change directory to aezwin and - depending on the version of the MS-Windows operating system that you use - make one of the following modifications:
 - for Windows'95: remove file aezwin.exe and rename aezwin95.exe to aezwin.exe
 - for Windows NT: remove file aezwin95.exe
7. Make sure that the executable files located in the \aezwin\ directory can be executed from any directory. This can be achieved by one of the following actions:
 - add the \aezwin\ directory to your PATH (this can be done, for example, by a modification of your autoexec.bat file; in such a case the computer must be rebooted).
 - experienced users of Windows 95/NT may want to move the executable files located in the \aezwin\ directory to any other directory that is included in the PATH environment variable. This will allow for executing programs from a DOS box regardless of the current working directory.

Chapter 5

User's guide to AEZWIN

The AEZWIN is a Graphical User Interface (GUI) to the application programs of the AEZ software, see Fischer and Antoine (1994a), consisting of a set of programs implemented under the MS-DOS system. These programs were originally called by several batch files. They have now been replaced by AEZWIN providing a menu option for selection. Additionally, AEZWIN integrates the Multiple-Criteria Model Analysis (further on referred to as MCMA) with the AEZ application programs.

INVOKING AEZWIN

The aezwin program can be invoked (like any other application running under MSWindows'95) in several ways, for example:

1. Double-click from the FileManager or Explorer the aezwin.exe file name.
2. Use the Run command and specify the aezwin.exe name.
3. Create a short cut pointing to \aezwin\aezwin.exe.
4. If the aezwin program is located on a path, then it can be executed from a DOS box.

The default working directory used by AEZWIN is located in \aezwin\work. All files generated by AEZ will be placed in directories as described in the documentation of AEZ, see (Fischer and Antoine, 1994b). All other files generated by AEZWIN and MCMA will be located in the working directory¹.

MENU SYSTEM

Figure 4 shows the main window of the AEZWIN program. This window is composed of three parts: main menu, info window and status line. The info window contains the title of the application. The status line (located at the bottom of the window) is used for displaying descriptions of a current selection from a menu. In the right corner of the status line current time is displayed, in the two small windows next to it the status of the NumLock and CapsLock keys is displayed when activated.

The main menu of AEZWIN is composed of eight menu items. Each menu consists of a pull-down submenu with items that are listed below:

1. **Database** - to import, export or modify records in the AEZ database, other than the land inventory. The following sub-menu items are available:
 - **Import Data** - select this option to import crop suitability rules and other information from ASCII text file format into the database system.

¹ The Users' Guide and Tutorial are based on Kenyan datasets which are readily available in AEZWIN.

- **Modify DB** - select this option to enter the rule database for browsing or editing.
 - **Prepare data** - select this option to prepare necessary data files before calculation of attainable yields (program AEZCCS02) and crop productivity (program AEZCCS03).
Note: this step must be repeated whenever the database is modified and the changes should be reflected in the analysis.
 - **Export data** - select this option to export crop suitability rules and other information from the database to ASCII text file format.
2. **Land Resources** - to view inventory files and to calculate, view or print various statistics from the land resources inventory. The following sub-menu items are available:
- **View inventory** - select this option to load the land resources inventory file of the currently selected district into the configured editor¹.
Note: a district configuration remains current, even over different sessions, until explicitly changed (as explained further down).
 - **Statistics** - this menu selection loads a program for two-way and three-way cross-tabulation of the fields in the land resources inventory. The default configuration processes the inventory for all of Kenya regardless of the currently selected district.
Note: running the cross-tabulation program will overwrite any previous output from the program. Therefore, if you want to retain output files you must rename or copy them before re-running the cross-tabulation program.
 - **View** - select this option to load the results of the last cross-tabulation into the default editor.
 - **Print**² - send the results of the last cross-tabulation to the printer.
3. **Yields** - generate average agronomically attainable yields by agro-climatic zone. The following sub-menu items are available:
- **Generate Table** - select this option to run the yield generator, program AEZCCS02, for the currently selected input level.
Note: this step is necessary before any crop suitability or district analysis can be performed.
 - **Print** - select this menu option to print the yield table created during the last execution of program AEZCCS02. Be warned that depending on the setting of print options, the file can be quite large.
4. **Crop Suitability** - run the crop suitability assessment and determine the extents of land with cultivation potential for the currently configured district (or province) and input level. The following sub-menu items are available:
- **Set district/scenario** - choose this option to change the current selection of district and/or level of input.

¹ Since the land resources inventory district files are not write-protected, care should be taken while viewing the files to avoid unwanted modifications. Currently, printing can be achieved when viewing results with the Notepad accessory

² The Print option is shown in most submenus. However, this option is still under development. Therefore printing options can not be activated (they are dimmed, hence none of them can be selected).

- **Create suitability table** - this menu selection loads a program that reads the land resource inventory file of the configured district and assesses each record, i.e. agro-ecological cell, in terms of crop suitability for all specified LUTs and tabulates the results in five productivity classes.
- **View** - select this option to load the results of the last suitability tabulation for the presently configured district and input level into the default editor.

Note: Create suitability table must be run before trying to view the results.

- **Print** - send the results of the last suitability tabulation for the presently configured district and input level to the printer.
5. **Productivity** - construct for each agro-ecological cell the feasible multiple (sequential) crop combinations, evaluate crop production options and filter out the best alternatives for later consideration in district analysis. The following sub-menu items are available:
 - **Set district/scenario** - choose this option to change the current selection of district and/or level of input.
 - **Create productivity DB** - this menu selection loads program AEZCCS03 and processes the land resources inventory for the currently configured district and input level. The resulting land productivity district database files are stored in directory \aez\kenya\bin¹. The control file read by program AEZCCS03 contains several parameters to configure program options and set the crop combination selection filter.
 6. **Analysis** - select a district for analysis, generate a single objective LP specification file, call the LP-solver, create an AEZ core model file for MCMA, create an LP DIT file, undertake interactive MCMA, create reports of district planning scenarios. The following sub-menu items are available:
 - **Set district/scenario** - choose this option to change the current selection of district, level of input and/or scenario.
 - **SC_Optimization** - this menu selection loads program AEZCCS04, the LP matrix generator, which reads the output file from district land productivity assessment and the respective scenario control file, and prepares a data file for input to a linear programming (LP) package used for single-criterion optimization. The LP solver program is then called for determining an optimal solution to the district planning scenario for the currently configured district, input level and scenario.
 - **View SC_Report** - select this option after having solved a district planning scenario. The menu selection loads the LP Report Writer, program AEZCCS05, which reads the district productivity file, the LP optimal solution file and the district scenario file, and creates tabular output of the results.
 - **MC_problem generation** - select this option to generate a model in LP DIT format.
 - **MC_Model analysis** - to run Multi-Criteria Model Analysis (MCMA); see (Granat and Makowski, 1998) for the documentation and Chapter 6 for a tutorial example.

¹ For disk space and execution speed considerations, the land productivity file is stored as a sequence of sequential binary unformatted records and cannot be viewed in a usual file editor.

- **View MC_Report** - select this option to load the results of the presently configured district, input level and scenario into the default editor.
7. **GIS Functions** - to display various raster images and to transfer control to a GIS system (if available and configured). The following sub-menu items are available:
- **Display maps** - choose this option to view any of the basic or derived thematic maps. With the full installation of the AEZ package the following groups of raster maps are available:
 - (a) Resource base
 - (b) Population
 - (c) Crop suitability
 - (d) Fuelwood species suitability
 - (e) Erosion hazard
 - (f) Miscellaneous
- Note: the raster image files are kept in compressed archives to reduce the required disk space. The display program provided with the KENYAAEZ software package unpacks the requested map and displays it in accordance with the corresponding raster display control file contained in directory `aez\kenya\run\maps`.*
- **IDRISI¹** - call geographical information system IDRISI (IDRISI option is dimmed, hence cannot actually be selected).
 - **Create inventory** - this menu item has been included to allow for re-creation of the land resources inventory files from the basic climatic and soil maps. Re-creation of the inventory is required if any of the ten basic resource maps has been modified. The *Create inventory* option is dimmed, hence it cannot actually be selected.
8. **Help** - to activate an on-line tutorial. There is only one submenu item Contents. Selection of this item provides the user with the choice of the software used for viewing the on-line tutorial.
- Netscape: it is required that a version (4.01 or higher) of Netscape is installed on the same computer on which AEZWIN is run.
 - zHelp: portable viewer that is distributed together with AEZWIN.

Users may prefer one way of accessing the on-line tutorial over the other. It is possible to use both help systems (Netscape and zHelp) simultaneously.

LP-DIT FORMAT FILES GENERATOR

To preserve flexibility of formats, program **lpgen2** has been developed in order to convert the generated model to the LP DIT format, as is required for MCMA. This program is used in a way transparent to the a user by selecting the item LPDIT generator from the Analysis menu of

¹ IDRISI is a primarily grid-based geographic analysis system, developed at Clark University. It is designed to provide inexpensive access to computer assisted geographic analysis technology. The software is protected by United States Copyright Law. Generous academic, student and research licenses are available upon request to: The IDRISI Project, The Graduate School of Geography, Clark University, 950 Main Street, Worcester, MA 01610, USA. The IDRISI software package is not included with this release of AEZ but can provide useful additional functionality.

AEZWIN. Selection of this item results in execution of **aez041g.exe** followed by **lpgen2.exe**. The program **aez041g.exe** is a modified version of the LP-matrix generator program **aez041.exe**. The **lpgen2** takes as the input files generated by **aez041g.exe** and creates the core model in the LP-DIT format. Optionally, **lpgen2** can be used from a command line to generate the MPS file. The following information about the command line options is provided here for using this program from a command line.

lpgen2 has the following command line:

```
lpgen2 -d lpditfile -s specsfile [-m mpsfile] [-c controlfile] [-g]
```

where:

| | |
|----------------|---|
| -d lpditfile | - the name of the output LP DIT format file |
| -s specsfile | - the name of the specs file generated by aez041g.exe |
| -m mpsfile | - optionally the MPS file can be generated |
| -c controlfile | - control file name, which contains temporary file names, generated by aez041g.exe , when this option is omitted the names scrxx.04 are assumed. |
| -g | - turns on human-readable debug information. |

Chapter 6

Exploring AEZ

The previous sections gave an overview of the software installation, introduction to menu options available in AEZWIN. In this Chapter, the use of the database and software system in land suitability and land productivity analysis will be explored.

EXPLORING THE LAND RESOURCES INVENTORY

The land resources inventory brings together several layers of information on physical environmental resources and allows the creation of unique ecological land units (agro-ecological cells) within which land form, soil and climate conditions are quantified and considered nearly homogeneous.

The climatic resource inventory of Kenya records both temperature and soil moisture conditions. The quantification of temperature attributes has been achieved by defining reference thermal zones. As temperature seasonality effects of latitude are minor, temperature zones are closely correlated to altitude ranges (Braun, 1982). To cater for differences in temperature adaptability of crops, pasture and fuelwood species, nine thermal zones have been distinguished, based on ranges of 2.5° Celsius.

Quantification of moisture conditions was achieved through the concept of reference length of growing period (LGP). The reference LGP is defined as the duration (in days) of the period when temperature permits crop growth and soil moisture supply exceeds half potential evapotranspiration; it includes the time required to evapotranspire up to 100 mm of soil moisture storage (FAO, 1981). Growing periods which include a sub-period when precipitation exceeds potential evapotranspiration are termed 'normal' LGPs as compared to 'intermediate' LGPs with no such humid sub-period. The moisture period regime has been inventoried by means of three complementary attributes:

- number of distinct length of growing periods within a year, summarized as a historical profile of pattern of length of growing periods per year (LGPpattern). Twenty-two such LGP-pattern classes are recognized in the Kenya inventory.
- the mean total dominant length of growing period, i.e., the sum of mean dominant and associated length of growing periods occurring during the year. Fifteen LGP zone classes, thirteen spanning 30-day intervals each, plus an all-year-dry and all-year-humid zone, are distinguished.
- year-to-year variability of each length of growing period and the associated moisture conditions.

The map of mean total dominant LGP zones and the map of LGP-pattern zones, together with tabular information on length and probability of occurrence of associated growing periods, provide the historical moisture profile which was compiled from data records of a large number of locations in Kenya.

The Exploratory Soil Map of Kenya (Sombroek, Braun and van der Pouw, 1982), at a scale of 1:1 million, was used to compile the soil resources inventory. 392 different soil map units, describing soil associations or soil complexes composed of dominant soils, associated soils and

inclusions (390 map units) and two map units representing water bodies and major urban areas are distinguished. A mapping unit composition table has been provided (van der Pouw, 1983) containing percentage allocation of the map units by soil type, slope class, soil texture and soil phases. It also contains information on land form and geology/parent material derived from the legend of the soil map.

In addition to the soil and climate information, six other layers of information have been incorporated in the land resources database. They provide information on cash crop zones, forest zones, parkland areas, location of irrigation schemes, tsetse infestation areas, and province and district boundaries.

The individual map layers were digitized and stored in a grid-cell (raster) format of 1085 rows and 900 columns, each grid-cell representing an area of one square kilometer. The land resources inventory combines both geo-referenced information as provided in the different map overlays and statistical information (percentage distribution) as contained in the soil mapping unit composition and slope composition tables. The compilation of the resource inventory includes:

- i. overlaying of map layers to create a spatial database file, and
- ii. application of soil mapping unit composition and slope composition tables to the related attribute data file.

This process produced a collection of about 90 000 data records, called agro-ecological cells. These data records are unique in terms of their geographical locations and the combination of their soils, land form and climate attributes. At this level of detail each agro-ecological cell represents a fairly homogeneous set of agro-climatic and soil physical conditions to adequately match land unit properties with crop requirements.

From the information contained in a land inventory record it is possible to identify the units in the GIS database to which an entry relates. Because of the disaggregation implied by the mapping unit composition table and the slope composition table, usually more than one land inventory record (i.e., agro-ecological cells evaluated) will refer to the same units. Therefore, the results must be aggregated to average values per raster point before transferring to a grid based GIS. The resource inventory file is created by superimposing administrative, climatic, soil and land-use data contained in separate maps. There are 18 attribute fields in a land inventory record as shown in Table 1.

TABLE 1
Land resources inventory attribute fields

| Field | Column | Field contents |
|-------|---------|--|
| 1 | 1 - 2 | province code, class values 1 to 8 |
| 2 | 3 - 4 | district code, class values 1 to 13, depending on province |
| 3 | 5 - 6 | thermal zone, 9 classes |
| 4 | 7 - 8 | mean total length of growing period (LGP), 15 classes |
| 5 | 9 - 10 | LGP-pattern, class values 1 to 22 |
| 6 | 11 - 13 | Kenya Exploratory Soil Map, mapping unit, 392 map units |
| 7 | 14 - 16 | soil unit code, class values 1 to 135 |
| 8 | 17 | coarse material indicator, class values 0 to 6 |
| 9 | 18 - 19 | texture code, class values 1 to 34 |
| 10 | 20 - 21 | phase combination, class values 0 to 73 |
| 11 | 22 - 23 | slope class, 11 classes |
| 12 | 24 - 26 | slope gradient in 1/10 percent |
| 13 | 27 - 28 | cash-crop zone indicator, class values 0 to 19 |
| 14 | 29 | forest zone, class values 0 to 3 |
| 15 | 30 - 31 | irrigation scheme, class values 0 to 21 |
| 16 | 32 | Tsetse infestation, 0=no or 1=yes |
| 17 | 33 | game park, class values 0 to 3 |
| 18 | 34 - 41 | cell extent; size of agro-ecological cell in ha |

The maps are stored in raster format, i.e., data arranged in a grid of 1085 rows and 900 columns of square pixels, each pixel representing an area of one square kilometer. Data is stored by row, from north-west to south-east. In this way, each map contains 976500 grid-cells, of which about 40 percent falls outside the national boundaries (coded as pixel value zero). The land resources inventory (LRI) must be recreated whenever one of the component maps is modified.

The third item, CREATE INVENTORY, available in the sub-menu under main menu option seven, GIS Functions, is provided for that purpose.

The second option under the main menu of AEZWIN, Land Resource, is used to view the land resource inventory, to compile 2-way and 3-way cross-tabulation statistics, and view and print these tables.

Example 1: Cross-tabulation provides statistics on the coincidence of pairs of classes of different resource inventory attributes. For instance, to tabulate the occurrence of forest zones according to different thermal zones, the procedure is as follows:

Step 1: From the main menu choose Land resource.

Step 2: In the sub-menu appearing on the screen, select option two, Statistics.

Step 3: The program prompts for the first attribute field to be selected. Classes of this field will form the rows of the cross-table. Enter 3, to choose the thermal zone field.

Step 4: The program prompts for the second attribute field to be selected. Classes of this field will form the columns of the cross-table. Enter 14, to select the forest zone field.

Step 5: The program prompts for the third attribute field to be selected. This is optional and allows for 3-way cross-tables. Enter 0, as we only want a 2-way table¹

The program starts processing the land resource inventory and report on progress. Processing 3-way cross-tables of the entire LRI may take considerable time.

Depending on software configuration, up to three tables are provided:

- (a) percentage of total area occupied by respective combinations of attribute values.
- (b) row normalized percentages, i.e., distribution of extents with a particular class value of attribute 1 over the entire range of class values of attribute 2.
- (c) column normalized percentages, i.e., distribution of extents with a particular class value of attribute 2 over the entire range of class values of attribute 1.

Table 2 shows row and column normalized results of cross-tabulating thermal zones versus forest zones in Kenya.

For instance, the row-normalized table shows that about half the area in thermal zone T7 (52.1 percent) is in forest class F1. The column-normalized table shows that more than 80 percent (31.6+39.1+11.3 percent) of forest class F1 occur in thermal zones T5 to T7. The border row and

¹ When a third attribute field is selected, the output will contain a 2-way cross-table of the first two attribute fields for each class value of the third attribute, i.e., there is the potential for bulky output.

column of the tables indicate the percentage of area of classes of attribute 2 and attribute 1, respectively.

TABLE 2
AEZ cross-tabulation, thermal zones vs. forest zones

Field 3 (Thermal_Zone) versus Field 14 (Forest_Zone)

After ROW - Normalization

| FOREST THZ | -- | F1 | F2 | F3 | Total |
|---------------|-------|------|-----|-----|-------|
| THZ 1 | 98.9 | .2 | .0 | 1.0 | 66.5 |
| THZ 2 | 100.0 | .0 | .0 | .0 | 9.9 |
| THZ 3 | 99.5 | .5 | .0 | .0 | 7.0 |
| THZ 4 | 97.2 | 2.8 | .0 | .0 | 7.8 |
| THZ 5 | 86.7 | 13.2 | .1 | .0 | 5.9 |
| THZ 6 | 52.5 | 43.5 | 3.9 | .0 | 2.2 |
| THZ 7 | 47.9 | 52.1 | .0 | .0 | .5 |
| THZ 8 | 57.5 | 42.5 | .0 | .0 | .2 |
| THZ 9 | 100.0 | .0 | .0 | .0 | .0 |
| Total | 96.8 | 2.5 | .1 | .7 | 100.0 |

After COLUMN - Normalization

| FOREST THZ | -- | F1 | F2 | F3 | Total |
|---------------|------|------|------|-------|-------|
| THZ 1 | 67.9 | 4.2 | .0 | 100.0 | 66.5 |
| THZ 2 | 10.2 | .2 | .0 | .0 | 9.9 |
| THZ 3 | 7.2 | 1.5 | .0 | .0 | 7.0 |
| THZ 4 | 7.8 | 8.8 | .0 | .0 | 7.8 |
| THZ 5 | 5.3 | 31.6 | 8.4 | .0 | 5.9 |
| THZ 6 | 1.2 | 39.1 | 91.6 | .0 | 2.2 |
| THZ 7 | .3 | 11.3 | .0 | .0 | .5 |
| THZ 8 | .1 | 3.2 | .0 | .0 | .2 |
| THZ 9 | .0 | .0 | .0 | .0 | .0 |
| Total | 96.8 | 2.5 | .1 | .7 | 100.0 |

For instance, the first value in the bottom row of the cross-table shows that most (96.8 percent) Kenyan land does not fall into one of the three forest zone classes; the first value in the last column indicates that about 2/3 of the country (66.5 percent) are in thermal zone T1 (warm tropics, mean annual daily temperature > 25 o Celsius).

GENERATING YIELD TABLES

The third option under the main menu runs a program (AEZCCS02) which generates tables of agronomically attainable primary¹ yield by crop type for all admissible combinations of pattern codes and length of growing period codes. The procedure adds up individual LGP-pattern component yields, using pattern distribution probability weights, to arrive at expected average annual yields (under single cropping). In addition to average yields, expected output under best and worst climatic conditions is calculated. At this stage, the assessment does not yet consider edaphic constraints.

The main body of the program consists of a four-fold nested loop: over two broad soil unit types (Fluvisols and other soils), a range of LGP-pattern codes, a range of length of growing period codes, and a range of crop codes. Growth cycle requirements are tested against the number of days available for plant growth. Minimum, maximum and average yields are stored for input to the land productivity assessment program.

Example 2: In the LRI about 35 percent of Kenya is shown as LGP-pattern zone 13, i.e. LGP-pattern symbol 2-1. According to the pattern proportion table, these areas have two distinct growing seasons in 70 percent of the years, and collapsing into one growing season in the remaining 30 percent of the years. Over 80 percent of the land in LGP-pattern zone 13 has a mean total dominant LGP of less than 120 days². A small fraction of the area is indicated as having a mean total LGP of 210-239 days (LGP code 9). An example of maize yields in that zone is considered below. According to the LGP-pattern rule table, for LGP code 9 in LGP-pattern zone 13 there are:

- (a) two growing periods in 70 percent of years, with a longer component growing period, LGP₂₁, of 120-149 days (component LGP code 6), and a shorter component growing period, LGP₂₂, of 60-89 days (component LGP code 4).
- (b) one component growing period in 30 percent of years, LGP₁₁, of 180-209 days (component LGP code 8).

In this program, both these situations are evaluated and average yields are derived. Table 3³ summarizes information on maize yields in LGP-pattern zone 13 (dominantly bimodal), mean dominant LGP zone 9 (210-239 days), at intermediate level of inputs. Crop types are considered viable only if the growth cycle fits entirely within the longest growing period (long rains) of the dominant LGP pattern component. In this example, the dominant LGP pattern component is bimodal (70 percent of years), the longest component LGP is LGP₂₁ with 120-149 days. From the information in Table 3 it can be concluded that Maize 3 performs best in low-land areas (thermal zone T1-T3, i.e., at an altitude < 1550 metres); in thermal zone T4 (approx. 1550-1950 metres

¹ A crop is termed primary when it occurs first in a sequential crop combination (or is single cropping).

² You could try to verify this statement by cross-tabulating LGP (attribute field 4) versus LGP-pattern (attribute field 5 in LRI)

³ Maize 5 to Maize 9 are refused in the example as the growth cycle does not fit within the longest component LGP of the dominant pattern, i.e., these maize types do not fit within 120-149 days.

altitude) only the shortest high-land maize types, Maize 4 with 120-140 days growth cycle, could be cultivated.

TABLE 3
An example of attainable maize yields at intermediate input level

| Crop | Growth Cycle (days) | Maximum Yield (kg/ha) | Thermal Zone | LGP21 120-149 (kg/ha) | LGP22 60-89 (kg/ha) | LGP11 180-209 (kg/ha) | Average Yield (kg/ha) |
|---------|---------------------|-----------------------|--------------|-----------------------|---------------------|-----------------------|-----------------------|
| Maize 1 | 70-90 | 2370 | T1, T2, T3 | 360 | 1860 | 2540 | 2064 |
| Maize 2 | 90-110 | 3510 | T1, T2, T3 | 0 | 2530 | 3450 | 2806 |
| Maize 3 | 110-130 | 4450 | T1, T2, T3 | 0 | 3200 | 4350 | 3545 |
| Maize 4 | 120-140 | 5320 | T4 | 140 | 3500 | 4880 | 3914 |
| Maize 5 | 140-180 | 5840 | T4 | 0 | 0 | 5200 | 0 |
| Maize 6 | 180-200 | 6440 | T4 | 0 | 0 | 4120 | 0 |
| Maize 7 | 200-220 | 6820 | T5 | 0 | 0 | 4560 | 0 |
| Maize 8 | 220-280 | 4490 | T5 | 0 | 0 | 2500 | 0 |
| Maize 9 | 280-300 | 4500 | T5, T6 | 0 | 0 | 490 | 0 |

LAND PRODUCTIVITY ASSESSMENT

Option 4 on the main menu runs a program (AEZCCSO3) which processes each record of the land resources inventory and computes the production potential by single crop as well as multiple sequential crop combinations taking into account the following characteristics:

- (1) Crop cycle requirements
- (2) Thermal zone suitability
- (3) LGP length and LGP-pattern characteristics
- (4) Soil unit rating
- (5) Slope gradient cultivation factor
- (6a) Coarse material rating
- (6b) Texture rule
- (7) Phase rule
- (8) Inter-cropping increments
- (9) Fallow land requirements

By applying specific rules a productivity factor is calculated relating average attainable yield in an agro-ecological cell to the maximum attainable yield of a particular crop. In each location every admissible crop combination is also evaluated in terms of estimated soil loss due to water erosion.

A record from the land resource inventory file is read and primary production for each crop is calculated under the specific agro-climatic conditions. Crop productivity assessment takes into account water stress, agro-edaphic requirements, inter-cropping increment multipliers, and rest period requirement factors.

If at least one feasible crop, i.e., a crop that is sufficiently productive in the given environment, is identified in the current cell, then relevant cell information is saved and evaluation continues.

As a next step, the factors of the USLE (Universal Soil Loss Equation) are calculated, which are independent of the considered crop combination: the rain erosivity factor, the rain erosivity distribution during the growing period, the soil erodibility multiplier, the slope length factor and the soil protection factor.

