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An Interactive Multiple-Criteria Analysis Tool for Land Resources Appraisal

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Foreword

The research documented in this paper is a continuation of collaborative work between the Food and Agriculture Organization of the United Nations (FAO) and two IIASA projects, namely, the Land Use Change and the Risk, Modeling and Policy (formerly Methodology of Decision Analysis) projects. This collaboration aims at expanding FAO's Agro-Ecological Zones (AEZ) methodology of land resources appraisal by incorporating decision support tools for optimizing the use of land resources.

This paper documents the recently developed user friendly model generator of the Kenya AEZ district planning model and the user interface to the multiple-criteria model analysis (MCMA) tools (which are documented in the companion paper). The software documented in this paper makes it possible to interactively generate models corresponding to various scenarios and then to analyze these models using modular MCMA software tools.

Abstract

Since the early 1980's, 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 the land resources for assessments of the potential of agricultural production systems. The characterization of land resources includes components of climate, soils and land form, basic for the supply of water, energy, nutrients and physical support to plants.

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 applied to the analysis of AEZ models. A user friendly interface has been developed and documented in order to permit use of the software also by persons with only very basic computing experience. The methodology of MCMA is illustrated in the companion paper by a detailed tutorial example.

Keywords: Agro-Ecological Zone (AEZ) methodology, Integrated Land Use Planning and Management, Multiple-Criteria Decision Analysis, Decision Support Systems, Interactive Aspiration-Reservation Based Decision Support, Linear Programming.

Contents

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1 Introduction

The purpose of this paper 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 **Win**dows, 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 which 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 1980's, 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 analyzing 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 were twofold:

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

AEZWIN is aimed at supporting interactive analysis of agricultural land-use options. An example of such analysis is documented in (Antoine, Fischer and Makowski, 1996; 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 (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 remaining part of this paper is organized in the following way. Section 2 give some methodological background of AEZ. The structure of the entire AEZWIN DSS is described in Section 3. Section 4 provides technical details about the hardware requirements and installation procedure. Section 5 briefly summarizes the use of AEZWIN. Section 6 contains a detailed tutorial for using AEZWIN and MCMA. Section 7 provides some examples of AEZ use. The core model utilized in AEZ is described in Section 8. Some remarks on trouble-shooting procedures can be found in Section 9. Section 10 contains information about the availability of the software and about coping with problems. Appendix A documents coding schemes for the Kenya case study.

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 time[1], there are limits to the sustainable

[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.

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 data base and a methodological framework to assess food production and population supporting potentials in developing countries, see (FAO/IIASA, 1991).

FAO has assisted member countries in finding rational solutions to various problems of land resources appraisal for planning sustainable agricultural development. 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 which are fundamental to any sound evaluation of land resources:

i. application of an inter-disciplinary approach, based on inputs from crop ecologists, pedologists, agronomists, climatologists, livestock specialists, nutritionists, and economists.

ii. land evaluation is only meaningful in relation to specific land uses.

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

iv. 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);

v. different kinds of land use must be considered in the context of meeting national or regional food crop-mix and livestock products demand.

vi. 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.

vii. land-use patterns must be constructed so as to optimize land productivity in relation to political and social objectives taking into account physical, socio-economic and technological constraints.

2.1 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 the Figure 1.

(1) LUT descriptions: These define the fundamental objects of analysis which 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 (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. The AEZ Kenya study distinguishes 64 crop LUTs, 31 fuelwood LUTs and a synthetic[2] grassland LUT, each at three levels of input. Also, 10 representative livestock systems are considered per input level.

(2) The term 'Crop Catalog' 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.

[2] 24 grass and 8 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.