A major task in the land productivity assessment is the construction of sequential crop combinations. Amongst all possible combinations admissible cropping patterns are filtered out, evaluated and, subject to certain performance criteria, saved for later processing.

The crop combinations are also assessed in terms of soil erosion hazards. A crop combination specific multiplier in the USLE is calculated, i.e., a combined crop cover and management sub-factor, derived by matching the members of a sequential cropping pattern to the component LGPs of the current LGP-pattern and mean total LGP codes. Estimated annual soil loss is then translated into estimated productivity loss. This sequence is carried out sequentially for each agro-ecological cell.

The screen display of program AEZCCS03 (see Figure 17) provides information on the progress of the assessment. It shows the attributes of the agro-ecological cell being processed and indicates the number of crop combinations analyzed and selected for later use. Evaluation of larger districts with several thousand agro-ecological cells, e.g., Meru district, may take several minutes.

Example 3: Interpreting an agro-ecological cell of the land resources inventory

Program AEZCCS03 is a centrepiece of the AEZ package. It creates the necessary database for district planning scenarios. It is, therefore, worthwhile to take a closer look at the operations performed in the program to generate production options using the above procedure.

For that purpose, a record from the land resource inventory or an agro-ecological cell in Meru district is considered. The cell data record reads:

```

3 6 1 913224 33034 0 2 35 00 000    1150
-----+-----+-----+-----+-----+-----+-----+-----+

```

The line underneath the data record indicates the width of the individual attribute fields; the cross marks the end of each field. The record contains the information summarized in Table 4.

A few remarks may be helpful: Mapping unit Pn1 belongs to the land form of non-dissected erosional plains. In the legend of the soil map it is described as: 'well drained, very deep, dark reddish brown to dusky red, friable clay; in places bouldery (nito-rhodic FERRALSOLS)'. The land extent under consideration falls into thermal zone 1, i.e. a mean daily temperature > 25° Celsius applies, corresponding to an altitude below 800m.

In the mapping unit composition table there is only one entry for mapping unit Pn1, i.e. only one soil type (nito-rhodic Ferralsols) is identified, texture and slope class apply to the entire unit. No phase is indicated.

TABLE 4
Agro-ecological cell data record

| Field | Column | Value | Contents | Explanation |
|-------|---------|-------|--------------------|-------------------------------------|
| 1 | 1 - 2 | 3 | province code | Eastern Province |
| 2 | 3 - 4 | 6 | district code | Meru |
| 3 | 5 - 6 | 1 | thermal zone | mean daily temp. > 25 Celsius |
| 4 | 7 - 8 | 9 | mean total LGP | growing period of 210 to 239 days |
| 5 | 9 - 10 | 13 | LGP-Pattern | 2-1, with a probability of 70:30 |
| 6 | 11 - 13 | 224 | mapping unit | soil mapping unit Pn1 |
| 7 | 14 - 16 | 33 | soil unit | code Nito-rhodic Ferralsols |
| 8 | 17 | 0 | coarse material | no coarse material indicated |
| 9 | 18 - 19 | 34 | texture code | clay |
| 10 | 20 - 21 | 0 | phase combination | no soil phase indicated |
| 11 | 22 - 23 | 2 | slope class | slope class AB: 0-5 % |
| 12 | 24 - 26 | 35 | slope gradient | average slope gradient of 3.5% |
| 13 | 27 - 28 | 0 | cash-crop zone | no cash crop zone indicated |
| 14 | 29 | 0 | forest zone | no forest indicated |
| 15 | 30 - 31 | 0 | irrigation scheme | no irrigation scheme indicated |
| 16 | 32 | 0 | tsetse infestation | no potential for tsetse infestation |
| 17 | 33 | 0 | game park | cell does not belong to game park |
| 18 | 34 - 41 | 1150 | extent | extent of agro-ecological cell (ha) |

The attached slope class code is 2, i.e. slope class AB, representing slopes in the range of 0-5%. According to the slope composition table, the mapping unit must be split into two entries, half the cell relating to a slope range of 0-2 %, the other half relating to a slope range 2-5%. The land resource inventory record that was chosen refers to the latter with an average slope gradient of 3.5%.

The calculated mean total length of growing period for the cell, located in the north-east of Mount Kenya, is LGP code 9, i.e., sufficient moisture supply for a total growing period of 210-239 days, indicating quite favorable conditions.

LGP-pattern code 13 means that there are usually two distinct growing periods, (in seven out of ten years according to historical profiles), and one combined growing period in about 30 percent of the years. The reference table relating the mean total dominant LGP to the corresponding mean total associated LGPs (see FAO/IIASA: 1991 Technical Annex 7) lists the following for the bimodal case: the first associated component LGP, LGP21 with code 6, is 120-149 days, the second associated LGP, LGP22 with code 4, lasts 60-89 days.

Example 4: Evaluating an agro-ecological cell

The list of crop types considered in the AEZ assessment for Kenya is listed in Appendix A.2. It contains 64 types of food and cash crops, one synthetic grassland type, and 31 fuelwood species (12 species with nitrogen fixation ability, 19 species without). First, the growth cycle requirements of all 64 crop types are tested against the length of the dominant component LGP; in this example, LGP₂₁ with a length of 120-149 days¹. For the land unit under consideration, (see Example 3), 23 crop types pass both the thermal zone screen and the growth cycle matching. These include one or more types of maize, millet, sorghum, dryland rice, cowpea, green gram, pigeonpea, groundnut, soybean, cassava, sweet potato, and sisal.

¹ Perennial crops, pastures and fuelwood species are assessed in relation to the indicated mean total LGP of 210-239 days.

For instance, consider production of low-land maize type Maize 3, 110-130 days. In the previous section, Example 2, the maximum attainable yield in zones with LGP-pattern 13 and LGP 9 was determined at 3.6 t/ha/year. The soil unit rating of nito-rhodic Ferralsols for maize is S2, like with most Ferralsols, i.e., suitable with some limitations depressing yields on average by 25 percent. The clay texture does not affect the rating. The modest average slope gradient of 3.5 % passes the slope cultivation association screen which tolerates dryland crops on terrain with slope gradients of up to 30 %. Fallow requirements to maintain soil fertility and ensure sustainable production, under given conditions and input level, are set at 21 percent, i.e., 1 out of 5 years the land would not be permitted to be under crop cultivation.

In a reasonably long mean total length of growing period, as we are considering here, additional yields from multicropping must be considered. The intercropping increment depends on the level of inputs, the length of the growing period and the overall crop suitability (FAO/IIASA, 1991, Technical Annex 4). At the intermediate level of inputs, with moisture availability well above 120 days, the intercropping increment for maize is estimated at around 7.5 percent, i.e., a LER (land equivalent ratio) of 1.075. Combining agro-climatic and agro-edaphic assessment, and allowing for intercropping increment, we arrive at an average yield of 2.9 t/ha/year for lowland type Maize 3 (i.e., $3.6 \times 0.75 \times 1.075 = 2.9$)

In the given agro-ecological conditions, *Leucaena leucocephalis* (crop sequence number 76) and *Sesbania sesban* (crop sequence number 77) are assessed as most productive fuelwood species with nitrogen fixation ability. *Eucalyptus grandis* (crop sequence number 95) and *Eucalyptus saligna* (crop sequence number 96) fare best among species without such ability. The LGP-pattern and length of the growing period allow for two crops to be grown each year. The algorithm constructing sequential crop combinations can be customized by several control options. For details of the control file see FAO/IIASA (1991, Technical Annex 7). In particular, threshold values for acceptance of crop combinations can be specified by the user. With options set to default values, the algorithm constructs 109 feasible 1- and 2-member crop combinations in the current cell. In addition to agronomic feasibility, a filter mechanism, testing for economic and/or nutritional value, is used to identify the most productive crop combinations. In our example, 19 out of 109 sequential cropping activities were selected. The filter mechanism uses four criteria: revenue in average years (criterion V3) and bad years (criterion V4); nutritional value in average years (criterion V1) and bad years (criterion V2). A crop combination is retained for later use if it is reasonably¹ competitive in at least one of the four criteria. Table 5 lists the crop combinations which were accepted in the agro-ecological cell under consideration. According to this assessment, the best options include cassava, maize/grams and maize/millet; next is sweet potato with a short crop of millet, maize, green gram or sorghum.

Example 5: Evaluating soil loss from water erosion

Estimated soil erosion hazard in an agro-ecological cell depends on physical characteristics, land use and management level. It is quantified by means of a modified Universal Soil Loss Equation (USLE):

$$A = R \times K \times LS \times (C^* \times M) \times P \quad (1)$$

¹ Acceptance criteria can be user specified by means of threshold levels comparing the performance of a crop combination in relation to maximum criterion levels in the agro-ecological cell.

TABLE 5
Selected crop combinations, in land unit of example 3

| Nr | First | | Nr | Second | | Rank by Criterion | | | | Combined Rank |
|----|------------|--------------|----|-----------|--------------|-------------------|----|----|----|---------------|
| | Crop type | Growth Cycle | | Crop type | Growth Cycle | V1 | V2 | V3 | V4 | |
| 6 | Maize | 3 110-130 | 16 | P.Millet | 1 60-80 | 2 | 2 | 11 | 5 | 3 |
| 6 | Maize | 3 110-130 | 37 | G.Gram | 1 60-80 | 3 | 3 | 4 | 4 | 2 |
| 17 | P.Millet | 280-100 | 4 | Maize | 1 70-90 | 13 | 14 | 16 | 16 | 16 |
| 25 | Sorgh. | 3 110-130 | 16 | P.Millet | 1 60-80 | 10 | 5 | 15 | 15 | 14 |
| 38 | G.Gram | 2 80-100 | 4 | Maize | 1 70-90 | 15 | 16 | 12 | 14 | 15 |
| 40 | Grndnut | 2 100-140 | 16 | P.Millet | 1 60-80 | 12 | 12 | 3 | 3 | 7 |
| 40 | Grndnut | 2 100-140 | 37 | G.Gram | 1 60-80 | 16 | 15 | 2 | 2 | 9 |
| 48 | Soybean | 2 100-140 | 16 | P.Millet | 1 60-80 | 11 | 10 | 14 | 7 | 12 |
| 48 | Soybean | 2 100-140 | 37 | G.Gram | 1 60-80 | 14 | 13 | 10 | 6 | 13 |
| 49 | Cassava | 150-330 | | | | 1 | 1 | 1 | 1 | 1 |
| 50 | Sw.Pot. | 1 115-125 | 16 | P.Millet | 1 60-80 | 5 | 4 | 13 | 13 | 9 |
| 50 | Sw.Pot. | 1 115-125 | 37 | G.Gram | 1 60-80 | 9 | 11 | 5 | 12 | 11 |
| 51 | Sw.Pot. | 2 125-145 | 4 | Maize | 1 70-90 | 6 | 6 | 7 | 8 | 5 |
| 51 | Sw.Pot. | 2 125-145 | 16 | P.Millet | 1 60-80 | 4 | 6 | 8 | 8 | 4 |
| 51 | Sw.Pot. | 2 125-145 | 23 | Sorgh. | 1 70-90 | 7 | 6 | 9 | 8 | 7 |
| 51 | Sw.Pot. | 2 125-145 | 37 | G.Gram | 1 60-80 | 8 | 6 | 6 | 8 | 6 |
| 63 | Sisal | 150-270 | | | | | | | | |
| 65 | Pasture | 0-365 | | | | | | | | |
| 76 | Leucaena | 120-365 | | | | | | | | |
| 95 | Eucalyptus | 180-365 | | | | | | | | |

In the moisture zone discussed in the previous examples, with a mean dominant length of growing period of 210-239 days, the rainfall erosivity factor is estimated to be $R=369$ erosion index units. This value is based on estimated relationships between LGP, rainfall amount and rainfall energy.

The soil erodibility factor K accounts for rate of soil loss, in t/ha/year per erosion index unit. It ranges from less than 0.1 for the least erodible soils to approaching 1.0 for the most susceptible soils. In the model, each agro-ecological cell is assigned to one out of seven erodibility classes, depending on soil type, soil phase and texture. Nito-rhodic Ferralsols with clay texture are considered to be of low erodibility. They are adjudged soil erodibility class 2, with an average soil erodibility factor of $K=0.11$.

In this example, slopes are fairly gentle, in the range of 2-5 %. For an assumed slope length of 150 meters and an average slope angle of 3.5 %, the resulting slope length factor becomes $LS=0.8$.

The combined crop cover and management factor, $C^* \times M$, is determined by evaluating ground cover for different crop development stages and integrating over the growing season. For example, the crop combination of maize (long rains) and millet (short rains) results in an average cover factor of 0.5. This is further adjusted to 0.4 for increased¹ ground cover during rest periods - the fallow requirement is 21 percent, i.e., 1 out of 5 years. From the above, without additional physical protection measures, the soil loss is estimated as:

$$A_{p=1.0} = 369 \times 0.11 \times 0.8 \times 0.4 = 13\text{t/ha/year} \quad (2)$$

¹ Note that lower cover factors indicate better ground cover.

This corresponds to an estimated 1.1 mm topsoil loss per year. Under good management with additional protection measures, consisting of tied ridging, trash lines and converse terraces, a physical protection factor $P=0.067$ results, and annual soil loss would reduce to

$$A_{P=0.067} = A_{P=1.0} \times 0.067 = 1t/ha/year \quad (3)$$

an amount well below tolerable levels of soil loss. Even without such measures, the regeneration capacity of topsoil - modeled as a function of thermal zone and length of growing period - stipulates an annual addition of topsoil of 1.3 mm, making up for the estimated erosion losses. Therefore, the productivity of the crop combination maize/millet is not assumed to be adversely affected by water erosion in the given agro-ecological cell.

Example 6: Estimating the food production potential

The assessment procedures outlined in the examples above have been applied to all LUTs in all 91000 agro-ecological cells of the Kenya land resource inventory. This process produced a geo-referenced database containing information on the extent and productivity of potentially arable land resources and associated production potential of crops, pastures and fuelwood species. To quickly get an indication of the food production potential in Kenya, at intermediate level of input, a simple procedure was introduced to decide ad-hoc which of the crop combinations that passed the filter mechanism should be selected as 'best' land use. The objective was to maximize a weighted sum of energy and protein production available for food consumption in each cell.

For presentation, the results were then aggregated over agro-ecological cells to broad agro-climatic zones, as well as district, province and national level. The information base was also summed over crop types to indicate production potentials of crop species, e.g., production of maize rather than nine individual maize types.

Four classes are used in the presentation of results, relating average crop yields in an agro-ecological cell to maximum attainable yield¹. Classes C1 to C4 represent average yields of >80 % (very productive), 60-80% (productive), 40-60% (moderately productive), 20-40% (marginally productive), respectively, compared to maximum attainable yields.

Country results at the intermediate level of inputs are given in Table 6. The table shows estimates of arable land by productivity class and of potential crop production. Extents of potentially rainfed arable land given in the upper part of the tables are calculated in two steps: (i) All crop combinations were evaluated according to their performance under different climatic conditions as described by the LGP-pattern attribute of a cell. (ii) Among all qualifying crop combinations the one maximizing the weighted sum of food energy plus protein was selected as describing a cell's land potential.

The estimates of arable land were grouped according to mean total dominant LGP into four broad climatic zones: the arid zone (areas with mean total dominant length of growing periods <120 days), the semi-arid zone (areas with LGPs of 120 to 179 days), the sub-humid zone (areas with LGPs in the range of 180 to 269 days), and a humid zone (areas with LGPs >270 days).

¹ Agronomically attainable yield potential from an agro-climatic viewpoint, i.e. on suitable soils and terrain in suitable thermal zones.

TABLE 6
Kenya food production potential, at intermediate input level

Arable Land by Productivity Classes (100 ha):

| NR ZONE | C1 >80 | C2 60-80 | C3 40-60 | C4 20-40 | Total C1-C4 | Total Harv. | MCI % | Total Extent | C1-C4 % of Zone | Value of Criterion |
|--------------|-------------|--------------|--------------|--------------|----------------|----------------|------------|-----------------|--------------------|-----------------------|
| 1 ARID | 0 | 222 | 812 | 1708 | 2742 | 2742 | 100 | 423756 | 0.6 | 6340 |
| 2 SEMIARID | 972 | 2136 | 6388 | 7225 | 16721 | 19834 | 119 | 68133 | 24.5 | 40564 |
| 3 SUBHUMID | 3756 | 5291 | 5143 | 5359 | 19548 | 28842 | 148 | 37779 | 51.7 | 147005 |
| 4 HUMID | 3440 | 9709 | 7785 | 5989 | 26923 | 38692 | 144 | 46425 | 58.0 | 194848 |
| TOTAL | 8167 | 17357 | 20128 | 20282 | 65934 | 90110 | 137 | 576093 | 11.4 | 388757 |

Food Maximizing Crop Production:

| NR CROP | --- Land by Productivity Class (100 ha) --- | | | | | ----- Total ----- | | | | |
|--------------|---|--------------|--------------|--------------|----------------|-------------------|----------------|----------------------|------|------|
| | C1 >80 | C2 60-80 | C3 40-60 | C4 20-40 | Total C1-C4 | 2nd Harv. | Total Harv. | Production (1000 mt) | | |
| | | | | | | | | MIN | AVG | MAX |
| 1 BARLEY | 1757 | 1999 | 593 | 574 | 4924 | 1798 | 6722 | 842 | 1242 | 1517 |
| 2 MAIZE | 2574 | 2217 | 4647 | 6256 | 15695 | 6269 | 21963 | 2740 | 3767 | 4761 |
| 3 OATS | 0 | 0 | 0 | 0 | 0 | 897 | 897 | 11 | 75 | 98 |
| 4 MILLET | 429 | 2036 | 5731 | 5362 | 13558 | 3349 | 16907 | 1145 | 1327 | 1423 |
| 5 RICE | 75 | 541 | 320 | 887 | 1822 | 2918 | 4740 | 310 | 433 | 506 |
| 6 SORGH | 353 | 327 | 366 | 1870 | 2916 | 2630 | 5546 | 275 | 424 | 534 |
| 7 WHEAT | 12 | 17 | 49 | 5 | 83 | 30 | 113 | 11 | 15 | 22 |
| 8 COWPEA | 114 | 83 | 41 | 15 | 254 | 93 | 347 | 36 | 42 | 45 |
| 9 GRAM | 61 | 155 | 330 | 142 | 687 | 2606 | 3292 | 50 | 91 | 127 |
| 10 GRNDNT | 0 | 3 | 0 | 0 | 3 | 31 | 34 | 1 | 2 | 2 |
| 11 BEANS | 458 | 714 | 118 | 569 | 1860 | 3091 | 4950 | 226 | 349 | 456 |
| 12 PIGPEA | 383 | 293 | 327 | 139 | 1141 | 6 | 1147 | 116 | 158 | 189 |
| 13 SOYBEAN | 12 | 249 | 76 | 53 | 389 | 373 | 762 | 33 | 66 | 84 |
| 14 CASSAVA | 344 | 721 | 1019 | 1832 | 3915 | 0 | 3915 | 3966 | 4475 | 4624 |
| 15 SW.POT | 0 | 0 | 0 | 37 | 37 | 1358 | 1395 | 383 | 475 | 576 |
| 16 WH.POT | 0 | 475 | 1910 | 767 | 3153 | 1165 | 4318 | 1627 | 2658 | 4027 |
| 17 BANANA | 0 | 82 | 146 | 120 | 348 | 0 | 348 | 372 | 402 | 558 |
| 19 SUGCANE | 0 | 44 | 190 | 791 | 1024 | 0 | 1024 | 2441 | 2611 | 2670 |
| 20 COFFEE | 1214 | 1398 | 308 | 450 | 3369 | 0 | 3369 | | | |
| 23 PYRETH | 514 | 3707 | 3644 | 1284 | 9150 | 0 | 9150 | | | |
| 25 TEA | 108 | 2508 | 729 | 120 | 3465 | 0 | 3465 | | | |
| TOTAL | 8407 | 17567 | 20544 | 21274 | 67792 | 26614 | 94406 | | | |

In the calculations, all land marked in the resource inventory as forest zone and/or game park is excluded. The extent of potentially cropped land in Kenya, under the conditions described above¹, amounts to some 6.6 million ha. About 2.6 million ha are adjudged very good or good potential (classes C1 and C2), 2.0 million ha are rated moderately productive (class C3). The balance, another 2.0 million ha, is of low potential (class C4).

¹ Note that the selection criterion used here differs from the algorithm used for determining potentially arable land described in FAO/IIASA (1991: Technical Annex 8).

The arable extents in classes C1 to C4 account for 11.4 percent of Kenya's total land area. In the sub-humid and humid zones 52 and 58 percent, respectively, of the land is rated suitable for rainfed crop production, and about 1/4 in the semi-arid zone. Maize and millet would account for 2.9 million ha of arable land. The estimated multi-cropping index amounts to 137 percent. The sub-humid and humid zones, although only accounting for about 15 percent of Kenya's land area, contribute some 70 percent of arable land.

Chapter 7

The land use allocation model (LUAM)

This Chapter discusses the preparation of land-use scenarios for analysis. With program AEZCCS03, each agro-ecological cell has been assessed in terms of all feasible agricultural land use options of interest in the analysis. The assessment records expected production of agro-ecologically feasible cropping activities, in terms of main produce as well as relevant by-products (e.g., crop residues and byproducts), extents by suitability class, input requirements and degradation hazard, i.e., potential soil and productivity loss due to water erosion. Such an inventory is essential to devising 'optimal' land use patterns that simultaneously take into account physical, socio-economic, technological and environmental objectives and constraints. The AEZ productivity assessment forms the back-bone of the physical layer of the constraint set.

A detailed specification of the AEZ core model for land use allocation is far beyond the scope of this report. Therefore only an outline of the essential features of the model is provided here. The reader interested in the model specification is advised to consult (FAO/IIASA, 1991).

With the implementation of multi-criteria decision support tools, searching for optimal land use is not limited to optimization of a single-objective goal function over a set of constraints. Instead, a user of the model can examine various tradeoffs between several objectives within the given set of constraints. In the Kenya study, the criteria are selected out of the set of outcome variables. The constraints defining the core model are linear (see Section 8.4). Therefore the resulting optimization problem is linear and a reliable and fast solver makes it possible to analyze large scale problems which can arise in this context, with several thousand decision variables and constraints.

The land allocation model has been developed for integrating livestock, crop and fuelwood production sectors within the AEZ framework. Like with any model of this kind, the formulation gets revised and improved as new insights, needs or new quantified information becomes available. The strength of the approach lies in its extensive and consistent use of spatial information for assessing agricultural land use options within the context of district development planning, considering simultaneously several objectives such as maximizing revenues from crop and livestock production, maximizing food output, maximizing district self-reliance in agricultural production, and minimizing environmental damages from erosion.

THE AEZ CORE MODEL GENERATOR

The core model is generated by the program AEZCCS04, which reads the results from the land productivity assessment and prepares a core model description file for input to a linear programming package according to the specifications given in the scenario control input file. The model is generated in standard MPS file format for single-criterion optimization and in the LP DIT format for multi-criteria model analysis.

In the scenario control input file the user specifies the mode of operation, several program control switches and, optionally, parameters and controls to construct various user-selectable constraints of the linear program.

The main program loop starts with reading the cell information record from the land productivity file created by program AEZCCS03. Basic accounting of cell extents takes place, population density relevant to the current cell is retrieved, and the crop combination records relating to the current cell are screened. Each crop combination record is assessed for potential food and feed supplies, crop residues and by-products. Input requirements for production in terms of seeds, fertilizer, power and pesticides are derived from a technology matrix, and the respective weights in the criterion functions are determined. The relevant coefficients of the LP constraint matrix are generated.

After having processed all the crop combination records available for the current land inventory cell, the program proceeds with reading the next cell information record continuing this sequence of operations until all cells have been read and dealt with.

Finally, the program turns to the livestock systems feeding and distribution constraints. While processing all the crop combination information, the program also calculates and aggregates data on feed supply by livestock zone. This information is used to generate livestock zone and livestock system specific feed balances and livestock system share constraints. The program ends with writing out the LP specification - criterion functions, constraint matrix, right hand sides, and bounds on activities - in standard SPECS and MPS data file format.

In the following section we give a summary of the model, describing the criterion functions and constraints that can be used in the analysis.

DECISION VARIABLES

The AEZ core model contains three groups of decision variables which, respectively, determine optimal land use, livestock numbers supported, and optimal allocation of feed supplies to different livestock systems:

- the land use shares, i.e., the share of agro-ecological cell j allocated to a cropping, grassland or fuelwood activity k ;
- the number of animal units of livestock system s kept in zone z ,
- the feed ration of feed item h from crop i allocated to livestock system s in period t in zone z .

These variables form the columns of the constraint matrix, the core model activity set. Values of these variables are provided by the solver as the result of solving a parametric optimization problem that is automatically generated in order to compute a Pareto-efficient solution corresponding to preferences which are interactively specified by a user.

Values of decision variables and of criteria can be inspected by the user and are then used for generating district reports for the given AEZ model scenario.

OUTCOME VARIABLES

Typically, six to eight variables are interactively selected from the set of outcome variables (defined in the core model outlined in Section *The AEZ core model constraint set*) to serve as criteria in multi-criteria analysis of the AEZ model. The following outcome variables are defined in the Kenya study:

1. maximize food output (weighted sum of food energy and protein available for human consumption after conversion and processing into food commodities);

2. maximize net revenue;
3. minimize production costs;
4. maximize gross value of output;
5. minimize weighted sum of arable land use (weight of 1 assigned to crops and fuelwood species, and 0.1 to grassland);
6. minimize area harvested;
7. maximize food output in bad years (weighted sum of food energy and protein available for human consumption as in 1 above, but evaluated for climatic conditions typical for years with low precipitation levels);
8. minimize total erosion (total soil loss over all land units);
9. maximize district self-reliance (minimum of the individual commodity group self-sufficiency ratios, i.e., target production over demand achieved);
10. minimize erosion at the level of agro-ecological cells (largest soil loss per ha occurring in any used land unit).