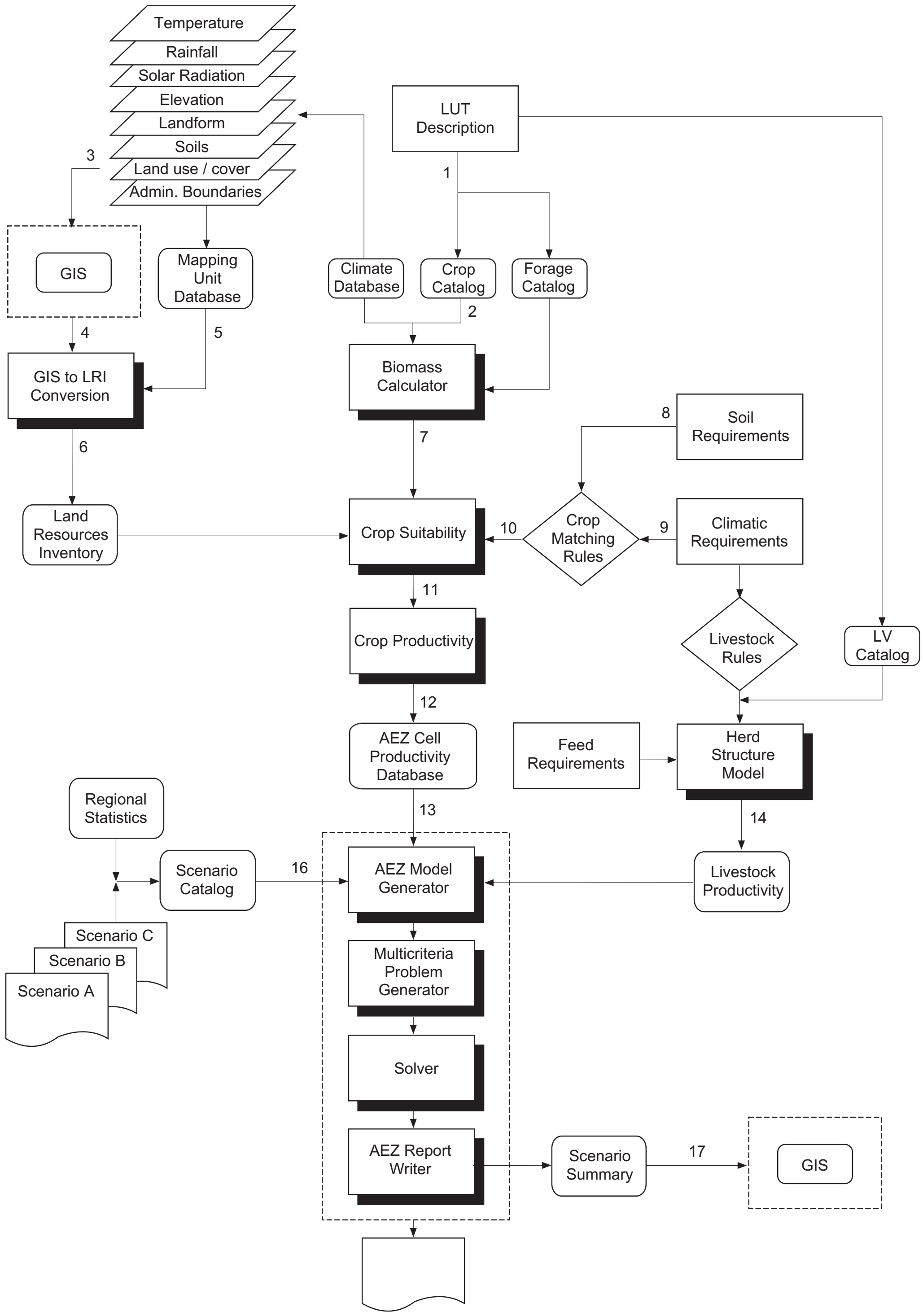


Figure 1: AEZ information flow and integration

(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 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, which form the basic unit of analysis used in AEZ applications. The collection of 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.[3]

(8) Crops, grasses and fuelwood species, as well as livestock species have climatic requirements which 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

[3]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.

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

(10) Matching rules for comparing requirements of crops and livestock to the attributes of a particular agro-ecological cell are devised by experts (or modeling) 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 catalog, 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 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.