The last criterion provides an example of an objective that reflects the spatial detail of the GIS resource database. Other examples of criteria where the spatial content of the information is important could, for instance, express crop diversification or equity of expected farm incomes.

THE AEZ CORE MODEL CONSTRAINT SET

A realistic assessment requires a thorough description of relevant constraints to be considered in the selection of optimal land use. These can relate to technological conditions, physical limitations, social, institutional and economic constraints, and political targets.

In the following, we briefly discuss the set of constraints that has been implemented in the Kenya study. Not all the constraints need to be activated in every scenario, but can be included as appropriate and relevant.

Demand targets by aggregate commodity group. Lower and/or upper bounds or equality constraints on food availability, specified by broad commodity groups, e.g., cereals, pulses, roots, meats, etc., can be used to satisfy food demand targets from domestic production and imports. The user can either supply absolute levels of target demand or have demand targets constructed by the core model generator from per capita demand targets and demographic information.

Commodity production targets. Lower and/or upper bounds or equality constraints on individual commodity production, e.g., wheat, white potato, beef, etc., can be selected to achieve appropriate commodity bundles in the production plan. This, for instance, could be an appropriate device to enforce sufficient production of cash-crops in food maximizing scenarios.

Limits on harvested area. The harvested area by broad commodity group (e.g., cereals, pulses, roots, etc.) can be controlled by means of lower and/or upper bounds and equality constraints implemented at district level. This can be useful to ensure desired allocation of land to cash-crops or fuelwood production.

Crop-wise land use constraints. Lower and/or upper bounds and equality constraints to limit crop-wise use of arable land resources have been implemented. Although not much applied in the assessment of production potentials, these constraints allow for control over land allocation in the optimization procedure.

Total arable land use constraint. Lower and/or upper bounds or equality constraints on total arable land use by broad climatic zone and/or district serve to reflect considerations regarding land use other than for agricultural production purposes, e.g., forest areas, specific non-agricultural uses, etc. In the Kenya study, when assessing crop and livestock production potentials, total arable land constraints were usually not enforced. Hence, all potentially suitable land in all zones is assumed to be available for agricultural purposes, except for non-agricultural land use requirements, forest and game park areas.

Production input requirements. These constraints are associated with the quantification of production inputs required according to the specified level of technology. Input requirements are derived from a technology matrix by interpolation; i.e., from a set of tabular functions that relate, for each crop and livestock system, different yield levels to input requirements in terms of seed (traditional and/or improved), fertilizer (N, P, and K), power, and plant protection/veterinary inputs. In addition, labor required for soil conservation measures is quantified. This set of constraints can be applied to ensure that input requirements for crop and livestock production fall within the limits of the available resources in terms of relevant input categories, e.g., labor, capital, fertilizer, power, etc. Negative input-output coefficients are used in case of activities which generate resources, e.g., power from animals.

Crop-mix constraints. A set of constraints, optionally to be specified either by broad climatic zones, i.e., arid and dry semi-arid (average LGP of 0-120 days), moist semi-arid (LGP of 120-180 days), sub-humid (LGP of 180-270 days) and humid (LGP of 270-365 days) zone, or by agro-ecological zone, i.e., overlay of thermal zones with individual LGP zones, can be used to exercise control over cropping patterns by enforcing limitations on shares (minimum and maximum levels) of arable land use to be occupied by individual crop groups. The level of enforcement for this set of constraints is controlled by the selection of scenario parameters.

Human calorie/protein ratio requirements. These constraints ensure that, by broad climatic zones, the crop production plan is such that the ratio of calories to protein obtained from food products stays within nutritionally acceptable ranges.

Distribution of livestock population over livestock zones. The concept of livestock zones has been introduced to relate the climatic information contained in the resource inventory to broader climatic zones relevant to describing and delineating different livestock systems and formulating their integration with the crop production plans of the respective agro-ecological zones. Each livestock zone falls into a subset of the climatic subdivision used in the land resource inventory. Sixteen livestock zones are distinguished in the Kenya study. The livestock population distribution constraints allow to impose lower and/or upper bounds or equality constraints on shares in total livestock populations (herd TLUs) to be considered in each of the livestock zones.

Distribution of livestock systems. This set of constraints affects the composition of the supported livestock population within each livestock zone in terms of different livestock systems. This is done by imposing lower and/or upper bounds or equality constraints on the shares of individual livestock systems in the total number of livestock units supported in the zone. In

the Kenya study, up to ten livestock systems, out of a total of some thirty systems, at traditional, intermediate and improved management levels, have been considered in each livestock zone: this includes pastoral production systems of camel, cattle, and sheep and goat, and sedentary production systems of cattle, sheep and goat, pigs and poultry.

Constraints on number of animals. Lower and upper bounds on the number of TLUs by livestock system can be specified to guide the selection and allocation of livestock systems.

Livestock feed requirement constraints. When setting up feed demand-supply balance constraints it is important to include relevant aspects of quality and quantity of feed supplies in time and space. In the Kenya study, livestock feed balance constraints are implemented by individual livestock zones. The livestock zones are conveniently formulated in terms of the thermal regime and the length of growing period. The required feed supply to support livestock populations has to be provided from feed sources within each livestock zone, i.e., crop by-products and residues, pastures and browse, fallow grazing, browse from fuelwood trees, and { in some scenarios { primary products. Each set of constraints, by zone, is formulated in terms of four items: minimum and maximum daily dry matter intake, digestible protein of feed ration, and metabolizable energy.

Since the seasonal variation in quality and quantity of feed supplies often plays a critical role for livestock raising in pastoral areas, two feeding periods within the year { wet season and dry season { have been distinguished. The length of each period in a particular agro-ecological cell varies according to the climatic information in the land resources inventory. It is assumed that the length of the wet season equals the site-specific length of growing period.

The seasonal crude protein feed quality constraints ensure that the digestible crude protein (DCP) contents of the livestock system specific seasonal feed intake lies within the prescribed tolerance band, and that the annual average DCP contents of the feed intake does not fall below average annual requirements. Similarly, the seasonal metabolizable energy (ME) feed quality constraints ensure that the ME contents of the seasonal feed intake lies within the prescribed tolerance band and that the annual average ME contents of the feed intake does not fall below average annual requirements. For example, improved animals with higher productivity also require higher energy concentration in the diet. In summary, feed balance constraints have been imposed for each of the livestock zones in terms of four relevant nutritional parameters and for each of two feeding seasons.

Zone level production risk constraint. The AEZ land resources inventory of Kenya includes some information on the variability of rainfall, and hence, the varying length and type of the growing period. This allows for assessing production options in terms of good, average and bad years. While valuations used in the objective function usually refer to average productivity, zone level risk constraints are implemented to ensure that the resulting land allocation emphasizes the stability of the production plan also in bad years, i.e., in vulnerable areas to give preference to crop combinations that will produce also in bad years, even at the expense of lower average output.

Cell use consistency constraint. It is necessary to explicitly impose that the sum of shares allocated to different crop production activities in each land unit does not exceed 100 percent, i.e., that each piece of land can only be used and allocated once (this does not preclude sequential multi-cropping). Unlike the constraints described above, which are independent of the number of records in the land inventory, the cell use consistency constraint has to be imposed whenever more than one cropping activity is feasible in a particular agro-ecological cell. As a consequence, the number of rows in the constraints matrix might become large.

Crop rotation constraints: Continued mono-cropping over time is not considered a sustainable agricultural practice under most circumstances as it exhausts soil fertility more easily and may cause pest and disease problems. Although the AEZ land use allocation model is essentially static, not explicitly considering crop rotations over time, this element has been captured by imposing upper limits on the share of each cell that can be occupied by an individual crop activity. For example, imposing a limit of 70 percent as maximum share for maize in a particular cell can be interpreted as requiring that maize cannot be grown in more than 7 out of 10 cropping years, in addition to fallow requirements. The mono-cropping restrictions are controlled through scenario parameters and are implemented as simple lower and upper bounds on cropping activities. They are not enforced in a cell when no alternative cropping options exist. Also, cassava and perennial crops like banana, oil-palm or sugar cane, or environmentally less demanding land uses, like crop combinations including legumes, or pastures and fuelwood species, are not restricted by mono-cropping constraints.

Cell level production risk constraints. As outlined above for the zone level, crop production risk constraints are also implemented at the cell level to ensure that the resulting land allocation emphasizes the stability of the production plan also in bad years. The constraint is specified such that land use options selected in the optimal solution should provide output levels in "bad" years that do not fall below a user specified threshold level in comparison to the best possible output obtainable in bad years among all viable cropping options.

Environmental impact constraints. Environmental impact constraints were included to ensure that the optimal production plans are also environmentally compatible, demanding that the environmental impacts in each cell must not exceed tolerable limits. At this stage, only soil degradation from water erosion is quantified. Tolerable soil loss is dealt with by filtering out unacceptable crop combinations rather than imposing inequalities in the constraints matrix.

THE SCENARIO CONTROL FILE

The setting of control parameters and selection and level of constraints included in a district scenario are guided by a district scenario control file.

The Analysis menu (see Figure 22) provides a possibility to select a scenario through a dialog illustrated in Figure 19. Such a scenario may be defined by experienced users in a traditional way by editing configuration files. However, an interactive module for editing scenarios is available for users who prefer an interactive definition of scenarios. The corresponding dialog (that can be activated by pressing the Edit scenario button in the dialog shown in Fig. 19) is illustrated on Fig. 20 in order to provide an illustration of the kind of selections that the user can determine to define a particular scenario. The Edit scenario dialog provides an easy way to generate a scenario file that is used for controlling the AEZ-CCS program. Such a scenario file can also be prepared by any text editor. Example 6 shows a simple version of the LP control input data file for Meru district, to optimize land use for maximum food production at intermediate level of inputs, subject to meeting food preferences and production targets for cash crops. This control file is used both by the AEZ core model generator program (program AEZCCS04) as also the report writer (program AEZCCS05).

Example 6: Scenario control file, Meru district

```

# MERU DISTRICT (306) - EASTERN PROVINCE
BIN.306 /* productivity assessment file */
COMDAT /* additional crop factor tables */
LVSDAT /* livestock system definition tables */
DBG.LP /* debug output file */
OUT.306 /* AEZCCS04/05 scenario output file */
POPDIST /* population distribution by AEZ */
EXTENTS /* total extents of AEZ */
SCRO104 /* temporary file, LP matrix coefficients */
SCRO204 /* temporary file, LP right hand sides */
SCRO304 /* temporary file, crop combination data */
SCRO404 /* temporary file, LP activity bounds */
SCEB.SMY /* scenario district summary records */
  1 /* MODE : program mode */
  0 /* IDEBUG: debug level */
  1 /* IPRINT: print level */
  1 /* FPLAND: include forest and parkland in agric. land base? */
  1 /* FLCPP : automatic demand constraint generation? */
0.000 /* DEGSH : share of estimated productivity loss considered */
0.000 /* RISK1 : district level risk parameter */
0.750 /* RISK2 : cell level risk parameter */
District Population
889000. : 1980
1633883. : 2000
Consumption per capita (kg / cap / year)
CEREALS PULSES ROOTS SUGAR OILS BANANAS FUELWD MEATS MILK EGGS
133.2 21.9 73.0 11.0 1.1 80.3 100.0 18.2 84.0 1.0
Livestock System Distribution Shares : Pastoral - Int/High Pot. Zones
CAMELS SHP+GOAT CATTLE
1 1 1
.000 .186 .814
CATTLE1 CATTLE2 CATTLE3 GOATS SHEEP1 SHEEP2 PIGS PLTRY1 PLTRY2
3 3 3 1 1 1 1 3 0
.791 .791 .791 .119 .064 .002 .004 .021 .021
LP NAME:
Meru - Maximize Calories (Fuelwood and Cash-Crops included)
TARGET DEMAND constraints (1 = EQ , 2 = GE , 3 = LE, 0 = NA)
---+-----+-----MT-----
01 CEREALS 0 0.00
%
PRODUCTION constr.: Acreage Production Irrig. prod.:
---+-----+-----1000 ha-----+-----MT-----+-----MT-----
20 COFFEE 1 36.00 0 .0000 .0000
21 COTTON 1 15.30 0 .0000 .0000
23 PYRETH 1 .3000 0 .0000 .0000
25 TEA 2 6.100 0 .0000 .0000
%
INPUT constraints:
---+-----+-----UNITS-----+-----PRICE-----
01 SEED TRAD. 0 .0000 0.00
%
MISCELLENOUS constraints:
---+-----+-----UNITS-----+
01 INVESTMENT 0 .0000
%
```


TABLE 7
Variables read from scenario control input file

| Card Nr. | Variable name | # of items read | Format specification |
|----------|------------------------|-----------------|----------------------|
| 01 | TXTLIN | 1 | (A80) |
| 02 | FNBIN | 1 | (A50) |
| 03 | FNTB1 | 1 | (A50) |
| 04 | FNTB2 | 1 | (A50) |
| 05 | FNDBG | 1 | (A50) |
| 06 | FNPRT | 1 | (A50) |
| 07 | FNRND1 | 1 | (A50) |
| 08 | FNRND2 | 1 | (A50) |
| 09 | FNSCR1 | 1 | (A50) |
| 10 | FNSCR2 | 1 | (A50) |
| 11 | FNSCR3 | 1 | (A50) |
| 12 | FNSCR4 | 1 | (A50) |
| 13 | FNAGGR | 1 | (A50) |
| 14 | MODE | 1 | (I2) |
| 15 | IDEBUG | 1 | (I2) |
| 16 | IPRINT | 1 | (I2) |
| 17 | FPLAND | 1 | (I2) |
| 18 | FLCPP | 1 | (I2) |
| 19 | DEGSH | 1 | (F5.2) |
| 20 | RISK1 | 1 | (F5.2) |
| 21 | RISK2 | 1 | (F5.2) |
| 22 | CALREQ | 1 | (F5.2) |
| 23 | PRTREQ | 1 | (F5.2) |
| 24 | UMONO | 1 | (F5.2) |
| 25 | TLUFLW | 1 | (F5.2) |
| 26 | SHNFIX | 1 | (F5.2) |
| 27 | TXTLIN | 1 | (A80) |
| 28 | TPOP1 | 1 | (F10.0) |
| 29 | TPOP2 | 1 | (F10.0) |
| 30 | TXTLIN | 1 | (A80) |
| 31 - 32 | CPP | NFAG | (/10F8.0) |
| 33 | TXTLIN | 1 | (A80) |
| 34 | TXTLIN | 1 | (A80) |
| 35 | IRHS(...) ^a | MLVS1 | (I6,9I8) |
| 36 | LVDST | MLVS1 | (10F8.0) |
| 37 | TXTLIN | 1 | (A80) |
| 38 | IRHS(...) | MLVS2 | (I6,9I8) |
| 39 | LVDST(MLVS1+1) | MLVS2 | (10F8.0) |
| 40 | TXTLIN | 1 | (A80) |
| 41 | LPNAME | 1 | (A30) |

^a'(...)' indicates array subscript value calculated from configuration specific parameter constants.

Table 7 provides the list of variables read from the control file used to run AEZ core model generator program AEZCCS04. In the table only the fixed portion of the control file is explained. In addition, the user can optionally indicate various LP constraints related to target demand, production levels and land use, availability and use of production inputs, and investment constraints. The variables in Table 7 relate as follows:

TXTLIN character*80 variable for reading text lines which have been included to improve readability of scenario control data file.

FNBIN name of file (including full path) containing cell information and crop combination records from land productivity assessment program AEZCCS03.

FNTB1 name of file (including full path) containing aggregation indices and miscellaneous crop and commodity conversion and weight factors (CF-cards, CQ-cards and AG-cards).

FNTB2 name of file (including full path) containing livestock zone and system definition tables (LZ-cards, LS-cards and LQ-cards).

FNDBG name of file (including full path) where debug output and error messages are to be printed.

FNRND1 name of unformatted random access file (including full path) containing population distribution parameters by agro-ecological zone, i.e. by location unique in terms of THZ/PTN/LGP code.

FNRND2 name of unformatted random access file (including full path) containing total extents of agro-ecological zones.

FNSCR1 name of unformatted sequential file (including full path) used as temporary work space for holding LP constraint matrix records.

FNSCR2 name of unformatted sequential file (including full path) used as temporary working space for holding LP constraints right-hand-side records.

FNSCR3 name of unformatted sequential file (including full path) used as temporary work space.

FNSCR4 name of unformatted sequential file (including full path) used as temporary working space for holding LP activity bound records.

FNAGGR name of unformatted random access file (including full path) containing aggregate district results for re-printing and aggregation to national or province totals (only used in AEZCCS05).

MODE 1-digit run mode ag : 0 = multi-criteria (generates all criteria) 1, . . . , 11 = number of criterion to be optimized (see Section 8.3)

IDEBUG debug level; controlling level of detail to be written out to debug file during program execution.

IPRINT print level; controlling level of detail to be written out to print file during program execution.

FPLAND 1-digit forest/park land use indicator : 0 = forest and park land set aside 1 = include forest land in agricultural base 2 = include game park land in agricultural base 3 = include forest land and park land in agricultural base

FLCPP control ag for constructing district target production levels from per caput demand targets.

DEGSH share of production loss from soil degradation to be taken into account in calculations ($0 \leq \text{DEGSH} \leq 1$).

RISK1 district level risk parameter ($0 \leq \text{RISK1} \leq 1$). The yield tables generated in program AEZCCS02 contain minimum, average and maximum yields according to the LGP pattern distribution parameters. The risk constraint requires that production under worst climatic conditions from the calculated optimal land use cannot fall below RISK1 times maximum attainable production under worst conditions. In other words, the constraint ensures that the cropping pattern generated in the LP, based on average climatic conditions, also provides a 'sufficiently good' solution in bad years.

RISK2 cell level risk parameter ($0 \leq \text{RISK2} \leq 1$). This constraint acts as above but at the cell level instead of district level.

CALREQ minimum calorie food requirement per person per day (Kcal/cap/day).

PRTREQ minimum protein requirement per person per day (grams protein/cap/day).

UMONO upper limit on cell use for mono-culture. This value acts as an upper bound on activity levels related to mono-culture.

TLUFLW share of fallow land that can be used for grazing, i.e. livestock production ($0 \leq \text{TLUFLW} \leq 1$).

SHNFI share of acreage used for fuelwood production to be allocated to species without nitrogen fixation abilities ($0 \leq \text{SHNFI} \leq 1$).

TPOP1 district/regional population in base year (e.g. 1980 in Kenya Case Study).

TPOP2 district/regional population in target year (e.g. year 2000 or 2010).

CPP district/regional consumption pattern per caput in terms of aggregate food commodity list.

LVDST livestock system distribution parameters in pastoral zone (0 - 119 days length of growing period) and intermediate/high productive zones (LGP - 120 days).

LPNAME header text of linear program.

In addition to the fixed portion of the scenario control file, the user can provide data to generate various core model constraints that must be entered in four sections:

(A) net production constraints at aggregate food commodity level, e.g; target production level of pulses

- (B) acreage and production constraints by agricultural commodity, e.g; wheat acreage, coffee acreage, maize production level
- (C) input use constraints, e.g. fertilizer use availability;
- (D) miscellaneous constraints: e.g. conservation labor supply, investment limit.

Each of the constraints requires specification of a constraint type indicator and a constraint value. The constraint type indicator determines the kind of constraint that will be generated: 0 = unconstrained, 1 = equality constraint, 2 = lower bound inequality, 3 = upper bound inequality.

Selection and possible modification of a scenario concludes the definition of an instance of the AEZ core model, which can be generated and analysed in a way outlined in Section 6.

Chapter 8

Tutorial guide for AEZWIN

This Chapter intends to guide the reader through a complete sequence of steps necessary to set up and undertake district scenario analysis with AEZWIN. The purpose of the Tutorial is also to familiarize users with the functionality of the menus and the main screens and dialogs in the software system.

ON-LINE HELP

The version of this document available on the Web has been written in L A T E X using additional commands that have been defined in order to make it possible to automatically prepare electronic versions of this document, which in turn can be viewed by one of the two browsers, namely *Netscape* and *zHelp*. Such an approach has several advantages:

- The on-line help is based on an automatically generated electronic version of the corresponding documentation, therefore it is easy to keep the on-line help consistent with a hard copy version of the documentation.
- The on-line help can be viewed by *Netscape* (which is commonly used on both MS-Windows and Unix installations) and/or by *zHelp* (portable browser which is distributed with this application). Due to the limitations of *zHelp* (which does not support the full implementation of the HTML) the functionality of the corresponding version of the on-line help is slightly limited.
- Additional commands for L A T E X define labels which are automatically associated with corresponding pages of the on-line help. These associations are converted into a dictionary, which is distributed with the on-line help. This makes it possible to implement a context-sensitive help, i.e., controlling loading of appropriate pages by the software. However, the context sensitive help is combined with providing the user with a freedom of reading any part of the electronic version of the documentation.

Figure 4 illustrates the way of activating the on-line help. The subsequently displayed dialog shown in Figure 5 provides a choice between the *Netscape* and the *zHelp* browsers. Note, that one can use both browsers (by loading them one after another). The welcome pages of both browsers are shown in Figure 6 and Figure 8, respectively. Additionally the information illustrated on Figure 7 is displayed before the *zHelp* browser is shown, if the context sensitive help is enabled for a particular application.

The welcome pages of each browser contain a summary of information pertaining to the use of a particular browser. The use of both browsers is easy and intuitive and therefore no more details about navigating through the on-line help is provided here.

FIGURE 4
Main menu of the application with the selection of an on-line help

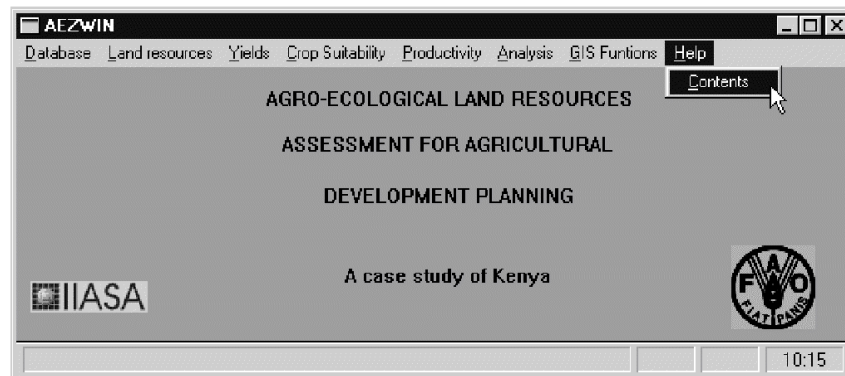


FIGURE 5
Dialog for the selection of a help browser



FIGURE 6
Welcome page of the on-line help viewed by the Netscape browser

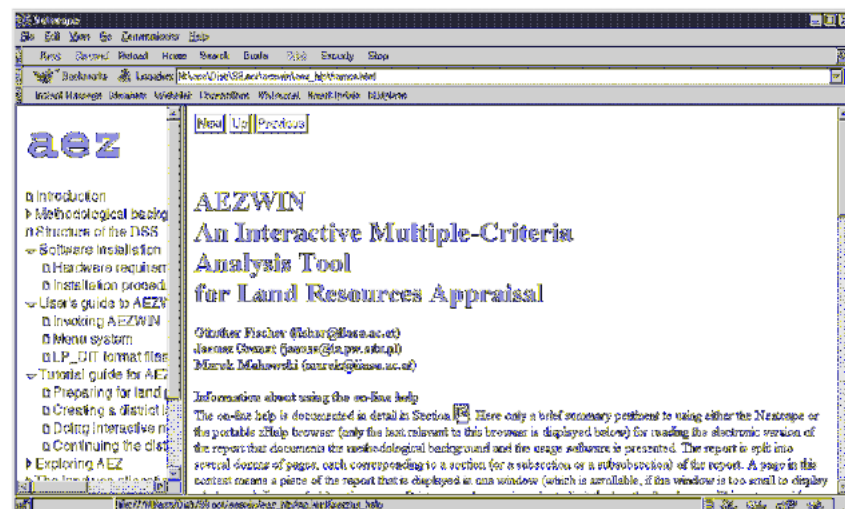
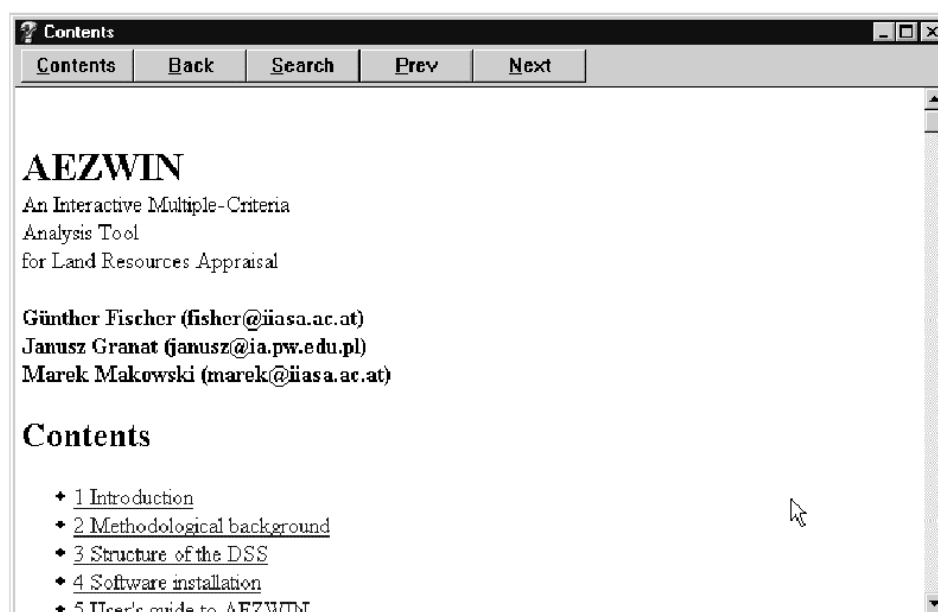


FIGURE 7
Information about availability of context sensitive help



FIGURE 8
Welcome page of the on-line help viewed by the zHelp browser



PREPARING FOR LAND PRODUCTIVITY ASSESSMENT

After starting AEZWIN, a window with the eight basic menus is presented to the user (Figure 4). In order to prepare the data the following steps should be completed:

After installation of the system the data required by the application programs must be extracted from the database and prepared for program execution. This step is executed from the Database menu by choosing Prepare data (Figure 9). The program prepares several tables and matching rules of the AEZ system for all three levels of input. Three programs are called in a row, the results of the first one are illustrated on Figure 10 (after a program is finished the user should hit any key to continue). The resulting files are set up in random access format and stored in directory \aez\kenya\inpt. Note that this initial step is required after installation and whenever the database has been modified (or files in directory \aez\kenya\inpt have been deleted).