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[4] 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 (please see Section 5 for details). The scenario-specific core model generation must currently be done on

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

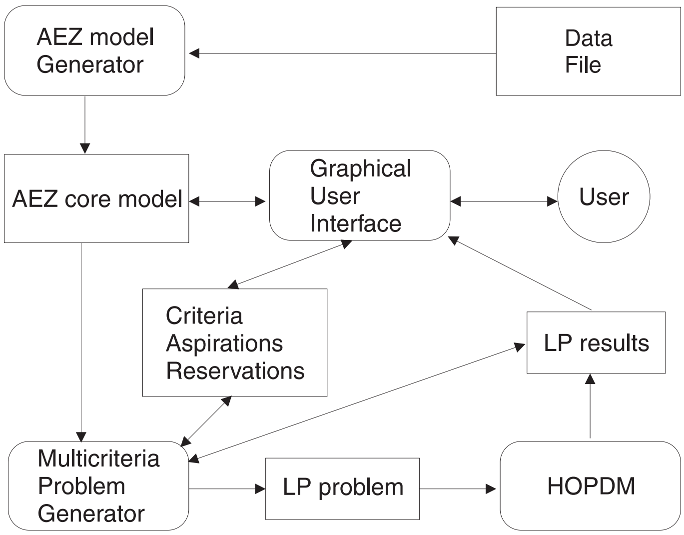


Figure 2: The functional structure of the MCMA module.

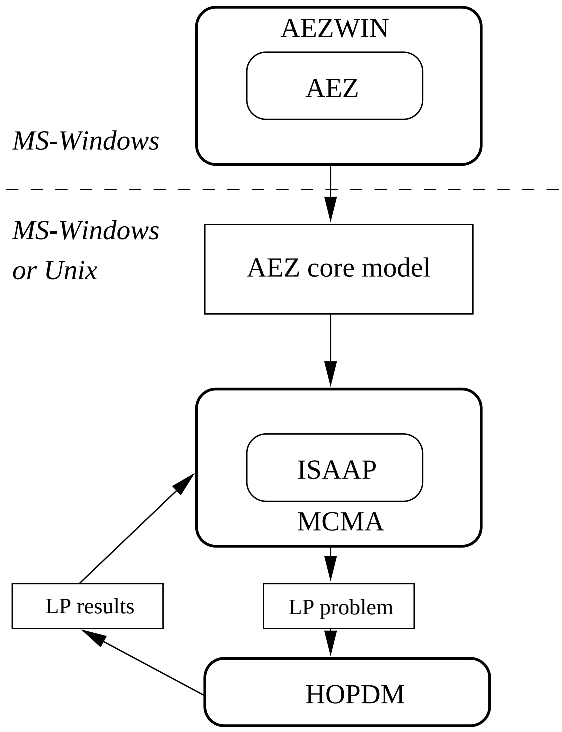


Figure 3: The components of a Decision Support System for Agro-Ecological Land Resources Assessment for Agricultural Development Planning.

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. MCMA implemented with AEZWIN is based on aspiration-reservation led multiple-criteria model analysis and the 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 for a user,

- 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 Section 4 for details).

4 Software installation

4.1 Hardware requirements

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

- a Pentium PC,
- 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 $\times$ 768 should be used.

4.2 Installation procedure

The software is being distributed by ftp in the form of a self-extracting archive named `install.exe`. 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 slower[5] (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]*.*
   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 e.g. 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.

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

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

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.

5.1 Invoking AEZWIN

The `aezwin` program can be invoked (like any other application running under MS-Windows'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 directory.

5.2 Menu system

Figure 4 (on page 17) 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.
   - 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 editor [6].
     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[7] - 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.
   - 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: *you must run* Create suitability table *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.

[6] 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.

[7] 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).

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\bin`.[8] 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 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, (you may want to see 5.3 for a short description of LP_DIT, although use of this format is transparent).
   - MC_Model analysis - to run Multi-Criteria Model Analysis (MCMA); see (Granat and Makowski, 1998) for the documentation and Section 6 for a tutorial example.
   - 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:

[8] 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.

(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 KENYA-AEZ 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`.

- IDRISI[9] - 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 which 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.

5.3 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 typically used in a way transparent for a user by selecting the item LP-DIT generator from the Analysis menu of AEZWIN. However, we document here the actual actions which are activated by this selection.

Selection of this item results is 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

[9]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, U.S.A.. The IDRISI software package is not included with this release of AEZ but can provide useful additional functionality.

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.

6 Tutorial guide for AEZWIN

This section intends to guide the reader through a complete sequence of steps necessary to set up and undertake district scenarios 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.

6.1 On-line help

This report has been written in LaTeX with 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 LaTeX 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 illustrate the way of activating the on-line help. The subsequently displayed dialog shown on 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 on Figure 6 and Figure 8,

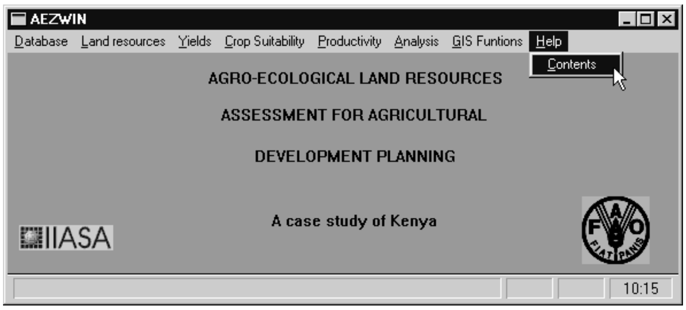


Figure 4: Main menu of the application with the selection of an on-line help.

Figure 5: Dialog for the selection of a help browser.

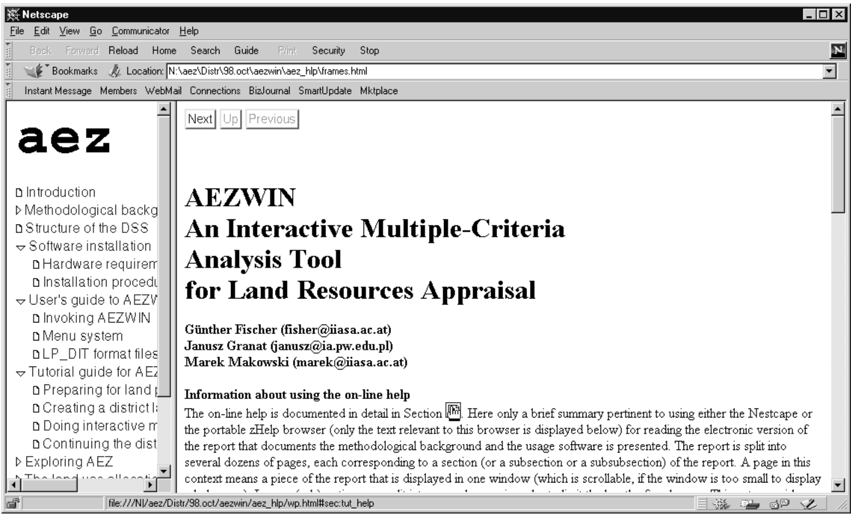


Figure 6: Welcome page of the on-line help viewed by the Netscape browser.

Figure 7: Information about availability of context sensitive help.

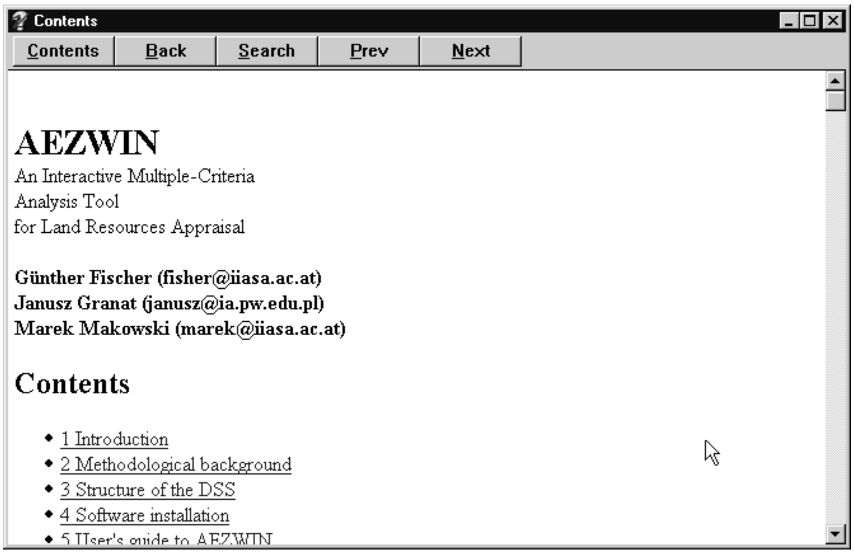


Figure 8: Welcome page of the on-line help viewed by the zHelp browser.