FIGURE 9
Preparation of the data

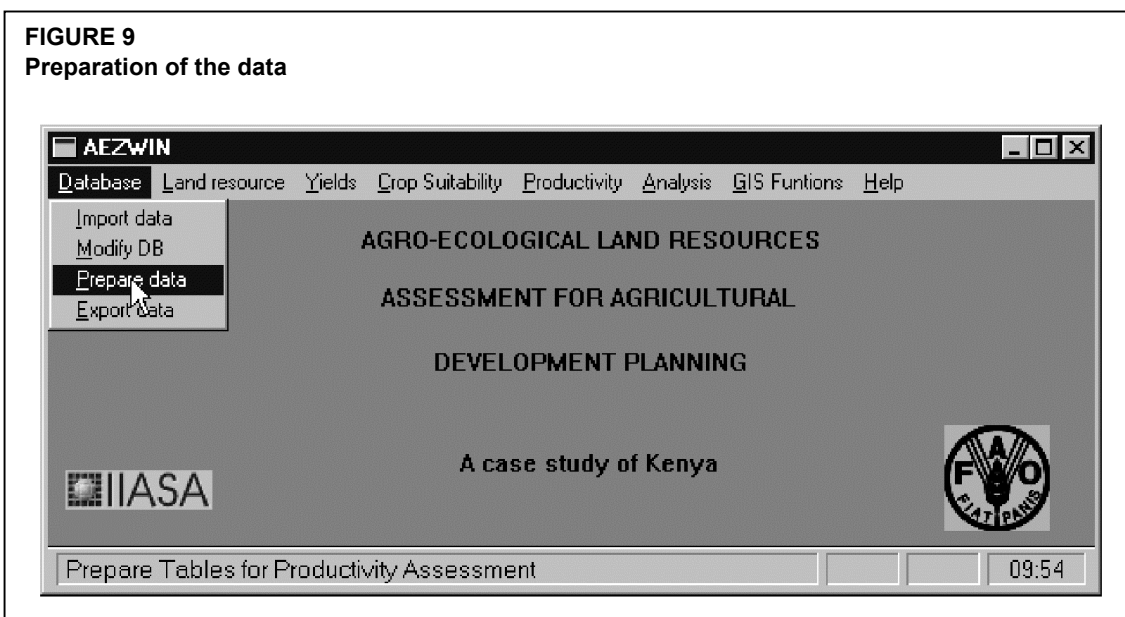
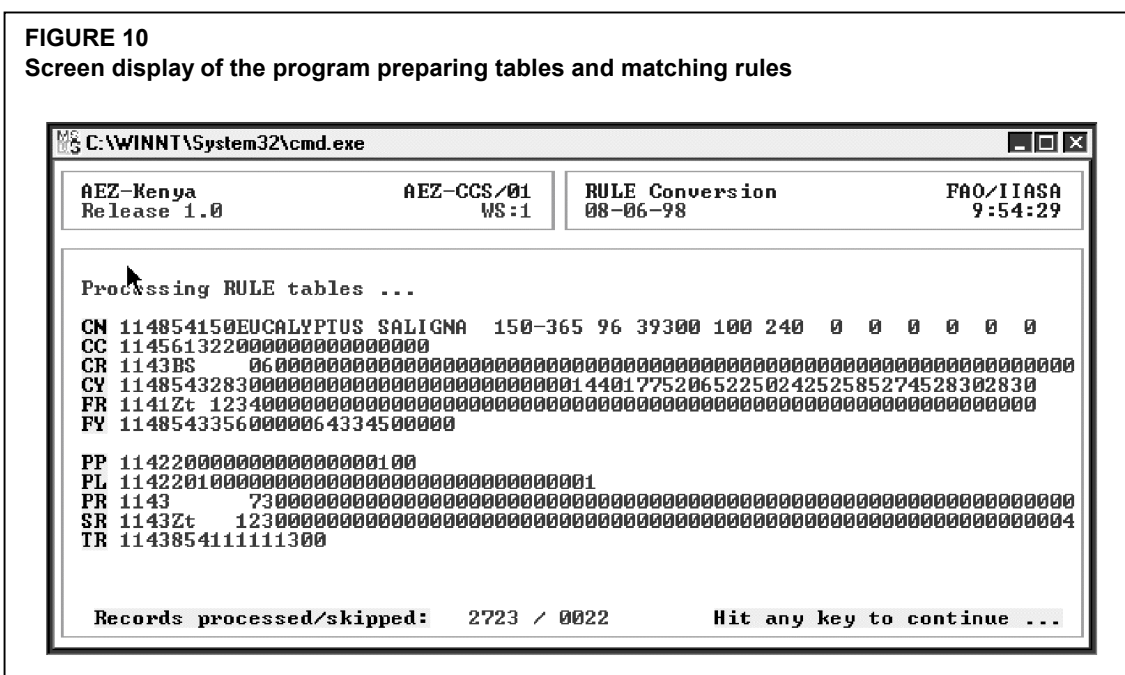


FIGURE 10
Screen display of the program preparing tables and matching rules



2. The next preparatory step is to generate tables of agronomically attainable yields for the full range of agro-climatic conditions, i.e., for all combinations of length of growing periods (LGP) and pattern of LGP that have been inventoried and stored in the rule base. The yield generator is called from menu Yields by selecting Generate table (Figure 11). While executing, the program shows the range of LGP and Pattern LGP codes that are being processed and indicates the number of crops accepted for each case (Figure 12). As in the previous step, the program prepares the yield tables in random access format (stored in directory \aez\kenya\inpt) for all three levels of input. Generation of yield tables is required after system installation, and also whenever the database is changed and the command “Prepare data” is executed from the Database menu.

FIGURE 11
Selection of the Generate table submenu from the Yields menu

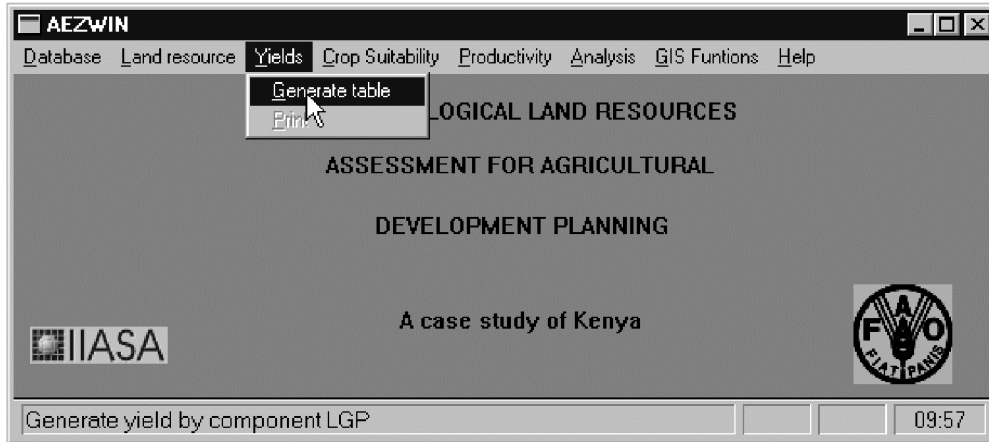


FIGURE 12
Screen display of program that generates yield tables

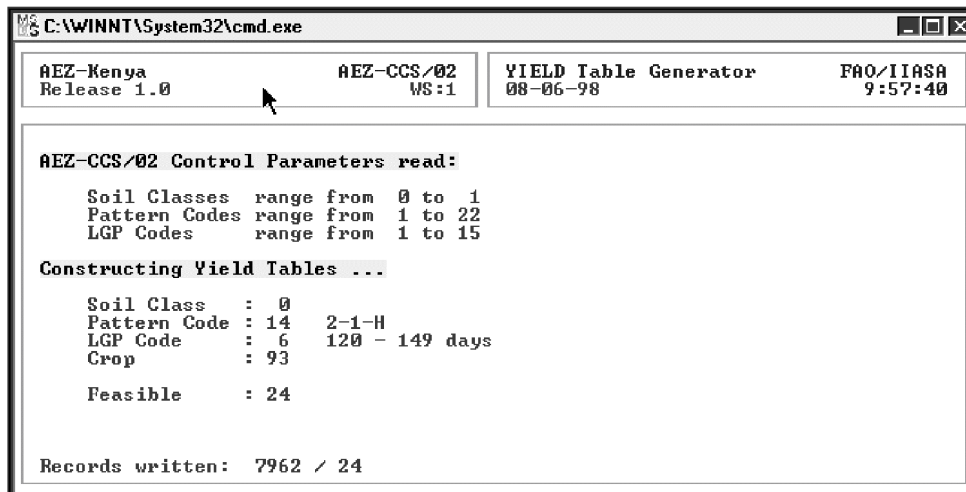
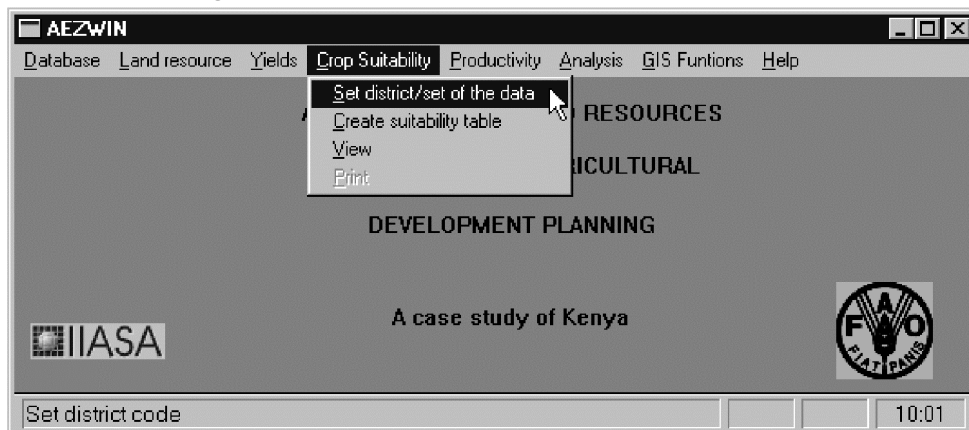
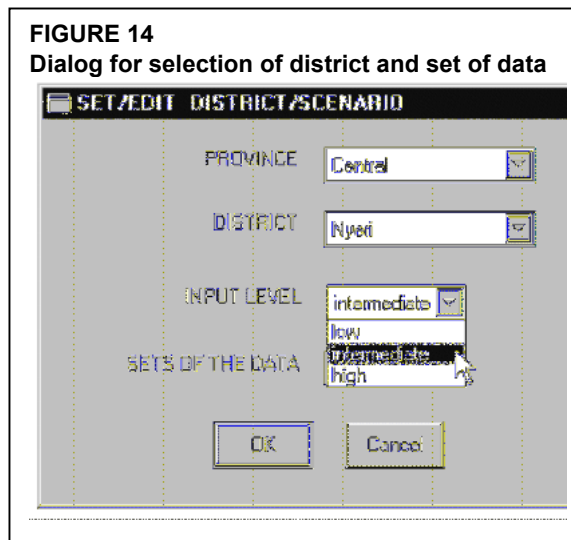


FIGURE 13
Activation of the dialog for selection of the district and of the data



3. Next, to facilitate preparation of consistent district scenarios, it is convenient to undertake crop suitability analysis. This will tabulate by crop LUT and crop (i.e., group of LUTs belonging to the same crop, such as maize of different crop cycle lengths) the extents of different suitability classes. Note that at this stage sequential multi-cropping combinations are not yet considered. Crop suitability is calculated by district. Therefore, we must first select the district to work on. From menu Crop Suitability, chose the first item Set district/set of the data (Figure 13). This brings up a brief dialog window where the province, district, input level, and assumption set must be specified. In the example shown in Figure 14 Nyeri district in Central province has been selected for suitability analysis at an intermediate level of inputs. Two control files for suitability analysis, set A and B, are included with AEZWIN. When using set A, the program attempts to fit a crop LUT optimally within the available growing period(s). With assumption set B, each crop LUT is 'grown' repeatedly as often as possible until all growing periods are exhausted. Usually users prefer to apply set A for suitability analysis. The tables generated by land suitability analysis contain useful information for setting targets in district planning scenarios, e.g., regarding expansion of cash crop areas.



CREATING A DISTRICT LAND PRODUCTIVITY DATABASE

The last preparatory step required before beginning with district planning scenarios is to generate a district land productivity database. The Set district dialog (which is activated from the Productivity main menu item) resembles the one used in suitability analysis, except that there is no field provided for selecting an assumption set (Figure 15). Since we will continue to work on Nyeri district at intermediate level of inputs, i.e., the same as used before for suitability analysis, there is actually no need to call up this dialog. The land productivity database for a selected district and input level is obtained under menu Productivity by selecting Create productivity DB (Figure 16). This selection brings up program AEZ-CCS03 processing each land unit (i.e., agro-ecological cell) of the respective district land resources inventory. The display shows the attributes of the currently processed land record and the number of cropping activities (single crops and sequential crop combinations) retained in the database (Figure 15). Section 7 contains detailed examples of the calculations involved in land productivity assessment. Note that the land productivity database is generated only for the currently selected district and input level. The resulting files are stored in directory \aez\kenya\bin. Therefore, this step has to be executed whenever one of the following conditions holds: (a) the basic data or yield tables were modified, (b) a district not previously analyzed was selected, or (c) an input level not previously analyzed for the current district was selected. Once the land productivity database is available it can be used for repeated district scenario analysis.

FIGURE 15
Dialog for selecting a district and input level

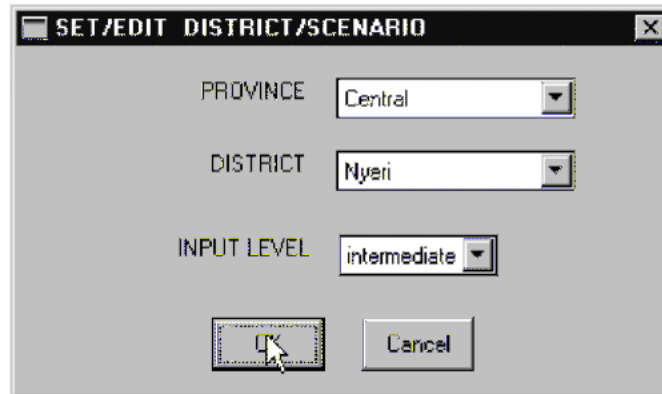


FIGURE 16
Dialog for generating land productivity database

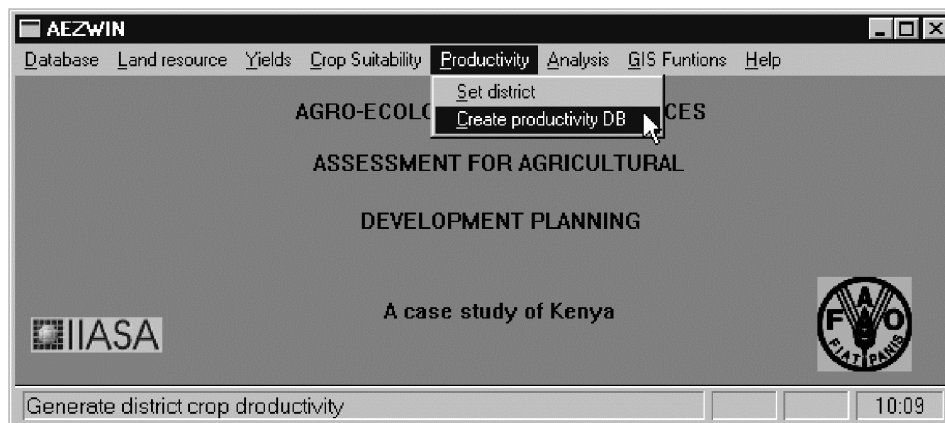
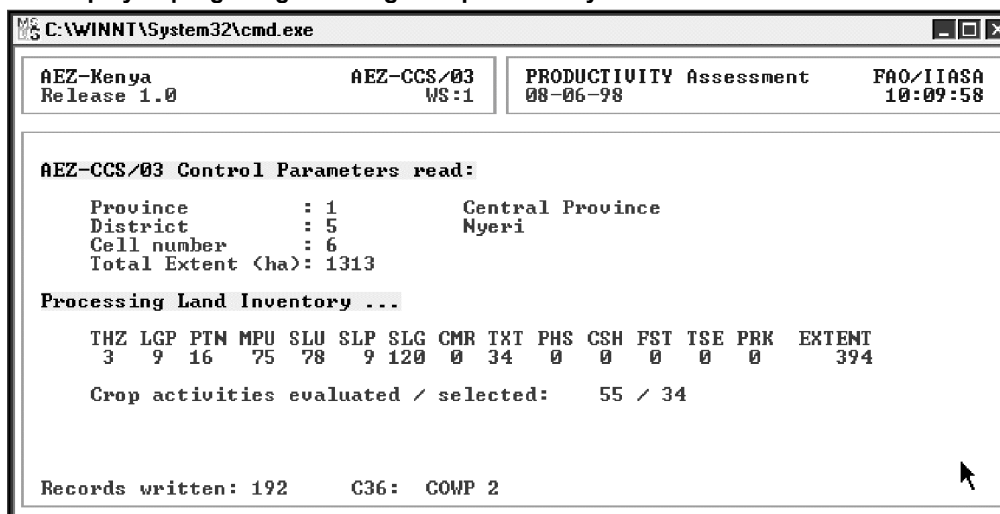


FIGURE 17
Screen display of program generating land productivity database



INTERACTIVE MULTI-CRITERIA MODEL ANALYSIS

The necessary steps are grouped under menu Analysis (Figure 18). As before, the first item allows selection of a district, input level, and scenario. Figure 19 is an example where Nyeri district in Central province was chosen, the land productivity database at the intermediate level of inputs is used, and scenario t09 is selected for analysis. The AEZ core model generator requires a control file that can be prepared outside AEZWIN with an ordinary text editor (of course, strictly adhering to the necessary format), or can be set interactively and modified by pressing the Edit scenario button in the dialog window. Scenario files are stored in directory \aez\kenya\run\ctrl. File names are valid MS-DOS names consisting of a three character prefix and a three digit suffix indicating respectively the scenario name and the numerical district code, e.g., t09.105. This example refers to scenario t09 for Nyeri (with a district code 105).

FIGURE 18
Menu selection for activating dialog for selection of district/scenario for analysis

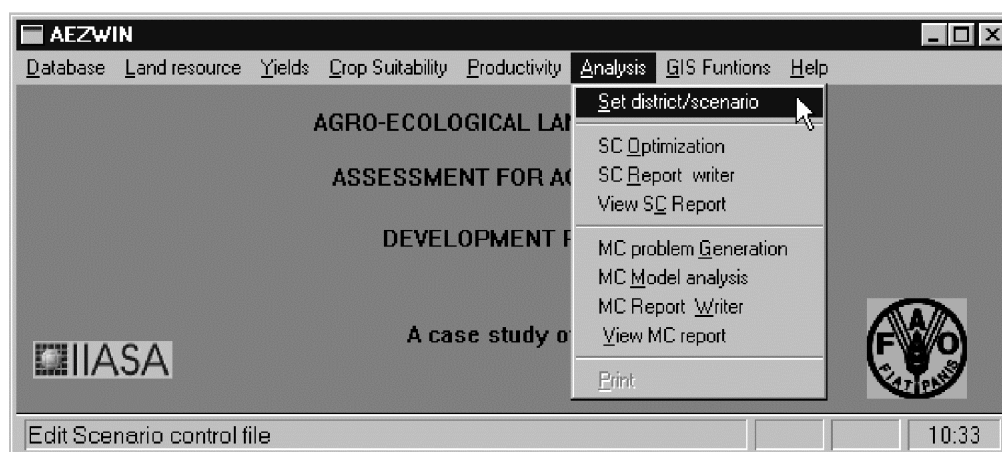


FIGURE 19
Dialog for selecting a district and editing a scenario

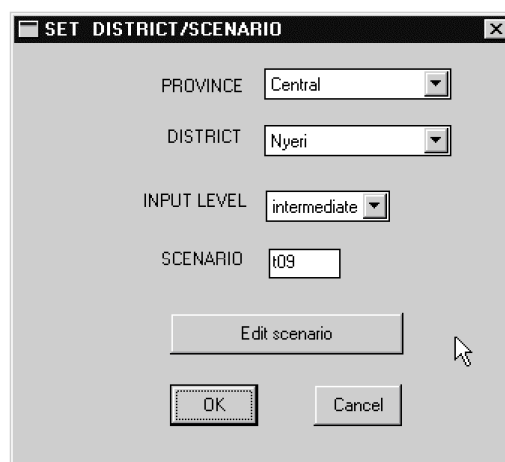


FIGURE 20
Edit scenario dialog

FIGURE 21
Dialog for modification of production targets

It is necessary to strictly follow these naming standards to avoid error conditions. The latter brings up another dialog window where different elements of the scenario control file can be modified (Figure 20). Information is either entered directly into the data fields of the dialog window, or typed into the spreadsheet-like data windows that can be called up by pressing one of the six data control buttons grouped to the right in the middle part of the scenario edit dialog. Figure 21 shows an example for entering (or modifying) production targets that is available after

pressing the Production button in the edit dialog. Note that production targets can be specified for either or both of output level and acreage. Section 8 presents a simple example of a control file for district analysis and describes the contents of the control file.

FIGURE 22
Menu selection for generation of core model for multi-criteria analysis

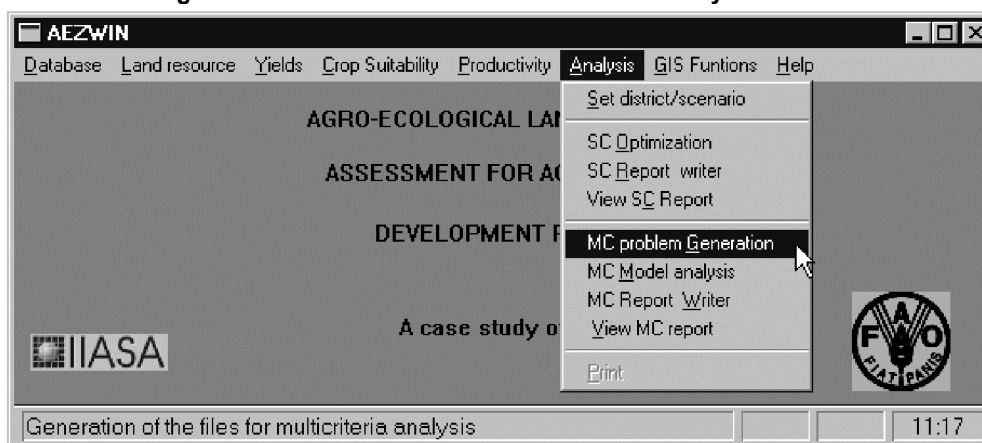


FIGURE 23
Screen display of the core model generator

```

C:\WINNT\System32\cmd.exe
-----
AEZ-Kenya          AEZ-CCS/04      LP Generator      FAO/IIASA
Release 1.5        WS:1            28-11-106        11:48:08

AEZ-CCS/04 Control Parameters read:
MODE = 9          PRINT = 1        NCMB = 3          TECH = 2
FLCPP = 1         DEGSH = 0.50     RISK1 = 0.00     RISK2 = 0.00
CALREQ = 2320     PRTREQ = 38.8    CALPRI = 59.8    MONO = 0.75
FPLAND = 0        TLUFLW = 0.50   SHNFIK = 0.75

Nyeri - Maximize Self-Sufficiency LP-09
Province          : 1          entral Province
District          : 5          yeri
Cell number       : 148
Total Extent (ha) : 167588
District population (1980, 2000) : 486000  824000
LP Coefficients generated : 23530

CELL processed ...
THZ LGP PTN MPU SLU SLP SLG CMR TXT PHS CSH FST TSE PRK EXTENT NFEAS
5 10 13 77 70 9 50 0 34 0 6 0 0 0 88 26

READING LAND PRODUCTIIVITY ASSESSMENT file ... bin.105

```

The Analysis menu separately groups commands for single-criterion analysis (i.e., SC Optimization, etc.) and for multi-criteria model analysis (i.e., MC problem Generation, etc.). The various choices are given in Figure 22 showing the items available under the Analysis menu. Single-criterion scenarios were discussed in some detail in (Fischer and Antoine, 1994a). Therefore, the following concerns multi-criteria model analysis. The first task is to generate a corresponding AEZ core model. The model generator operates in two steps: first the district land productivity database is read and the relevant coefficients of the constraint matrix are calculated in accordance with the settings of the chosen scenario control file. Second, the model is written out in LP DIT format as required by the numerical solver. Both steps are initiated by selecting MC problem Generation from the Analysis menu as shown in Figure 22. While executing, the problem

generator displays a summary of the scenario options and lists the attributes of the processed land units. An illustration is shown in Figure 23. Depending on the type of PC used and the size of the selected district (i.e., number of agro-ecological cells and their characteristics), the generation of the AEZ core model coefficients may take up to a few minutes. Note that several AEZ core model files can be stored and retained for MC model analysis. Obviously, whenever basic data is modified the district AEZ core model along with other information must be generated again. The default name of the core model is aez.cor and is stored in the directory \aezwin\work.