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.

6.2 Preparing for land productivity assessment

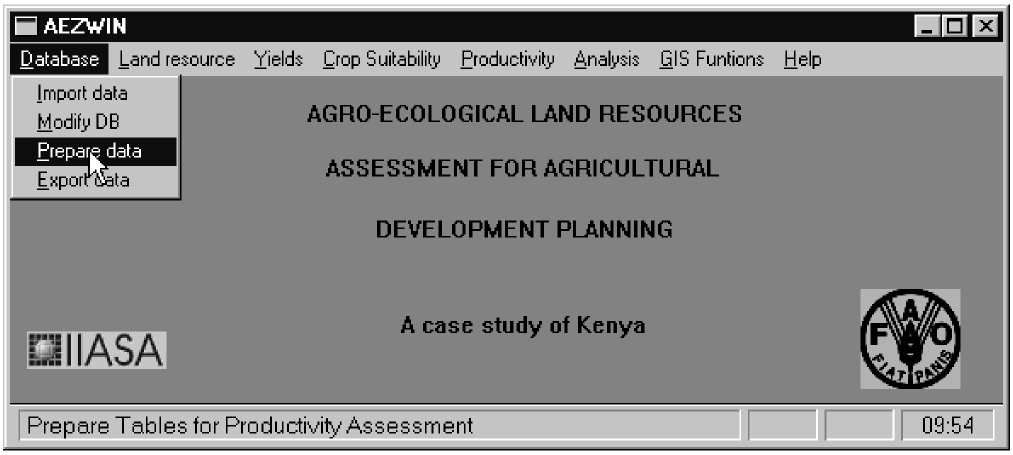


Figure 9: Preparation of the data.

After starting AEZWIN, a window with the eight basic menus is presented to the user (Figure 4 on page 17). In order to prepare the data the following steps should

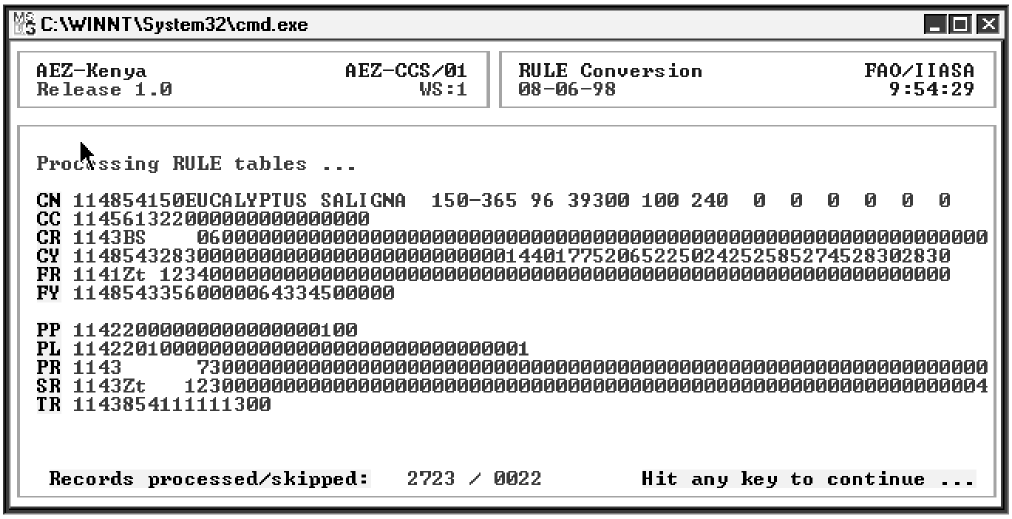


Figure 10: Screen display of the program preparing tables and matching rules.

be completed:

1. 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).