With a core model file existing for the current district, the interactive analysis can now be performed. From the Analysis menu chose MC Model analysis (Figure 24). The MCMA tool starts and reminds the user of the possibility to install on-line help (Figure 25). Help can be obtained using a native help system incorporated into MCMA, or by using Netscape as the Help browser. These options are offered to the user when choosing to install on-line help (Figure 26).

FIGURE 24
Menu selection for activation of the MCMA for the core model analysis

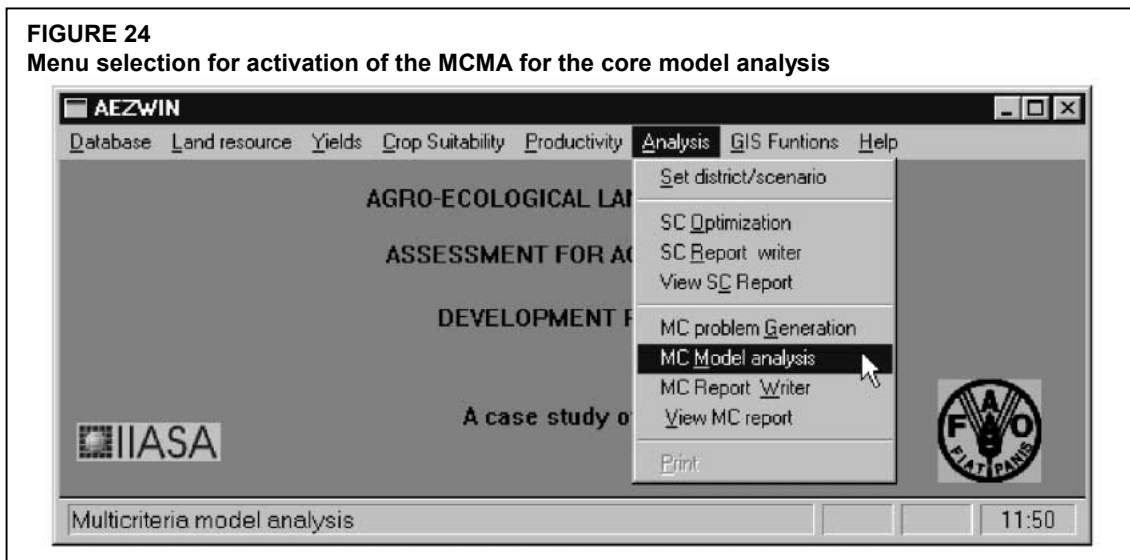
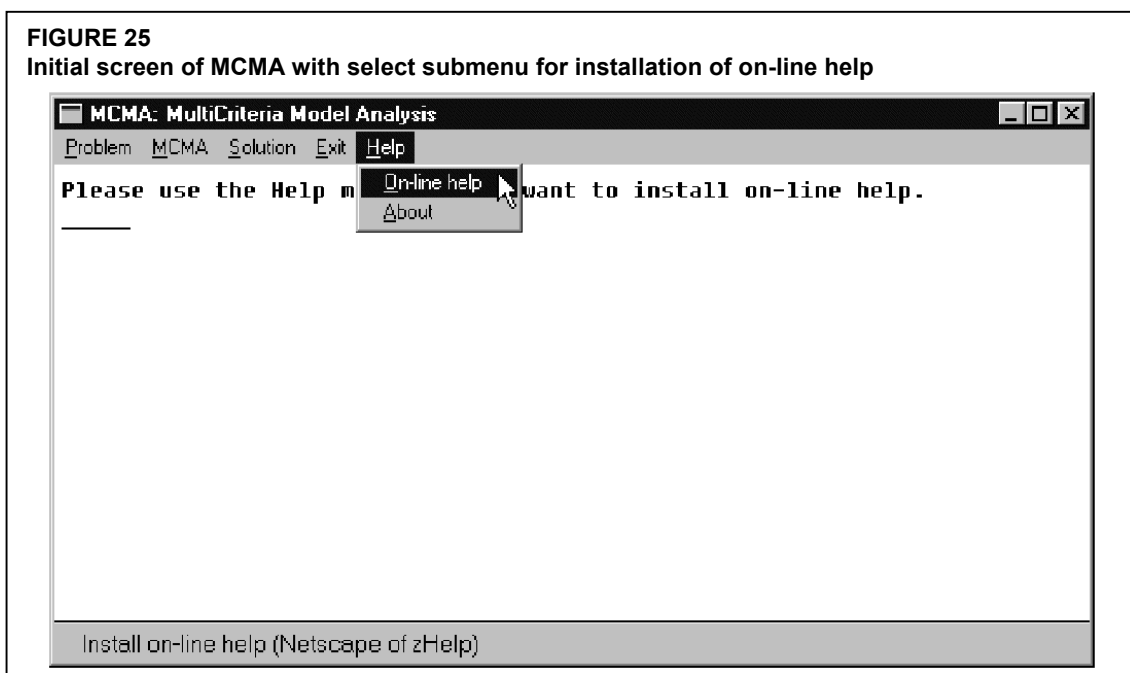


FIGURE 25
Initial screen of MCMA with select submenu for installation of on-line help



Next, open the Problem menu and select New problem (Figure 27) as the AEZ model file that is to be processed has just been created (there is also an option to continue with the results from a previous session). A file open dialog window appears offering a view of the available core model files (with an extension *.cor). The default is to select file aez.cor (Figure 28) which contains the last core model that was generated by the last call to MC problem Generation.

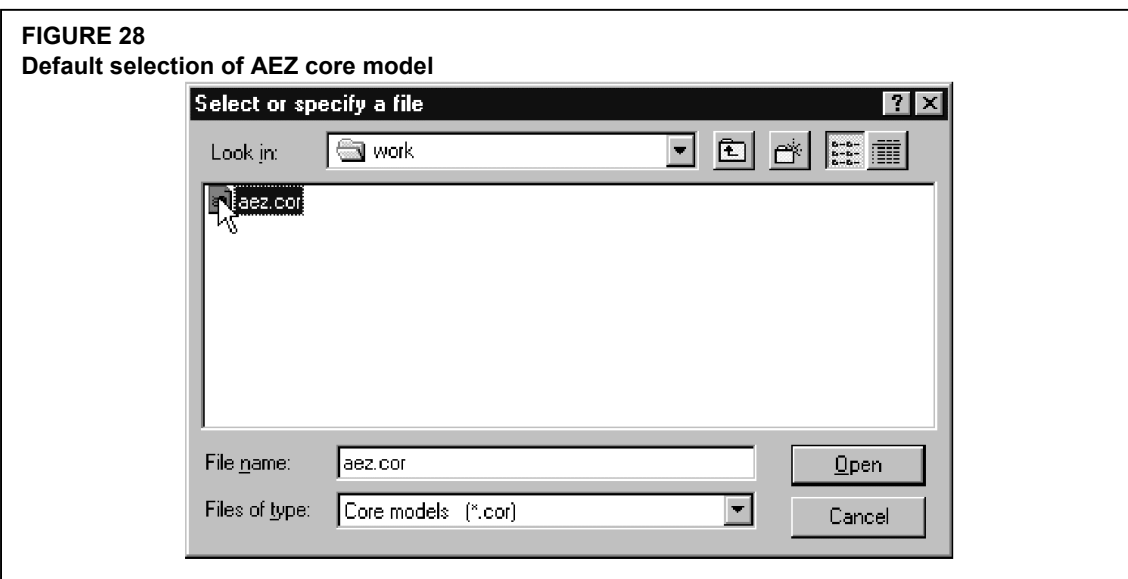
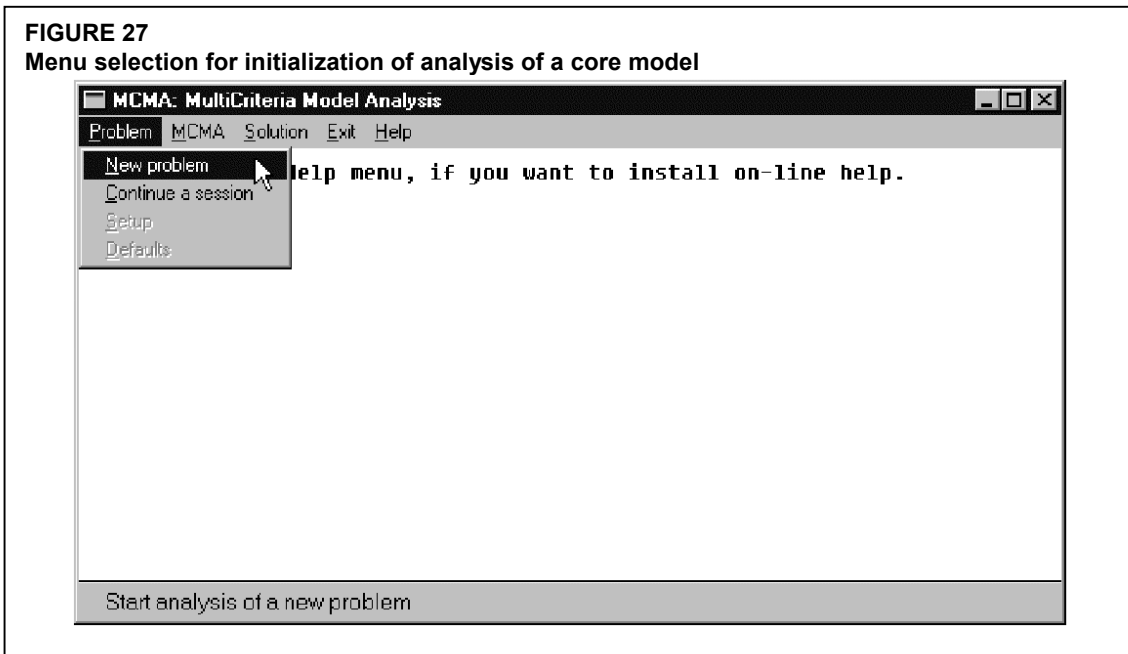
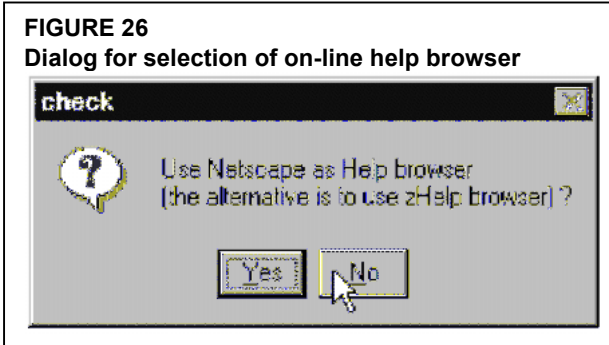
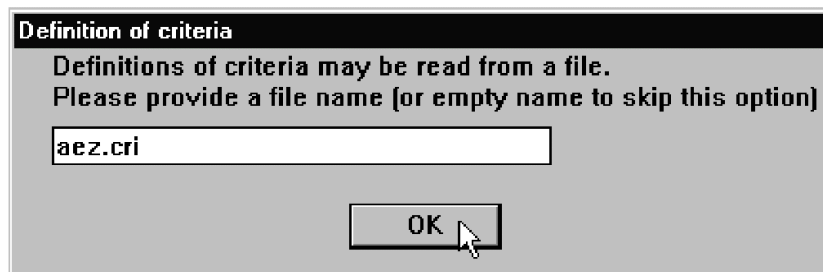


FIGURE 29

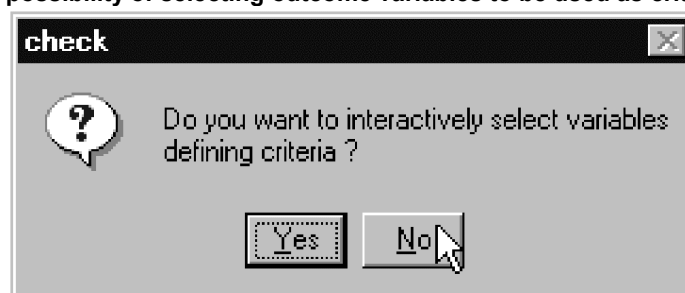
Default selection of a file containing predefined criteria for AEZ core model



After selection of a core model file, the user is requested to specify a file containing the definition of criteria. The default is to use file aez.cri that is provided with the installation. To accept the default (which is strongly recommended), click the OK button (Figure 29). File aez.cri indicates ten pre-defined criteria. The user is given the option to interactively select outcome variables from the full list (Figure 30). Responding with No skips selection of additional outcome variables and brings up a window containing the names of criteria variables, their units, and radio buttons showing the associated criterion type.

FIGURE 30

Dialog offering a possibility of selecting outcome variables to be used as criteria



The default values read from file aez.cri are shown in Figure 31. The contents of the file aez.cri that predefines the criteria using the corresponding variables of the AEZ core model is as follows:

| | | | | |
|----------|-----|------------|---------|---------|
| V0000001 | var | FoodAv | max | Gcal |
| V0000002 | var | NetRev max | mln_KSh | |
| V0000003 | var | ProCos | min | mln_KSh |
| V0000004 | var | GrosOumax | mln_KSh | |
| V0000005 | var | Land | min | ha |
| V0000006 | var | HarvAr min | ha | |
| V0000007 | var | FoodMimax | Gcal | |
| V0000008 | var | TotEro | min | tons |
| V0000009 | var | SSR | max | 0.125% |
| V0000010 | var | MaxEro | min | tons/ha |

FIGURE 31
Predefined criteria of AEZ model

| Definition of criteria | | | | | | | |
|------------------------|------------|---------|--------------------------------|---|----------------------------|------------------------------|--|
| variable | crit. name | units | criterion type | | | | |
| V0000001 | FoodAv | Gcal | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |
| V0000002 | NetRev | mln_KSh | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |
| V0000003 | ProCos | mln_KSh | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |
| V0000004 | GrosOu | mln_KSh | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |
| V0000005 | Land | ha | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |
| V0000006 | HarvAr | ha | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |
| V0000007 | FoodMi | Gcal | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |
| V0000008 | TotEro | tons | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |
| V0000009 | SSR | 0.125% | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |
| V0000010 | MaxEro | tons/ha | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |

FIGURE 32
Selection of criteria made for this tutorial

| Definition of criteria | | | | | | | |
|------------------------|------------|---------|--------------------------------|---|----------------------------|---|--|
| variable | crit. name | units | criterion type | | | | |
| V0000001 | FoodAv | Gcal | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |
| V0000002 | NetRev | mln_KSh | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |
| V0000003 | ProCos | mln_KSh | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input checked="" type="radio"/> ignore | |
| V0000004 | GrosOu | mln_KSh | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input checked="" type="radio"/> ignore | |
| V0000005 | Land | ha | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |
| V0000006 | HarvAr | ha | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input checked="" type="radio"/> ignore | |
| V0000007 | FoodMi | Gcal | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |
| V0000008 | TotEro | tons | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input checked="" type="radio"/> ignore | |
| V0000009 | SSR | 0.125% | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |
| V0000010 | MaxEro | tons/ha | <input type="radio"/> minimize | <input checked="" type="radio"/> maximize | <input type="radio"/> goal | <input type="radio"/> ignore | |

FIGURE 33
Information about starting computation of the pay-off table

info
X

Start computation of the pay-off table and a compromise solution.
 13 optimization problems will be generated and solved.
 Next interactive message will be displayed
 when the problem will be ready for MCMA.

FIGURE 34
Information about finishing computation of the pay-off table.



The first word in a line contains the name of a variable (column) or of a constraint (row) of the LP model. The second word must start with either v (to indicate that the name corresponds to a variable) or with c (for a constraint). Only the first letter of the second word is processed. The third word defines name of a criterion. The fourth word defines type of a criterion (one of: min, max or goal). The fifth word defines units in which the respective criterion value is expressed. In this example, the analysis is restricted to six criteria (FoodAv, NetRev, Land, FoodMi, SSR, and MaxEro). The remaining predefined criteria (ProCos, GrosOu, HarvAr, TotEro) are disabled by clicking on ignore (Figure 32). After clicking OK to confirm the changes in criterion selection, MCMA presents an information window detailing the number of optimization problems that will be solved to obtain the pay-off table and an initial compromise solution, and asking to confirm the start of computations. After pressing OK (Figure 33) a sequence of optimization problems is generated by MCMA (in order to compute the pay-off table and the compromise solution) and the solver is called repeatedly. Computation time required depends on the problem dimensions as well as computer hardware used. Usually, several minutes are required to construct the compromise solution. When the calculations are finished the user is informed accordingly (Figure 34).

The user is now requested to select the ISAAP item from the MCMA menu (Figure 35). The ISAAP tool provides a graphical interface which allows the user to interactively specify aspiration and reservation levels of each criterion, thereby implicitly defining an achievement scalarizing function for the multi-criteria model analysis. A detailed Tutorial of using MCMA and its ISAAP tool is provided in (Granat and Makowski, 1998). Initially, the ISAAP window will contain a graphical representation of the component achievement functions for each criterion and the compromise solution obtained after computation of the pay-off table. The compromise solution is computed by assuming Utopia and Nadir (i.e. the best and worst values of each criterion) as Aspiration and Reservation levels for each corresponding criterion. In the example on Nyeri district chosen here, six criterion variables are included, showing average food production FoodAv (in consumable energy, i.e., after subtracting for processing and losses), food output in 'bad' years FoodMi (according to the inventoried LGP-pattern derived from historical climatic analysis), net revenue from crops and livestock production NetRev, level of district food self-sufficiency SSR (defined as the minimum level among ten broader groups of commodities: cereals, roots, etc.), extent of cultivated land, and the maximum level of soil erosion estimated for any cultivated land unit MaxEro.

FIGURE 35
Screen with information about computed compromise solution and selected submenu to activate ISAAP

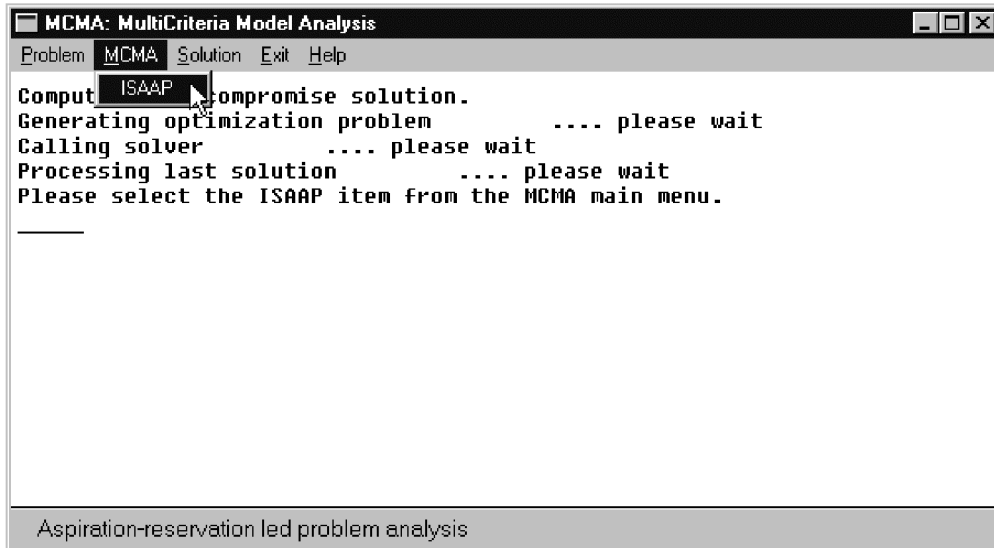
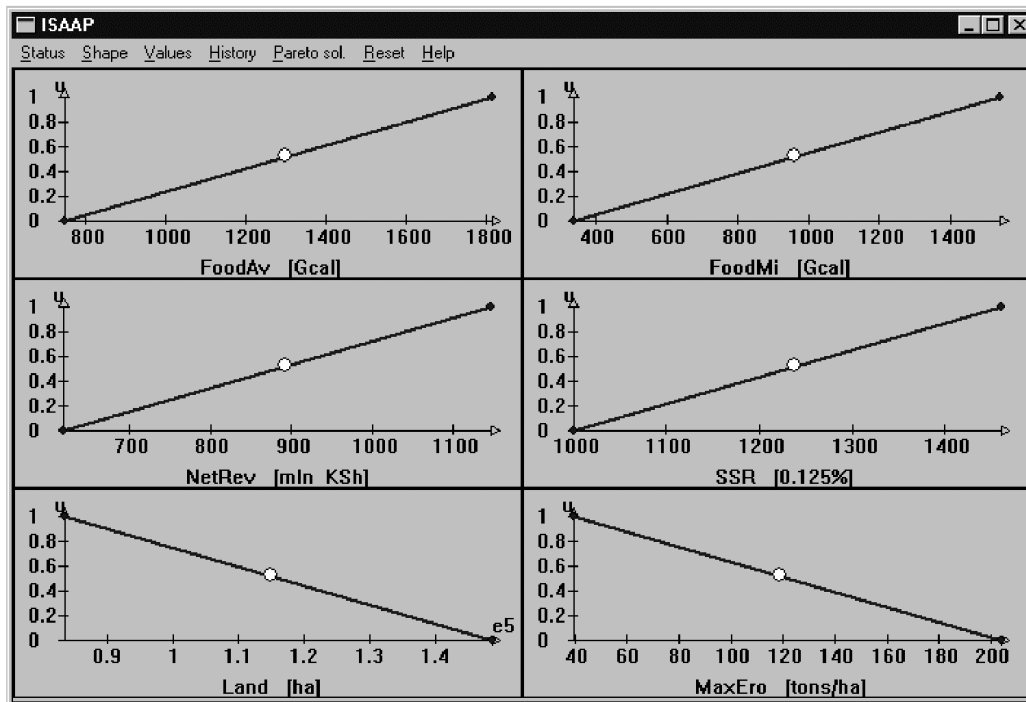
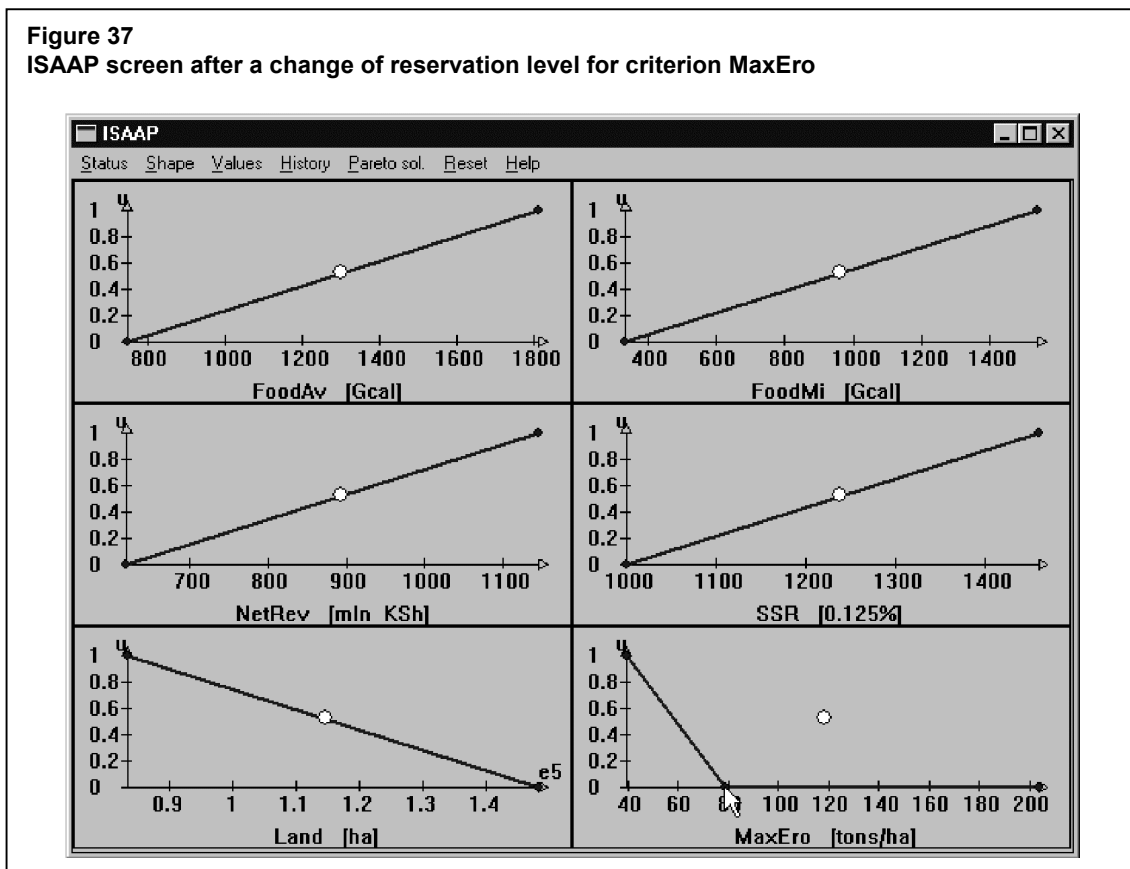


FIGURE 36
ISAAP screen with a compromise solution



For instance, the example shown in Figure 36 indicates that about 115 000 ha of cultivated land would be in use according to the compromise solution initially determined by MCMA (criterion Land in lower left part of Figure 36), and the highest estimated levels of annual soil loss due to water erosion would be as much as 120 tons/ha. Assuming that the latter is regarded as an

Figure 37
ISAAP screen after a change of reservation level for criterion MaxEro



unacceptably high level of erosion, the ease-of-use of ISAAP is demonstrated by modifying the aspiration level for MaxEro (in the lower right part of the ISAAP window). Click the horizontal axes of MaxEro at the tick mark for 80 tons/ha (Figure 37). This will change the reservation level for maximum erosion accordingly.