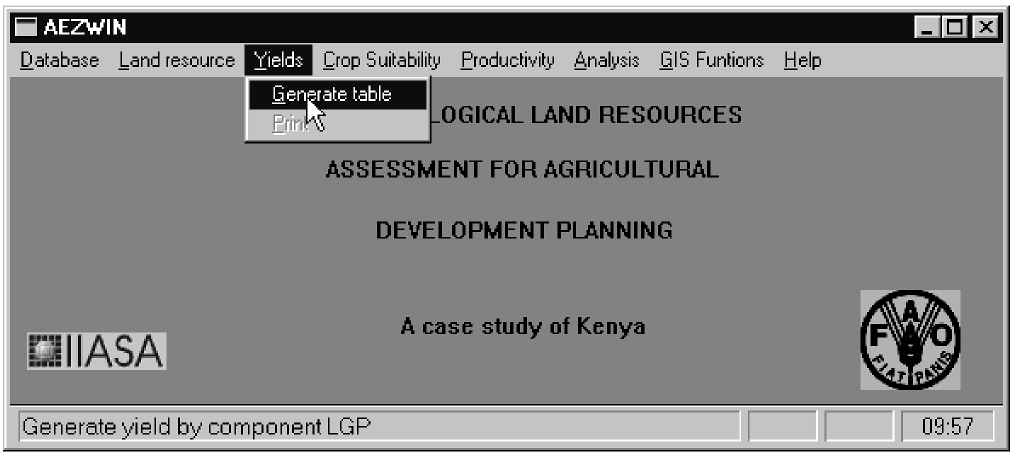


Figure 11: Selection of the Generate table submenu from the Yields menu.

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

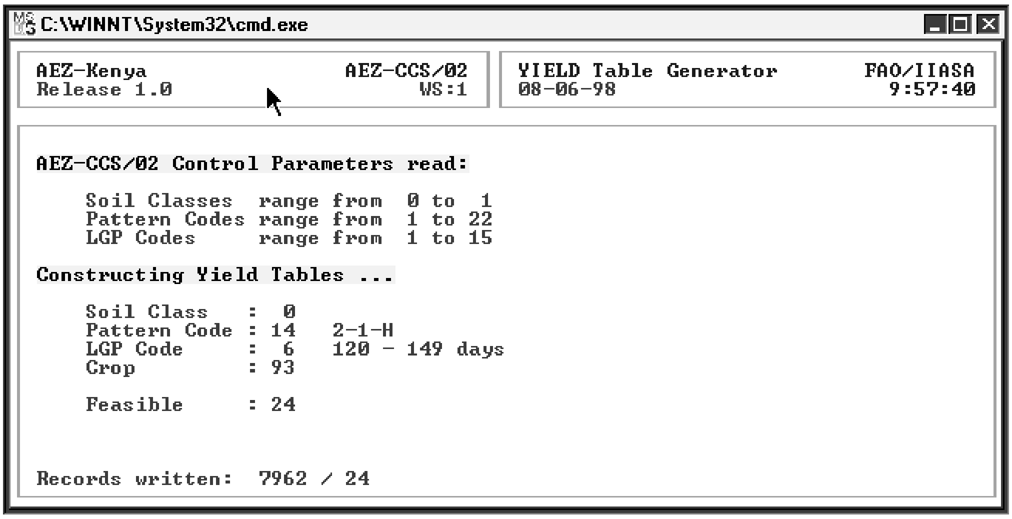


Figure 12: Screen display of program that generates yield tables.

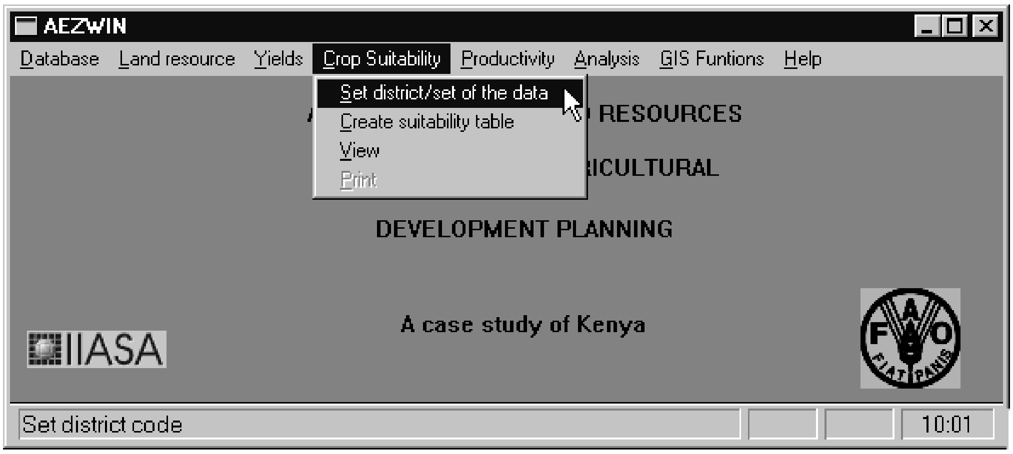


Figure 13: Activation of the dialog for selection of the district and of the data.