To evaluate the overall impact of improving merely this particular criterion, select Run from the Pareto sol. menu (Figure 38) of ISAAP to calculate the corresponding optimal solution. As shown in Figure 39, the level of MaxEro is reduced to about 60 tons/ha at the expense of reducing the level of achievement of all the other criteria. With this initial understanding regarding the responsiveness of the optimal multi-criteria solution to changes in the preference structure as expressed by aspiration and reservation levels of the different criteria, the next step is to work on all criteria simultaneously. The reservation levels for the food output, revenue and self-sufficiency criteria are increased, the criterion on cultivated land is relaxed, and the level of maximum erosion is further improved. At the same time, the aspiration levels for average food output and SSR are relaxed. Figure 40 shows the altered component achievement functions, and Figure 41 displays the optimal solution resulting from these changes. Note that ISAAP displays all the solutions obtained thus far, thereby letting the user rapidly develop an understanding of the problem characteristics.

For instance, in Figure 41 four criteria (FoodMi, NetRev, SSR, and MaxEro) attain values close to the specified reservation levels. This indicates that a further improvement of these criteria will be impossible to achieve or 'expensive' in terms of other criterion variables. To demonstrate this situation, the reservation level of FoodMi is increased (meaning more food output in 'bad' years), reservation level of SSR indicator is set to 1250, and the aspiration level of MaxEro is reduced from 60 to 50 tons/ha (Figure 42).

FIGURE 38
 Selection of submenu activating computation of Pareto-optimal solution for current selection of aspiration and reservation levels

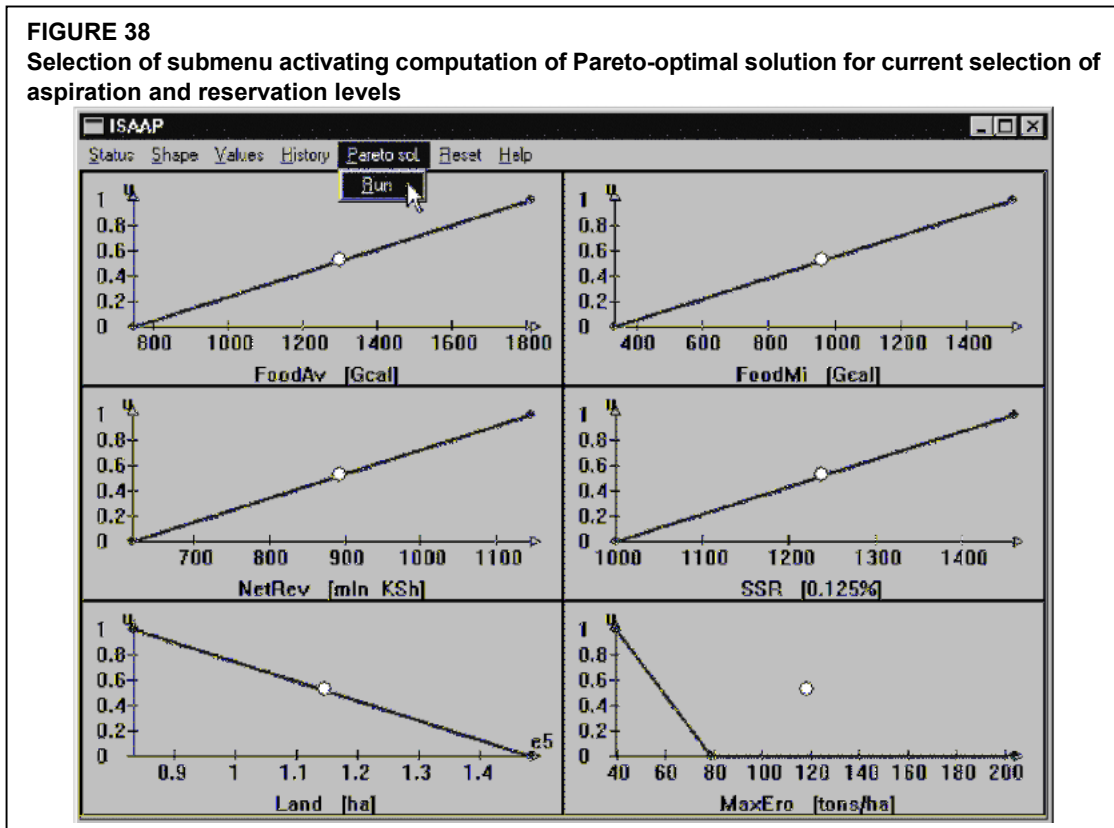


FIGURE 39
 Visualization of Pareto-optimal solution for the first modification of preferences

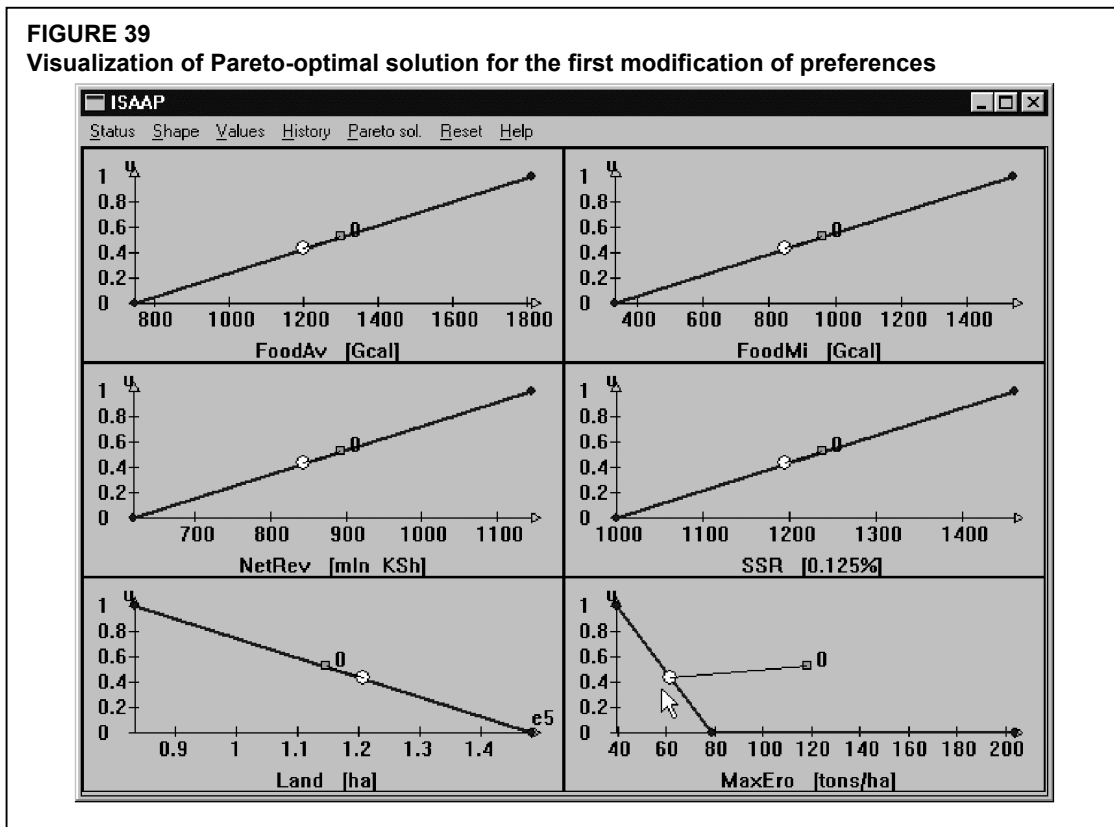


FIGURE 40
Second specification of aspiration and reservation levels

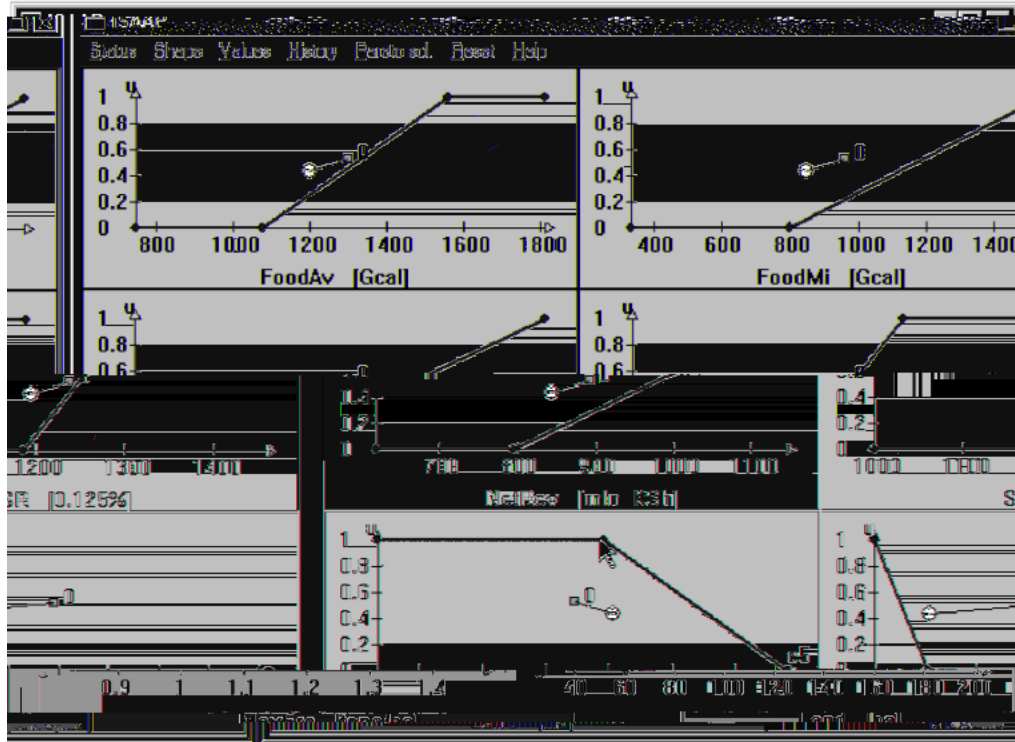


FIGURE 41
Pareto-optimal solution for the second specification of preferences

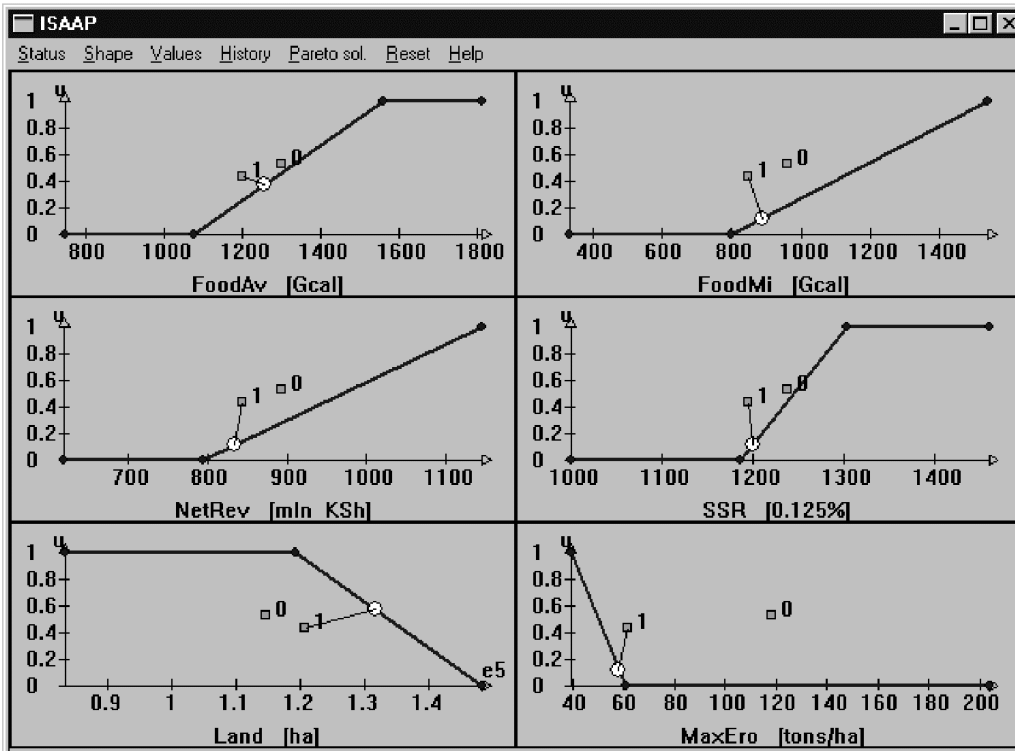


FIGURE 42
Illustration of setting very tight aspiration and reservation levels

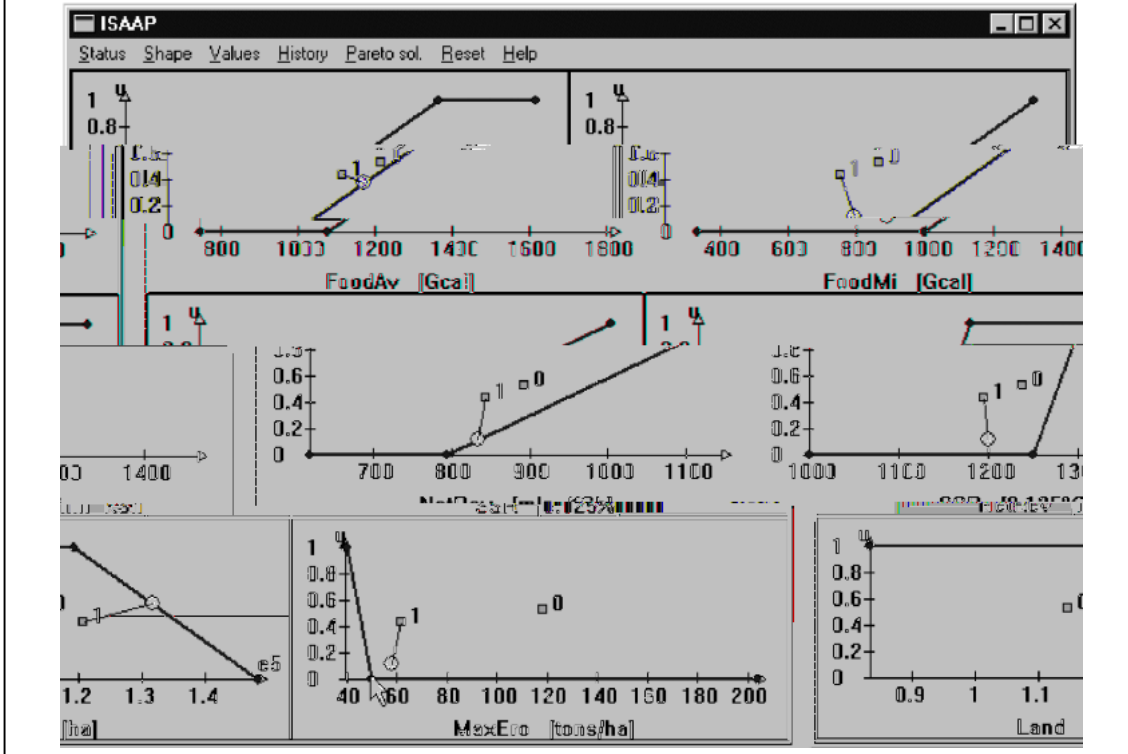
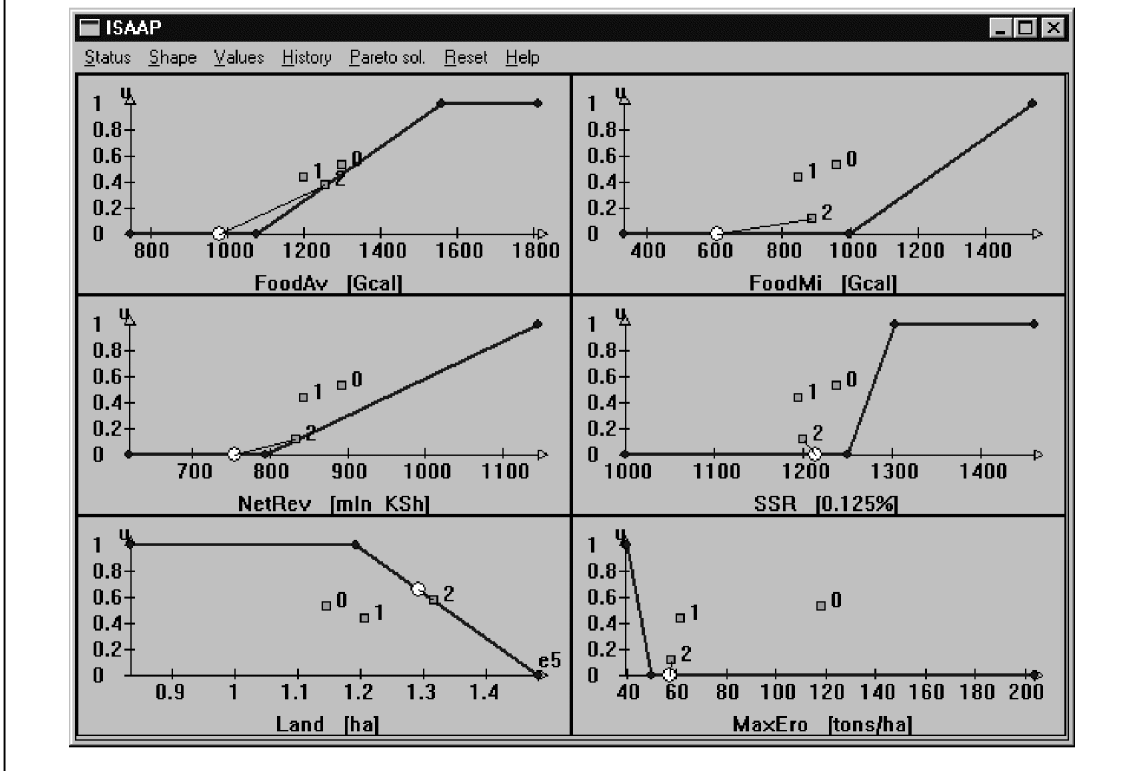
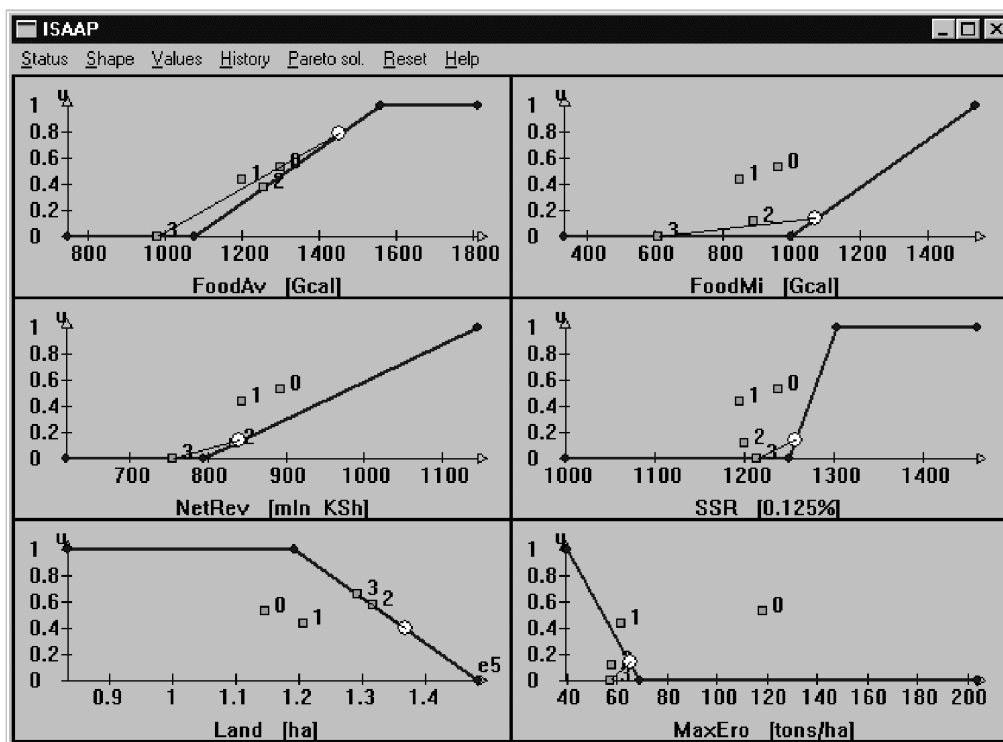


FIGURE 43
Pareto-optimal solution for unattainable reservation point



After selecting Run from menu Pareto sol., ISAAP presents an updated optimal solution. Note that for five out of six criterion variables the resulting solution is inferior to the specified reservation levels (the exception being Land) as is shown in Figure 43. This example illustrates also one of the important advantages of the aspiration/reservation based approach to multi-criteria model analysis: there is no risk in a specification of a reservation level that is not attainable because this method always provides a Pareto-efficient solution that is nearest to the specified aspiration level. One should also note that a specification of an attainable aspiration level (i.e. aspiration levels that can be achieved) will result in a Pareto-optimal solution that is uniformly better than such an aspiration level. The latter feature of the applied method shows its advantage over the classical Goal programming method (which would compute a solution corresponding to the set goals, even if such a solution is not Pareto-efficient).

FIGURE 44
Illustration of relaxation of reservation levels.



Obviously, some of the reservation levels (that were set too tight) must be relaxed to allow the solution to return within acceptable ranges. After modifying the reservation level for MaxEro to 70 tons/ha, all criterion values surpass the respective reservation levels (Figure 44). This interactive process can be easily continued and demonstrates that choosing too ambitious levels of conflicting targets is clearly non-feasible. In addition to changing the definitions of the achievement scalarizing function (that are parameterized by aspiration and reservation levels) by clicking with the mouse in the ISAAP window, reservation and aspiration levels can also be entered from the keyboard. Choosing Values from the ISAAP menu displays a data entry window containing two numerical fields (A=aspiration, R=reservation level) for each criterion variable (Figure 45). These can be edited and used to modify the component achievement functions by clicking the Set button. The numerical details of each optimal solution can be displayed by choosing View solutions from the History menu of ISAAP (Figure 46).

FIGURE 45
Dialog for setting values of aspiration and/or reservation levels from the keyboard

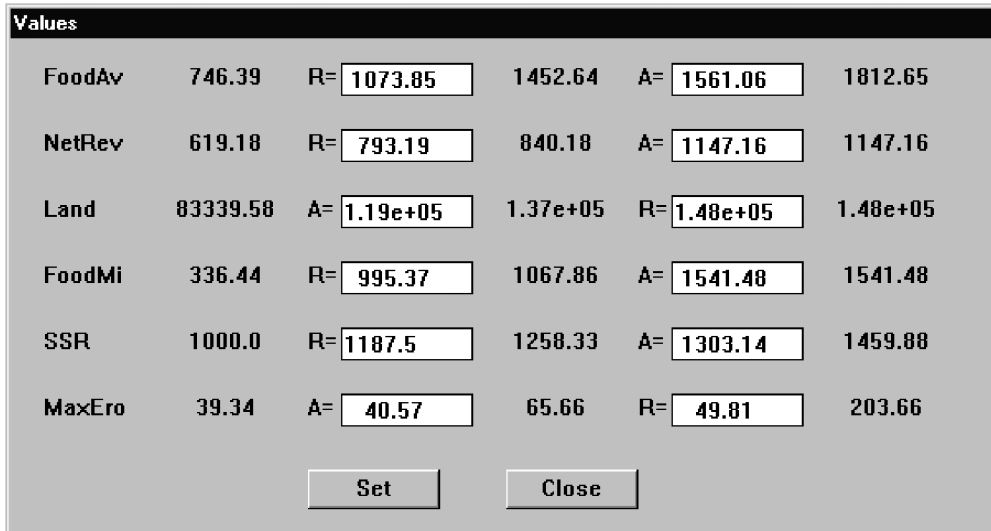
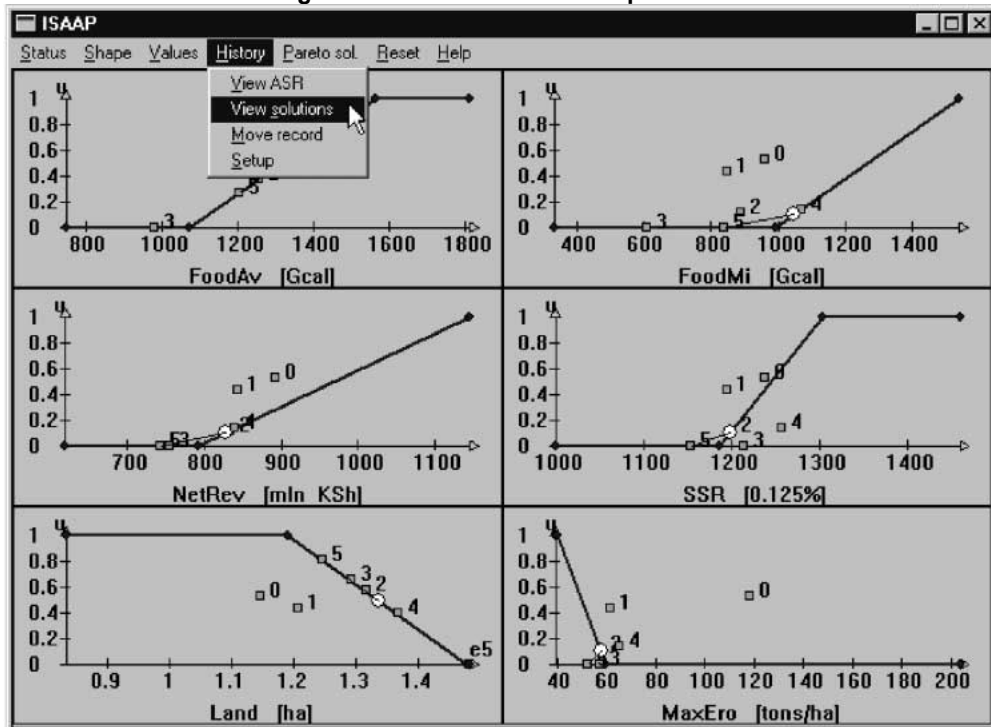


FIGURE 46
Submenu selection for viewing solutions in the form of a spreadsheet



A spreadsheet-like window will be shown containing the complete history of attained criterion values (Figure 47). Also, at any point in the analysis, MCMA allows to save the current solution to a disk file for later retrieval. When a satisfactory solution has been obtained the AEZ Report Writer can be called upon to prepare a detailed listing of crop and livestock production activities, land resources allocation, and resulting food supply levels.

FIGURE 47
Solution (criteria values) in the form of a spreadsheet

| View Solutions | | | | | | | |
|----------------|----------|---------|--------|----------|---------|---------|--------|
| | sol. nr. | FoodAv | NetRev | Land | FoodMi | SSR | MaxEro |
| 0 | 0 | 1298.56 | 892.60 | 1.15e+05 | 960.48 | 1238.15 | 118.57 |
| 1 | 1 | 1200.85 | 844.22 | 1.21e+05 | 850.06 | 1196.01 | 61.94 |
| 2 | 2 | 1254.95 | 834.28 | 1.32e+05 | 887.23 | 1201.14 | 58.38 |
| 3 | 3 | 979.01 | 755.37 | 1.29e+05 | 609.84 | 1214.99 | 57.37 |
| 4 | 4 | 1452.64 | 840.18 | 1.37e+05 | 1067.86 | 1258.33 | 65.66 |
| 5 | 5 | 1202.59 | 743.15 | 1.25e+05 | 838.33 | 1154.25 | 52.47 |
| 6 | 6 | 1406.80 | 827.65 | 1.34e+05 | 1048.54 | 1198.76 | 58.11 |

From the Analysis menu select the item for MC Report Writer (Figure 48). After querying the user for the solution file to be used, as shown in Figure 49, the Report Writer displays a summary screen similar to the display of the AEZ core model generator (Figure 50). When finished, the district results can be viewed by selecting View MC report from the Analysis menu. This loads the respective output file using the MS Windows Notepad.exe program from where the results can also be printed (Figure 51).

FIGURE 48
Selection of submenu for invoking the AEZ report writer

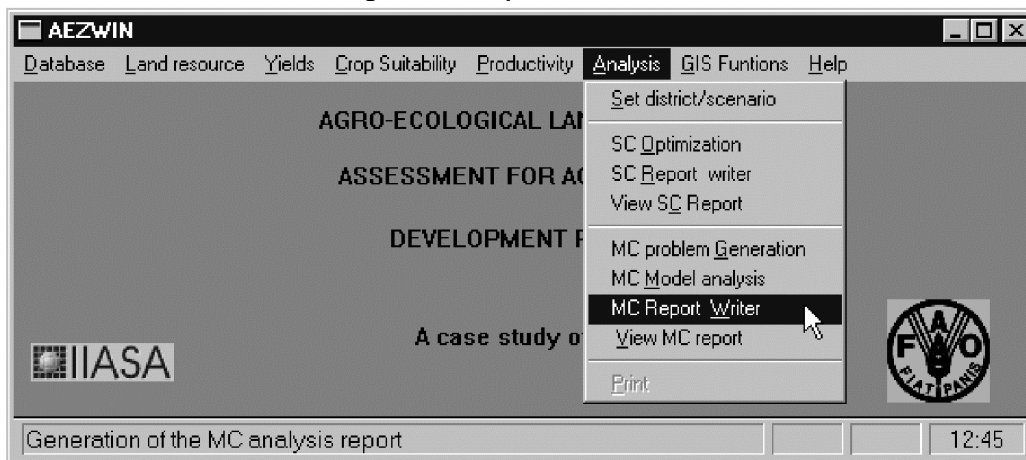


FIGURE 49
Selection of a solution to be analysed by the AEZ report writer

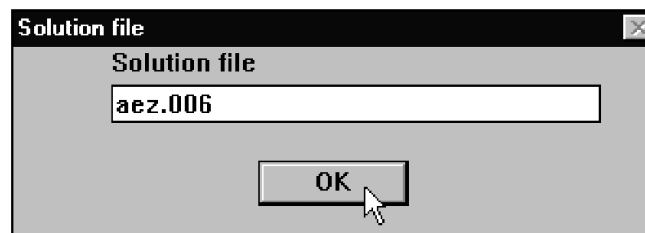


FIGURE 50
Screen display screen of the AEZ report writer

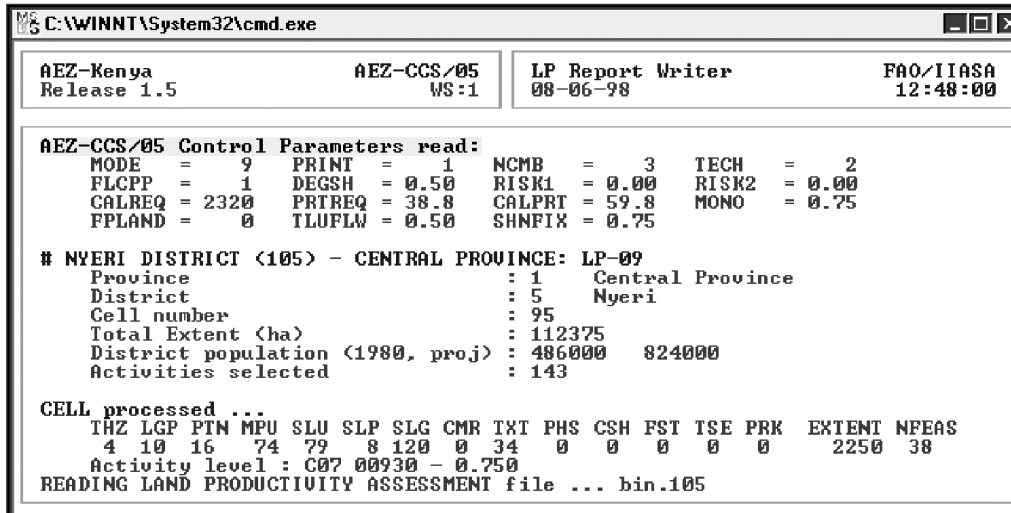
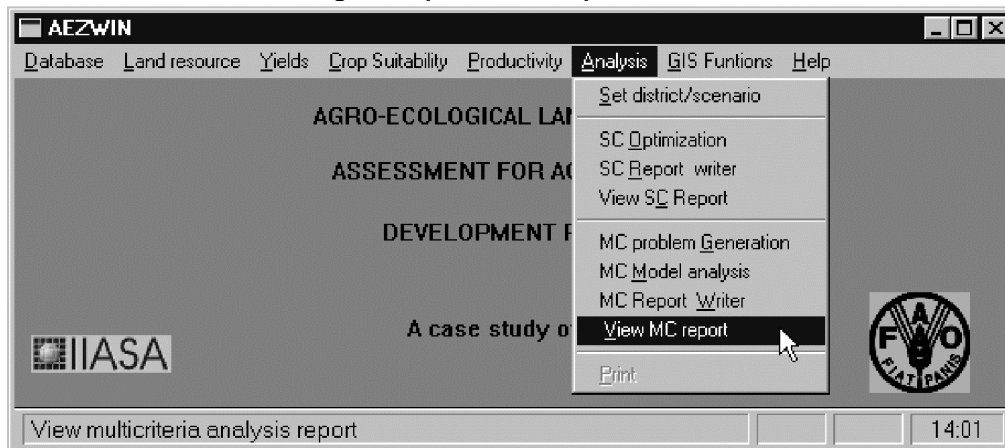


FIGURE 51
Selection of submenu for loading last report into Notepad.



CONTINUING THE DISTRICT ANALYSIS

This ends the brief Tutorial on using AEZWIN and MCMA. A user could continue with Set district/scenario from the Analysis menu, and either specify another district for analysis, or change the input level, e.g. to “high” (Figure 52). In either case this must be followed by calling the MC core model generator (Figure 53) and by interactive analysis using ISAAP.

FIGURE 52
Dialog for selecting the input level

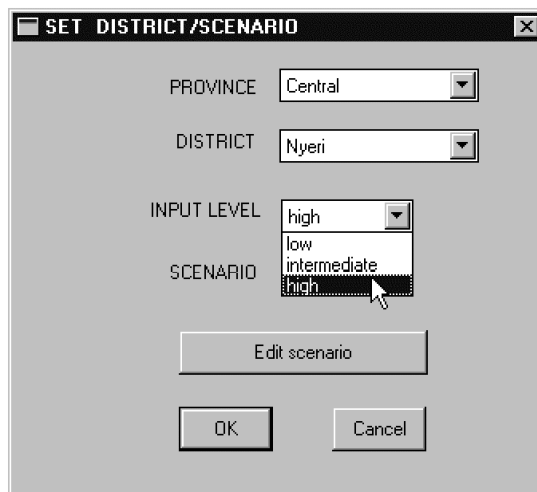
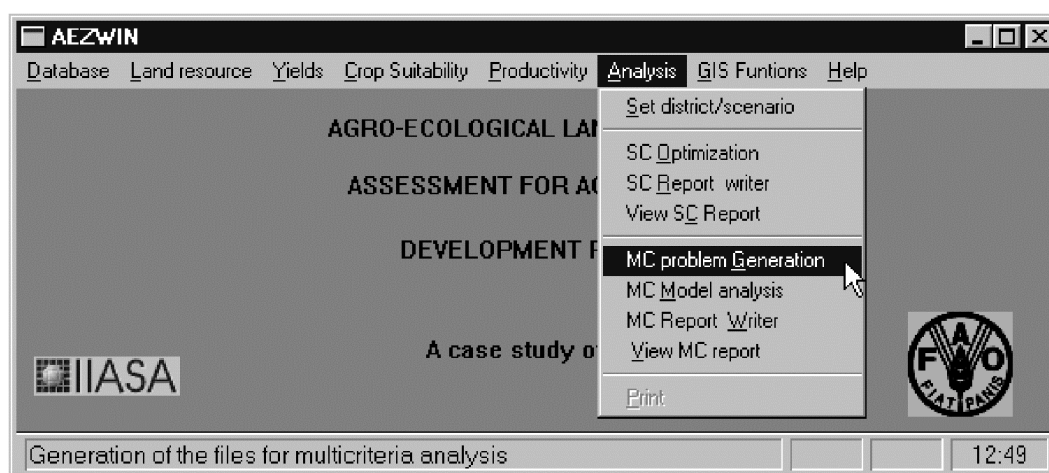
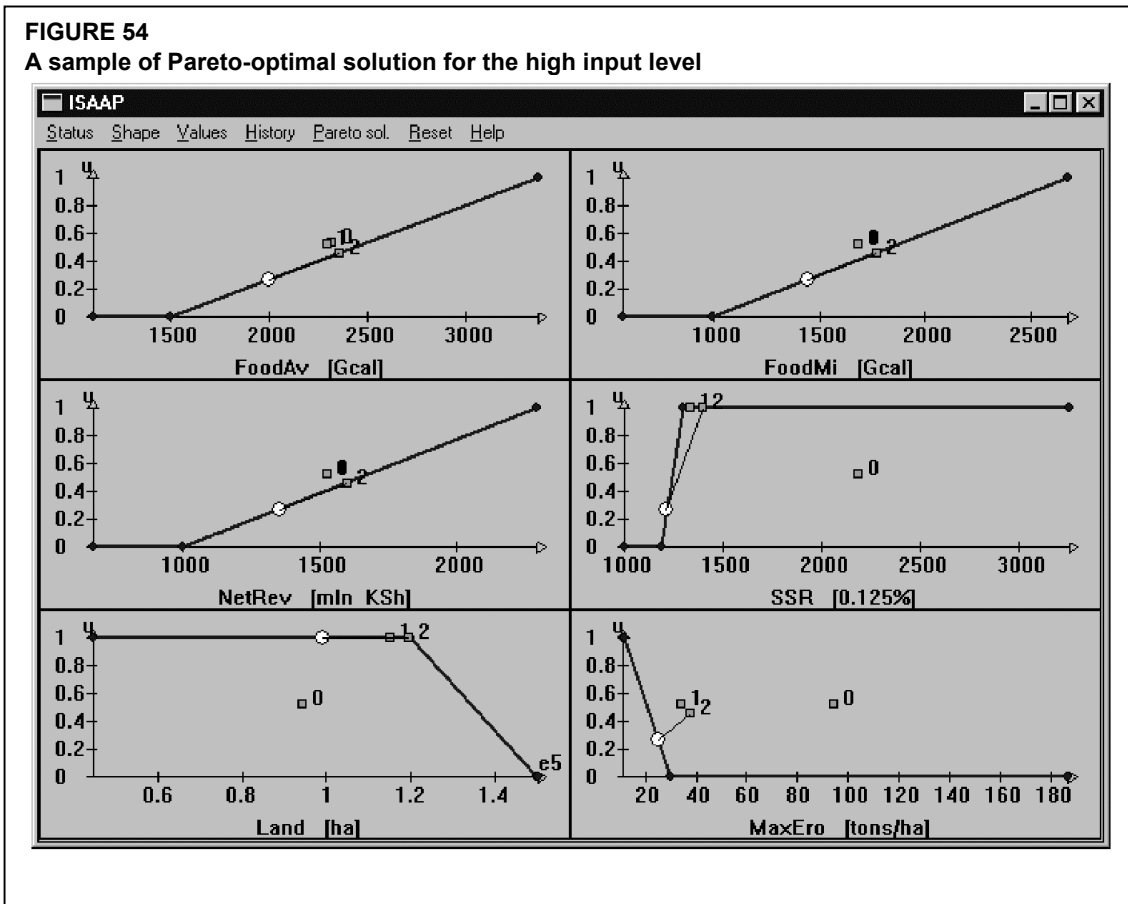


FIGURE 53
Submenu selection for generation of another AEZ core model (that corresponds to a new selection of input level)



An example for Nyeri at the high level of input, with set reservation levels set similar to the previous example, is shown in Figure 54. It illustrates that intensification (i.e., high levels of input) would allow much more flexibility in attaining improved criterion levels, e.g., maximum soil erosion and SSR

FIGURE 54
A sample of Pareto-optimal solution for the high input level



Chapter 9

Troubleshooting

The authors of the AEZWIN and MCMA software will try to do their best to help in resolving technical problems related to using the software described in this document. In order to increase efficiency of developing and testing the software, the users are kindly asked to first check, if the installation (or update) of the software followed the instructions provided in the documentation.

In case of problems that can not be solved without help from the authors, users are advised to perform the following steps:

- Make a back-up of the working directory.
- Make a list of all files from the working directory. Such a list of files must contain names, sizes and dates (including time) of all files located in the working directory.
- Prepare a detailed description of the problem.
- Write down exact specification of your hardware (which should include: type of the PC, amount of RAM, free disk space).

Please send to one of the authors of the software an e-mail composed of the following elements (please follow the sequence specified below):

- Detailed description of the problem.
- Contents of the \aezwin\files.lst file (this file is included in the self-extracting archive in \aezwin directory).
- The above specified list of files in your working directory.
- Contents of the files: _11.dos and aezwin.out.
- Specification of your hardware.
- Your e-mail address.
- Your full name, organization and postal address.

Depending on the type of problem a user may be asked to ftp selected files.

Suggestions for improvements/extensions of the software are most welcome and will be dealt with as resources permit.

Chapter 10

Availability of software and documentation

AEZWIN together with MCMA is available from the FAO (please contact Dr. Jacques Antoine, e-mail: Jacques.Antoine@fao.org for details). Please consult (Granat and Makowski, 1998) (or one of the Web home pages of the authors listed below) for the availability of MCMA alone.

The authors plan to continue further development of the software described in this paper. Therefore, it is likely that new versions of the AEZWIN and MCMA packages will be made available. Please consult the following URL for updated information:

- <http://www.ia.pw.edu.pl/~janusz>
- <http://www.iiasa.ac.at/~marek/soft>

Users of AEZWIN, who would like to use the latest available version of the MCMA should check the above listed Web sites¹ and down-load updates, when those will be available. For users of AEZWIN a version of the lpgen2.exe utility that matches a current version of MCMA will also be made available. Updated versions of the programs should replace the programs that are distributed in the aezwin directory.

This Interim Report serves as documentation for users of AEZWIN. Updated versions of this paper will be made available in electronic form, if the need arises. This version of the paper is available from the following URL:

<http://www.iiasa.ac.at/~marek/pubs>

and will be replaced by an updated version, when available.

All Interim Reports (up to December 1996 called Working Papers) published at IIASA are available from the Publication Department of IIASA. The Home Page of the IIASA Web server² provides an easy access to IIASA's publications, which can be examined in various ways (by author's name, project, date, etc). Postscript files can be obtained free of charge via the Web server. Hard copies of IIASA's publication can be ordered from the Publication Department of IIASA (orders can be placed also via the Web server). Most of the papers related to the MCMA research at IIASA are available in the form of PostScript files.

¹ Users who will register their names on one of those Web servers will get via e-mail information about availability of software updates.

² The URL of IIASA's Web server is: <http://www.iiasa.ac.at>.

Chapter 11

Conclusion

This paper documents the first version of the AEZWIN software. Therefore, at the time of writing this paper there is only limited practical experience with use of the software, limited to testing the AEZWIN by its authors and by experts from the FAO. However, the original AEZ software (to which AEZWIN provides a user friendly interface) has been successfully used for land-use analysis and therefore it is expected that AEZWIN will make the use of the AEZ methodology easier and more widely available. The MCMA methodology included in AEZWIN substantially extends the capabilities of the AEZ methodology. The authors are aware of a number of limitations of the current version of AEZWIN (caused by time and resource constraints for developing the software).

Until now, the MCMA has been implemented within the following documented applications:

- A DSS developed for the Regional Water Quality Management Problem, case study of the Nitra River Basin (Slovakia) documented in Makowski, Somlyody and Watkins (1995); Makowski, Somlyody and Watkins (1996). This application is a result of cooperation of Methodology of Decision Analysis (MDA) and Water Resources projects at IIASA.
- Multiple Criteria Analysis of Urban Land-Use Planning, see Matsushashi (1997).
- A number of engineering applications in mechanics, automatic control and ship navigation, summarized, see Wierzbicki and Granat (1997).

There are a number of other practical applications of MCMA which have not yet been documented.

The authors would appreciate comments and suggestions regarding functionality and robustness of AEZWIN and MCMA. Please do not hesitate to contact one of the authors (preferably by e-mail: see the front page for e-mail addresses) if you would like to obtain more information.

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Annex 1

Coding schemes: Kenya case study

The large number of different elements entering a detailed AEZ country study requires a multiplicity of coding schemes to be devised to enter and address the various indicators in a way suitable for data processing. This Annex contains the coding schemes relevant in the context of the Kenya Case Study:

KENYA DISTRICT CODES

| Code | Nr | District | Province |
|------|----|-----------------|------------------------|
| 01 | 01 | Kiambu | Central Province |
| 02 | 02 | Kirinyaga | |
| 03 | 03 | Muranga | |
| 04 | 04 | Nyandarua | |
| 05 | 05 | Nyer | |
| 01 | 06 | Kilifi | Coast Province |
| 02 | 07 | Kwale | |
| 03 | 08 | Lamu | |
| 04 | 09 | Mombasa | |
| 05 | 10 | Taita Taveta | |
| 06 | 11 | Tana River | |
| 01 | 12 | Embu | Eastern Province |
| 02 | 13 | Isiolo | |
| 03 | 14 | Kitui | |
| 04 | 15 | Machakos | |
| 05 | 16 | Marsabit | |
| 06 | 17 | Meru | |
| 01 | 18 | Nairobi | Nairobi Area |
| 01 | 19 | Garissa | North-Eastern Province |
| 02 | 20 | Mandera | |
| 03 | 21 | Wajir | |
| 01 | 22 | South Nyanza | Nyanza Province |
| 02 | 23 | Kisii | |
| 03 | 24 | Kisumu | |
| 04 | 25 | Siaya | |
| 01 | 26 | Baringo | Rift Valley Province |
| 02 | 27 | Elgeyo Maraquet | |
| 03 | 28 | Kajiado | |

| | | | |
|----|----|-------------|------------------|
| 04 | 29 | Kericho | |
| 05 | 30 | Laikipia | |
| 06 | 31 | Nakuru | |
| 07 | 32 | Nandi | |
| 08 | 33 | Narok | |
| 09 | 34 | Samburu | |
| 10 | 35 | Trans-Nzoia | |
| 11 | 36 | Turkana | |
| 12 | 37 | Uasin Gishu | |
| 13 | 38 | West Pokot | |
| | | | |
| 01 | 39 | Bungoma | Western Province |
| 02 | 40 | Busia | |
| 03 | 41 | Kakamega | |

CROP CODING SCHEME

| NR | Name | Code | -----Description----- | Cycle | IAG |
|----|--------|------|-----------------------|---------|-----|
| 01 | BARL 1 | 011 | BARLEY (spring types) | 090-120 | 01 |
| 02 | BARL 2 | 012 | BARLEY (spring types) | 120-150 | 01 |
| 03 | BARL 3 | 013 | BARLEY (spring types) | 150-180 | 01 |
| 04 | MAIZ 1 | 021 | MAIZE (lowland) | 070-090 | 02 |
| 05 | MAIZ 2 | 022 | MAIZE (lowland) | 090-110 | 02 |
| 06 | MAIZ 3 | 023 | MAIZE (lowland) | 110-130 | 02 |
| 07 | MAIZ 4 | 031 | MAIZE (highland) | 120-140 | 02 |
| 08 | MAIZ 5 | 032 | MAIZE (highland) | 140-180 | 02 |
| 09 | MAIZ 6 | 033 | MAIZE (highland) | 180-200 | 02 |
| 10 | MAIZ 7 | 034 | MAIZE (highland) | 200-220 | 02 |
| 11 | MAIZ 8 | 035 | MAIZE (highland) | 220-280 | 02 |
| 12 | MAIZ 9 | 036 | MAIZE (highland) | 280-300 | 02 |
| 13 | OAT 1 | 041 | OAT (spring types) | 090-120 | 03 |
| 14 | OAT 2 | 042 | OAT (spring types) | 120-150 | 03 |
| 15 | OAT 3 | 043 | OAT (spring types) | 150-180 | 03 |
| 16 | MLLT 1 | 051 | PEARL MILLET | 060-080 | 04 |
| 17 | MLLT 2 | 052 | PEARL MILLET | 080-100 | 04 |
| 18 | RICE 1 | 061 | RICE (dryland) | 090-110 | 05 |
| 19 | RICE 2 | 062 | RICE (dryland) | 110-130 | 05 |
| 20 | RICE 3 | 071 | RICE (wetland) | 080-100 | 05 |
| 21 | RICE 4 | 072 | RICE (wetland) | 100-120 | 05 |
| 22 | RICE 5 | 073 | RICE (wetland) | 120-140 | 05 |
| 23 | SRGH 1 | 081 | SORGHUM (lowland) | 070-090 | 06 |
| 24 | SRGH 2 | 082 | SORGHUM (lowland) | 090-110 | 06 |
| 25 | SRGH 3 | 083 | SORGHUM (lowland) | 110-130 | 06 |
| 26 | SRGH 4 | 091 | SORGHUM (highland) | 120-140 | 06 |
| 27 | SRGH 5 | 092 | SORGHUM (highland) | 140-180 | 06 |
| 28 | SRGH 6 | 093 | SORGHUM (highland) | 180-200 | 06 |
| 29 | SRGH 7 | 094 | SORGHUM (highland) | 200-220 | 06 |
| 30 | SRGH 8 | 095 | SORGHUM (highland) | 220-280 | 06 |
| 31 | SRGH 9 | 096 | SORGHUM (highland) | 280-300 | 06 |
| 32 | WHEA 1 | 111 | WHEAT (spring types) | 100-130 | 07 |