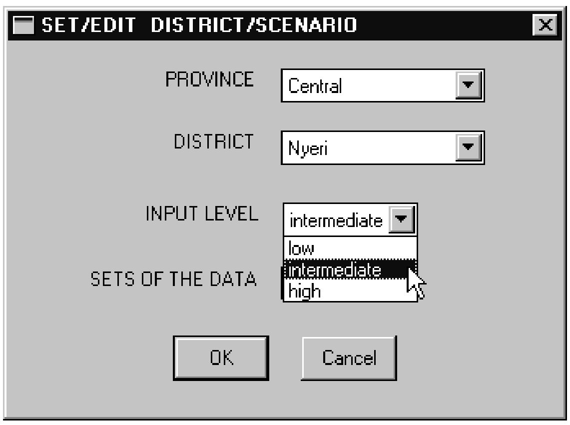


Figure 14: Dialog for selection of district and set of data.

in the rule base (for an example see section 7.2). 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 Prepare data is executed from the Database menu.

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 we have selected Nyeri district in Central province 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.

6.3 Creating a district land productivity database

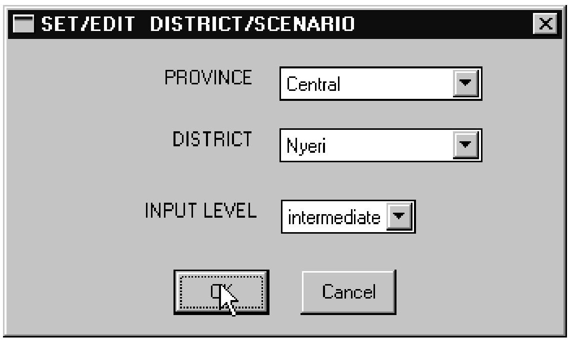


Figure 15: Dialog for selecting a district and input level.

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

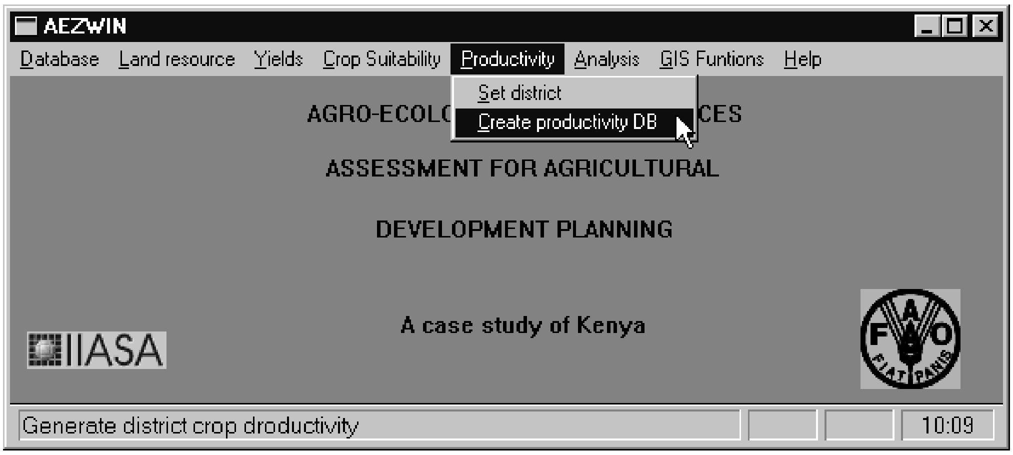


Figure 16: Dialog for generating land productivity database.