| | | | | | |
|----|---------|-----|------------------------|---------|----|
| 33 | WHEA 2 | 112 | WHEAT (spring types) | 130-160 | 07 |
| 34 | WHEA 3 | 113 | WHEAT (spring types) | 160-190 | 07 |
| 35 | COWP 1 | 211 | COWPEA | 080-100 | 08 |
| 36 | COWP 2 | 212 | COWPEA | 100-140 | 08 |
| 37 | GRAM 1 | 221 | GREEN GRAM | 060-080 | 09 |
| 38 | GRAM 2 | 222 | GREEN GRAM | 080-100 | 09 |
| 39 | GRND 1 | 231 | GROUNDNUT | 080-100 | 10 |
| 40 | GRND 2 | 232 | GROUNDNUT | 100-140 | 10 |
| 41 | BEAN 1 | 241 | PHASEOLUS BEAN | 090-120 | 11 |
| 42 | BEAN 2 | 242 | PHASEOLUS BEAN | 120-150 | 11 |
| 43 | BEAN 3 | 243 | PHASEOLUS BEAN | 150-180 | 11 |
| 44 | PIGP 1 | 251 | PIGEONPEA | 130-150 | 12 |
| 45 | PIGP 2 | 252 | PIGEONPEA | 150-170 | 12 |
| 46 | PIGP 3 | 253 | PIGEONPEA | 170-190 | 12 |
| 47 | SOYB 1 | 261 | SOYBEAN | 080-100 | 13 |
| 48 | SOYB 2 | 262 | SOYBEAN | 100-140 | 13 |
| 49 | CASV | 311 | CASSAVA | 150-330 | 14 |
| 50 | SPOT 1 | 321 | SWEET POTATO | 115-125 | 15 |
| 51 | SPOT 2 | 322 | SWEET POTATO | 125-145 | 15 |
| 52 | SPOT 3 | 323 | SWEET POTATO | 145-155 | 15 |
| 53 | WPOT 1 | 331 | WHITE POTATO | 090-110 | 16 |
| 54 | WPOT 2 | 332 | WHITE POTATO | 110-130 | 16 |
| 55 | WPOT 3 | 333 | WHITE POTATO | 130-170 | 16 |
| 56 | BANANA | 411 | BANANA | 300-365 | 17 |
| 57 | PALM | 421 | OIL PALM | 270-365 | 18 |
| 58 | SUGCAN | 431 | SUGARCANE | 210-365 | 19 |
| 59 | COFFEE | 511 | COFFEE(arabica) | 240-330 | 20 |
| 60 | COTTON | 521 | COTTON | 160-180 | 21 |
| 61 | PINE | 531 | PINEAPPLE | 330-365 | 22 |
| 62 | PYRETH | 541 | PYRETHRUM | 210-330 | 23 |
| 63 | SISAL | 551 | SISAL | 150-270 | 24 |
| 64 | TEA | 561 | TEA | 240-365 | 25 |
| 65 | GRASS | 611 | PASTURES/FODDER | 0-365 | - |
| 66 | ACACALB | 711 | ACACIA ALBIDA | 030-240 | 26 |
| 67 | ACACGER | 712 | ACACIA GERRARDII | 090-300 | 26 |
| 68 | ACACNIL | 713 | ACACIA NILOTICA | 030-270 | 26 |
| 69 | ACACSEN | 714 | ACACIA SENEGAL | 030-240 | 26 |
| 70 | ACACTOR | 715 | ACACIA TORTILUS | 030-270 | 26 |
| 71 | CALICAL | 716 | CALLIANDRA CALOTHYRUS | 150-365 | 26 |
| 72 | CONOLAN | 717 | CONOCARPUS LANCIFOLIUS | 030-270 | 26 |
| 73 | TAMAIND | 718 | TAMARINDUS INDICA | 030-270 | 26 |
| 74 | CASUEQU | 731 | CASUARINA EQUISETIFOL. | 090-300 | 26 |
| 75 | CASUCUN | 732 | CASUARINA CUNNINGHAN. | 120-365 | 26 |
| 76 | LEUCLEU | 751 | LEUCAENA LEUCOCEPHALA | 120-365 | 26 |
| 77 | SESBSES | 752 | SESBANIA SESBAN | 120-365 | 26 |
| 78 | CROTMEG | 811 | CROTON MEGALOCARPUS | 120-300 | 26 |
| 79 | GLIRSEP | 812 | GLIRICIDIA SEPIUM | 150-365 | 26 |
| 80 | GREVROB | 813 | GREVILLEA ROBUSTA | 120-365 | 26 |
| 81 | OLEOAFR | 814 | OLEO AFRICANA | 120-300 | 26 |
| 82 | BRIDMIC | 831 | BRIDELLA MICRANTHA | 120-365 | 26 |

| | | | | | |
|----|---------|-----|------------------------|---------|----|
| 83 | CALOCAP | 832 | CALODENDRUM CAPENSE | 150-365 | 26 |
| 84 | CASSIA | 833 | CASSIA SIAMEA | 090-300 | 26 |
| 85 | CUPRLUC | 834 | CUPRESSUS LUCITANICA | 180-330 | 26 |
| 86 | EUCACIT | 835 | EUCALYPTUS CITRIODORA | 120-300 | 26 |
| 87 | EUCAMIC | 836 | EUCALYPTUS MICROCORYS | 150-300 | 26 |
| 88 | EUCAMIT | 837 | EUCALYPTUS MICROTHECA | 030-270 | 26 |
| 89 | EUCATER | 838 | EUCALYPTUS TERETICORN. | 090-210 | 26 |
| 90 | FAURSAL | 839 | FAUREA SALIGNA | 120-365 | 26 |
| 91 | PARKACU | 840 | PARKINSONIA ACULEATA | 030-180 | 26 |
| 92 | PRUNAFR | 841 | PRUNUS AFRICANUM | 150-365 | 26 |
| 93 | EUCACAM | 851 | EUCALYPTUS CAMALDULEN. | 090-270 | 26 |
| 94 | EUCAGLO | 852 | EUCALYPTUS GLOBULUS | 150-330 | 26 |
| 95 | EUCAGRA | 853 | EUCALYPTUS GRANDIS | 180-365 | 26 |
| 96 | EUCASAL | 854 | EUCALYPTUS SALIGNA | 150-365 | 26 |

IAG - Aggregation index from crop list to agricultural production list.

AGRICULTURAL COMMODITIES CODING SCHEME

a) Crop Production:

| NR | Commodity | IAG | Weight | Extr | Cal | Prt | Waste |
|----|------------------|-----|--------|-------|------|-----|-------|
| 01 | BARLEY | 01 | 1.00 | 0.80 | 3370 | 75 | 2.5 |
| 02 | MAIZE | 01 | 1.00 | 0.90 | 3530 | 93 | 10.0 |
| 03 | OATS | 01 | 1.00 | 0.50 | 3940 | 126 | 8.0 |
| 04 | MILLET | 01 | 1.00 | 0.90 | 3380 | 80 | 10.0 |
| 05 | RICE | 01 | 1.00 | 0.63 | 3630 | 70 | 2.5 |
| 06 | SORGHUM | 01 | 1.00 | 0.90 | 3450 | 107 | 10.0 |
| 07 | WHEAT | 01 | 1.00 | 0.75 | 3640 | 110 | 5.0 |
| 08 | COWPEA | 02 | 1.00 | 1.00 | 3420 | 234 | 10.0 |
| 09 | GRAM | 02 | 1.00 | 1.00 | 3400 | 220 | 10.0 |
| 10 | GROUNDNUT | 05 | 0.32 | 0.69 | 3840 | 162 | 5.0 |
| 11 | BEANS | 02 | 1.00 | 1.00 | 3410 | 221 | 10.0 |
| 12 | PIGEON PEAS | 02 | 1.00 | 1.00 | 3430 | 209 | 10.0 |
| 13 | SOYBEANS | 05 | 1.00 | 1.00 | 4050 | 337 | 10.0 |
| 14 | CASSAVA | 03 | 1.00 | 1.00 | 1100 | 9 | 3.0 |
| 15 | SWEET POTATO | 03 | 1.00 | 1.00 | 980 | 15 | 10.0 |
| 16 | WHITE POTATO | 03 | 1.00 | 1.00 | 710 | 15 | 10.0 |
| 17 | BANANA | 04 | 1.00 | 1.00 | 600 | 10 | 15.0 |
| 18 | OIL PALM | 05 | 1.00 | 1.008 | 8400 | 5.0 | 0.0 |
| 19 | SUGAR CANE | 06 | 0.10 | 1.00 | 280 | 3 | 0.0 |
| 20 | COFFEE (ARABICA) | -- | 1.00 | 1.00 | 0 | 0 | 0.0 |
| 21 | COTTON | -- | 1.00 | 1.00 | 0 | 0 | 0.0 |
| 22 | PINEAPPLE | -- | 1.00 | 1.00 | 0 | 0 | 10.0 |
| 23 | PYRETHRUM | -- | 1.00 | 1.00 | 0 | 0 | 0.0 |
| 24 | SISAL | -- | 1.00 | 1.00 | 0 | 0 | 0.0 |
| 25 | TEA | -- | 1.00 | 1.00 | 0 | 0 | 0.0 |
| 26 | FUELWOOD | 07 | 1.00 | 1.00 | 0 | 0 | 0.0 |

b) Livestock Production:

| NR | Commodity | IAG | Weight | Extr | Cal | Prt | Waste |
|----|------------------|-----|--------|------|------|-----|-------|
| 01 | MEAT, BOVINE | 08 | 1.00 | 1.00 | 2250 | 147 | 0.0 |
| 02 | MEAT, SHEEP+GOAT | 08 | 1.00 | 1.00 | 1800 | 145 | 0.0 |
| 03 | MEAT, CAMEL | 08 | 1.00 | 1.00 | 1740 | 127 | 0.0 |
| 04 | MEAT, POULTRY | 08 | 1.00 | 1.00 | 1220 | 123 | 0.0 |
| 05 | MEAT, PIGS | 08 | 1.00 | 1.00 | 4060 | 105 | 0.0 |
| 06 | MILK, COWS | 09 | 1.00 | 1.00 | 630 | 31 | 5.0 |
| 07 | MILK, GOATS | 09 | 1.00 | 1.00 | 850 | 34 | 5.0 |
| 08 | MILK, CAMEL | 09 | 1.00 | 1.00 | 630 | 20 | 7.5 |
| 09 | WOOL, SHEEP | -- | 1.00 | 1.00 | 0 | 0 | 0.0 |
| 10 | EGGS, POULTRY | 10 | 1.00 | 1.00 | 1230 | 104 | 10.0 |

| | | |
|-------|---|---|
| IAG | - | Aggregation index from agricult. production list to aggregate food list |
| Extr | - | Extraction rate |
| Cal | - | Calorie content (Kcal per kg) |
| Prt | - | Protein content (grams protein per kg) |
| Waste | - | Waste (in percent) |

AGGREGATE COMMODITY GROUPS

| NR | Commodity Group |
|----|-----------------|
| 01 | CEREALS |
| 02 | PULSES |
| 03 | ROOTS |
| 04 | SUGAR |
| 05 | VEGET.OIL |
| 06 | BANANAS |
| 07 | FUELWOOD |
| 08 | MEATS |
| 09 | MILK |
| 10 | EGGS |

THERMAL ZONE CODING

| Code | Temperature (Celsius) | Altitude (metres) | Explanation |
|------|--------------------------|----------------------|------------------------|
| 001 | > 25.0 | 800 < | fairly hot to very hot |
| 002 | 22.5 - 25.0 | 800 - 1200 | warm |
| 003 | 20.0 - 22.5 | 1200 - 1600 | fairly warm |
| 004 | 17.5 - 20.0 | 1600 - 2000 | warm temperate |
| 005 | 15.0 - 17.5 | 2000 - 2350 | cool temperate |
| 006 | 12.5 - 15.0 | 2350 - 2700 | fairly cool |
| 007 | 10.0 - 12.5 | 2700 - 3100 | cool |
| 008 | 5.0 - 10.0 | 3100 - 3900 | very cool |
| 009 | < 5.0 | < 3900 | cold to very cold |

LGP-PATTERN CODING

| Code | Symbol | Pattern Proportion Rules (%) | | | | | |
|------|--------|------------------------------|-----|-----|----|----|-----|
| | | H | 1 | 2 | 3 | 4 | D |
| 01 | 1 | | 100 | | | | |
| 02 | H-1 | 60 | 40 | | | | |
| 03 | 1-H | 30 | 70 | | | | |
| 04 | 1-H-2 | 20 | 65 | 15 | | | |
| 05 | 1-2-H | 15 | 65 | 20 | | | |
| 06 | 1-2 | | 65 | 35 | | | |
| 07 | 1-2-3 | | 50 | 35 | 15 | | |
| 08 | 1-3-2 | | 50 | 20 | 30 | | |
| 09 | 1-2-D | | 40 | 35 | | | 25 |
| 10 | 1-D-2 | | 40 | 25 | | | 35 |
| 11 | 1-D | | 60 | | | | 40 |
| 12 | 2 | | | 100 | | | |
| 13 | 2-1 | | 30 | 70 | | | |
| 14 | 2-1-H | 15 | 30 | 55 | | | |
| 15 | 2-1-3 | | 25 | 55 | 20 | | |
| 16 | 2-3 | | | 75 | 25 | | |
| 17 | 2-3-1 | | 15 | 60 | 25 | | |
| 18 | 2-3-4 | | | 60 | 30 | 10 | |
| 19 | 2-1-D | | 15 | 70 | | | 15 |
| 20 | 3-2 | | | 40 | 60 | | |
| 21 | 3-2-1 | 15 | 35 | 50 | | | |
| 22 | D | | | | | | 100 |

LENGTH OF GROWING PERIODS

| Code | Symbol | # days |
|------|--------|-----------|
| 001 | LGP 01 | 0 |
| 002 | LGP 02 | 1 - 29 |
| 003 | LGP 03 | 30 - 59 |
| 004 | LGP 04 | 60 - 89 |
| 005 | LGP 05 | 90 - 119 |
| 006 | LGP 06 | 120 - 149 |
| 007 | LGP 07 | 150 - 179 |
| 008 | LGP 08 | 180 - 209 |
| 009 | LGP 09 | 210 - 239 |
| 010 | LGP 10 | 240 - 269 |
| 011 | LGP 11 | 270 - 299 |
| 012 | LGP 12 | 300 - 329 |
| 013 | LGP 13 | 330 - 364 |
| 014 | LGP 14 | 365- |
| 015 | LGP 15 | 365+ |

CASH CROP AREA CODING

| Code | Symbol | Explanation |
|------|--------|-----------------------|
| 001 | -- | no cash crops |
| 002 | 01 | Tea (secondary) |
| 003 | 02 | Coffee (secondary) |
| 004 | 03 | Sugarcane (secondary) |
| 005 | 04 | Cotton (secondary) |
| 006 | 05 | Pyrethrum |
| 007 | 06 | Sisal (secondary) |
| 008 | 10 | Tea (primary) |
| 009 | 12 | Tea / Coffee |
| 010 | 13 | Tea / Sugarcane |
| 011 | 15 | Tea / Pyrethrum |
| 012 | 20 | Coffee (primary) |
| 013 | 23 | Coffee /Sugarcane |
| 014 | 30 | Sugarcane (primary) |
| 015 | 34 | Sugarcane / Cotton |
| 016 | -- | n.a. |
| 017 | 40 | Cotton (primary) |
| 018 | 60 | Sisal (primary) |
| 019 | 70 | Pineapple (primary) |

FOREST LAND CODING

| Code | Symbol | Explanation |
|------|--------|---------------------|
| 001 | -- | no forests |
| 002 | F1 | registered forest |
| 003 | F2 | unregistered forest |
| 004 | F3 | proposed forest |

IRRIGATION SCHEME CODING

| Code | Symbol | Explanation |
|------|--------|---------------|
| 001 | -- | no irrigation |
| 002 | 01 | Turkwell |
| 003 | 02 | Katilu |
| 004 | 03 | Amolem |
| 005 | 04 | Kaputir |
| 006 | 05 | Bunyala |
| 007 | 06 | Ahero I |
| 008 | 07 | Ahero II |
| 009 | 08 | Marigat |
| 010 | 09 | Mwea |
| 011 | 10 | Malka Daka |
| 012 | 11 | Merti |
| 013 | 12 | Mbalambala |
| 014 | 13 | Carisa |
| 015 | 14 | Hola |
| 016 | -- | n.a |

| | | |
|-----|----|-----------------|
| 017 | 15 | Garsen |
| 018 | 17 | Taveta |
| 019 | 18 | Mandere |
| 020 | 19 | Bura (proposed) |
| 021 | 16 | Wema |

PARK LAND CODING

| Code | Symbol | Explanation |
|------|--------|----------------------------|
| 001 | -- | outside park area |
| 002 | P1 | National Park (U.N. Class) |
| 003 | P2 | Game Reserve |
| 004 | P3 | National Reserve |

TSETSE AREA CODING

| Code | Symbol | Explanation |
|------|--------|----------------------------|
| 001 | -- | no infestation |
| 002 | T | high infestation potential |

SLOPE CLASS CODING

| Code | Symbol | Slope Class | Mean Slopes of Quartiles | | | |
|------|--------|-------------|--------------------------|-------|-------|-------|
| | | | ---Q1 | ---Q2 | ---Q3 | ---Q4 |
| 01 | A | 0-2% | 0 | 1 | 1 | 2 |
| 02 | AB | 0-5% | 0 | 2 | 4 | 5 |
| 03 | B | 2-5% | 2 | 3 | 4 | 5 |
| 04 | BC | 2-8% | 2 | 4 | 6 | 8 |
| 05 | C | 5-8% | 5 | 6 | 7 | 8 |
| 06 | BCD | 2 - 16% | 2 | 6 | 11 | 16 |
| 07 | CD | 5-16% | 5 | 6 | 7 | 8 |
| 08 | D | 8-16% | 8 | 11 | 13 | 16 |
| 09 | DE | 8 - 30% | 8 | 16 | 22 | 30 |
| 10 | E | 16 - 30% | 16 | 21 | 25 | 30 |
| 11 | EF | >16% | 16 | 30 | 42 | 56 |
| 12 | F | >30% | 30 | 39 | 47 | 56 |

SOIL TEXTURE CODING

| Code | Symbol | Explanation |
|------|--------|-------------------|
| 010 | S | Sand |
| 011 | LCS | Loamy Coarse Sand |
| 012 | FS | Fine Sand |
| 013 | LFS | Loamy Fine Sand |
| 014 | LS | Loamy Sand |
| 020 | FSL | Fine Sandy Loam |
| 021 | SL | Sandy Loam |
| 022 | L | Loam |

| | | |
|-----|------|-----------------|
| 023 | SCL | Sandy Clay Loam |
| 024 | SIL | Silt Loam |
| 025 | CL | Clay Loam |
| 026 | SICL | Silty Clay Loam |
| 027 | SI | Silt |
| 031 | SC | Sandy Clay |
| 032 | SIC | Silty Clay |
| 033 | PC | Peaty Clay |
| 034 | C | Clay |

COARSE MATERIAL CODING

| Code | Symbol | Explanation |
|------|--------|----------------|
| 001 | G | Gravelly |
| 002 | VG | Very Gravelly |
| 003 | S | Stony |
| 004 | B | Bouldery |
| 005 | SB | Stony/Bouldery |
| 006 | BS | Bouldery/Stony |

SOIL PHASE CODING

| Code | Symbol | Explanation |
|------|--------|----------------------|
| 001 | R | Rocky |
| 002 | B | Bouldery |
| 003 | BM | Bouldery Mantle |
| 004 | S | Stony |
| 005 | SM | Stony Mantle |
| 006 | GM | Gravel Mantle |
| 007 | P | Lithic |
| 008 | PP | Paralithic |
| 009 | K | Petrocalcic (50-100) |
| 010 | KK | Petrocalcic (<50) |
| 011 | C | Pisocalcic (50-100) |
| 012 | CC | Pisocalcic (<50) |
| 013 | M | Petroferric (50-100) |
| 014 | N | Pisoferric (<100) |
| 015 | A | Saline |
| 016 | O | Sodic |
| 017 | AO | Saline-Sodic |
| 018 | F | Fragipan |
| 019 | G | Gravelly |

SOIL UNIT CODING

| Code | Symbol | Explanation |
|------|--------|------------------|
| 001 | A | Acrisols |
| 002 | Ac | Chromic Acrisols |
| 003 | Ag | Gleyic Acrisols |

| | | |
|-----|------|----------------------------|
| 004 | Ah | Humic Acrisols |
| 005 | Aic | Ferralsol-chromic Acrisols |
| 006 | Aif | Ferralsol-ferric Acrisols |
| 007 | Aio | Ferralsol-orthic Acrisols |
| 008 | Ao | Orthic Acrisols |
| 009 | Ap | Plinthic Acrisols |
| 010 | Ath | Ando-humic Acrisols |
| 011 | B | Cambisols |
| 012 | Bc | Chromic Cambisols |
| 013 | Bd | Dystric Cambisols |
| 014 | Be | Eutric Cambisols |
| 015 | Bf | Ferralsol Cambisols |
| 016 | Bg | Gleyic Cambisols |
| 017 | Bh | Humic Cambisols |
| 018 | Bk | Calcic Cambisols |
| 019 | Bnc | Nio-chromic Cambisols |
| 020 | Btc | Ando-chromic Cambisols |
| 021 | Bte | Ando-eutric Cambisols |
| 022 | Bv | Vertic Cambisols |
| 023 | C | Chernozems |
| 024 | Ch | Haplic Chernozems |
| 025 | Ck | Calcic Chernozems |
| 026 | E | Rendzinas |
| 027 | Ec | Cambic Rendzinas |
| 028 | Eo | Orthic Rendzinas |
| 029 | F | Ferralsols |
| 030 | Fa | Acric Ferralsols |
| 031 | Fh | Humic Ferralsols |
| 032 | Fnh | Nito-humic Ferralsols |
| 033 | Fnr | Nito-rhodic Ferralsols |
| 034 | Fo | Orthic Ferralsols |
| 035 | Fr | Rhodic Ferralsols |
| 036 | Fx | Xanthic Ferralsols |
| 037 | G/Ge | Gleysols/Eutric Gleysols |
| 038 | Gc | Calcaric Gleysols |
| 039 | Gd | Dystric Gleysols |
| 040 | Gh | Humic Gleysols |
| 041 | Gm | Mollic Gleysols |
| 042 | Gv | Vertic Gleysols |
| 043 | H | Phaeozems |
| 044 | Hg | Gleyic Phaeozems |
| 045 | Hh | Haplic Phaeozems |
| 046 | Hnl | Nito-luvic Phaeozems |
| 047 | Hol | Ortho-luvic Phaeozems |
| 048 | Hrl | Chromo-luvic Phaeozems |
| 049 | Hth | Ando-haplic Phaeozems |
| 050 | Htl | Ando-luvic Phaeozems |
| 051 | Hvl | Verto-luvic Phaeozems |
| 052 | I | Lithosols |
| 053 | Ir | Ironstone soils |

| | | |
|-----|-----|-------------------------|
| 054 | J | Fluvisols |
| 055 | Jc | Calcaric Fluvisols |
| 056 | Je | Eutric Fluvisols |
| 057 | Jt | Thionic Fluvisols |
| 058 | K | Kastanozems |
| 059 | Kh | Haplic Kastanozems |
| 060 | L | Luvic Luvisols |
| 061 | La | Albic Luvisols |
| 062 | Lc | Chromic Luvisols |
| 063 | Lf | Ferric Luvisols |
| 064 | Lg | Gleyic Luvisols |
| 065 | Lic | Ferralic Luvisols |
| 066 | Lif | Ferralic Luvisols |
| 067 | Lio | Ferralic Luvisols |
| 068 | Lk | Calcic Luvisols |
| 069 | Lnc | Nitric Luvisols |
| 070 | Lnf | Nitric Luvisols |
| 071 | Lo | Orthic Luvisols |
| 072 | Lv | Vertic Luvisols |
| 073 | M | Greyzems |
| 074 | Mo | Orthic Greyzems |
| 075 | Mvo | Orthic Greyzems |
| 076 | N | Nitisols |
| 077 | Nd | Dystric Nitisols |
| 078 | Ne | Eutric Nitisols |
| 079 | Nh | Humic Nitisols |
| 080 | Nm | Mollic Nitisols |
| 081 | Nth | Ando-humic Nitisols |
| 082 | Nve | Verto-eutric Nitisols |
| 083 | Nvm | Verto-mollic Nitisols |
| 084 | O | Histosols |
| 085 | Od | Dystric Histosols |
| 086 | Q | Arenosols |
| 087 | Qa | Albic Arenosols |
| 088 | Qc | Cambic Arenosols |
| 089 | Qf | Ferralic Arenosols |
| 090 | Qk | Calcic Cambic Arenosols |
| 091 | Ql | Luvic Arenosols |
| 092 | R | Regosols |
| 093 | Rc | Calcaric Regosols |
| 094 | Rd | Dystric Regosols |
| 095 | Re | Eutric Regosols |
| 096 | Rtc | Ando-calcaric Regosols |
| 097 | S | Solonchaks |
| 098 | Sg | Gleyic Solonchaks |
| 099 | Slo | Luvic Solonchaks |
| 100 | Sm | Mollic Solonchaks |
| 101 | So | Orthic Solonchaks |
| 102 | T | Andosols |
| 103 | Th | Humic Andosols |

| | | |
|-----|------|---------------------------|
| 104 | Tm | Mollic Andosols |
| 105 | Tv | Vitric Andosols |
| 106 | U | Rankers |
| 107 | V | Vertisols |
| 108 | Vc | Chromic Vertisols |
| 109 | Vp | Pellic Vertisols |
| 110 | W | Planosols |
| 111 | Wd | Dystric Planosols |
| 112 | We | Eutric Planosols |
| 113 | Wh | Humic Planosols |
| 114 | Ws | Solodic Planosols |
| 115 | Wve | Vetro-eutric Planosols |
| 116 | X | Xerosols/Yermosols |
| 117 | Xh | Haplic Xerosols/Yermosols |
| 118 | Xk | Calcic Xerosols/Yermosols |
| 119 | Xy | Gypsic Xerosols/Yermosols |
| 120 | Z | Solonchaks |
| 121 | Zg | Gleyic Solonchaks |
| 122 | Zo | Orthic Solonchaks |
| 123 | Zt | Takyric Solonchaks |
| 129 | Lava | Lava |
| 130 | Lava | 1 Lava flow |
| 131 | Lava | 2 Lava fields |
| 132 | Rock | Rock outcrops |
| 133 | Ice | Ice |
| 134 | Lake | Lake area |
| 135 | Town | Town |

LIVESTOCK ZONES CODING

| Code | Thermal Zone | LGP (days) |
|------|--------------|------------|
| 001 | T1 | 0-119 |
| 002 | T3,T4,T5 | 0-119 |
| 003 | T6 | 0-119 |
| 004 | T7 | 0-119 |
| 005 | T1,T2,T3,T4 | 120-179 |
| 006 | T5 | 120-179 |
| 007 | T6,T7 | 120-179 |
| 008 | T8 | 120-179 |
| 009 | T1,T2,T3,T4 | 180-269 |
| 010 | T5 | 180-269 |
| 011 | T6,T7 | 180-269 |
| 012 | T8 | 180-269 |
| 013 | T1,T2,T3,T4 | 270-365 |
| 014 | T5 | 270-365 |
| 015 | T6,T7 | 270-365 |
| 016 | T8 | 270-365 |

This report presents the recently developed Windows-based software package for agro-ecological zoning analysis at the national and subnational levels, including models for land suitability and land productivity assessment and a user interface to multi-objective land use optimization. The software package allows models to be generated interactively corresponding to various scenarios of land use and then to be analysed using modular multiple-criteria model analysis tools. The package is illustrated by the example of a detailed Kenya AEZ study.