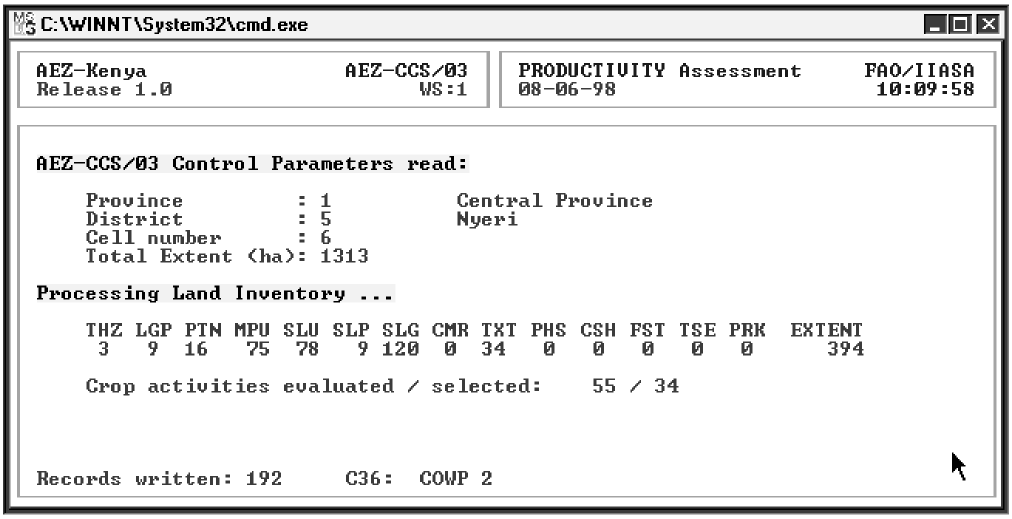


Figure 17: Screen display of program generating land productivity database.

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 7.3 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.

6.4 Doing interactive multi-criteria model analysis

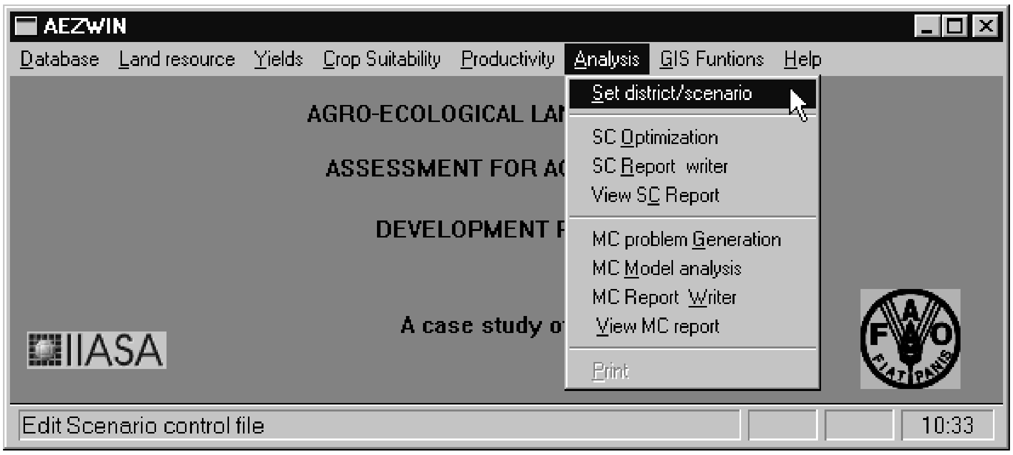


Figure 18: Menu selection for activating dialog for selection of district/scenario for analysis.

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

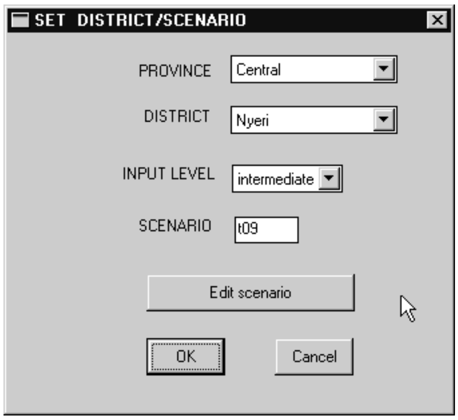


Figure 19: Dialog for selecting a district and editing a scenario.

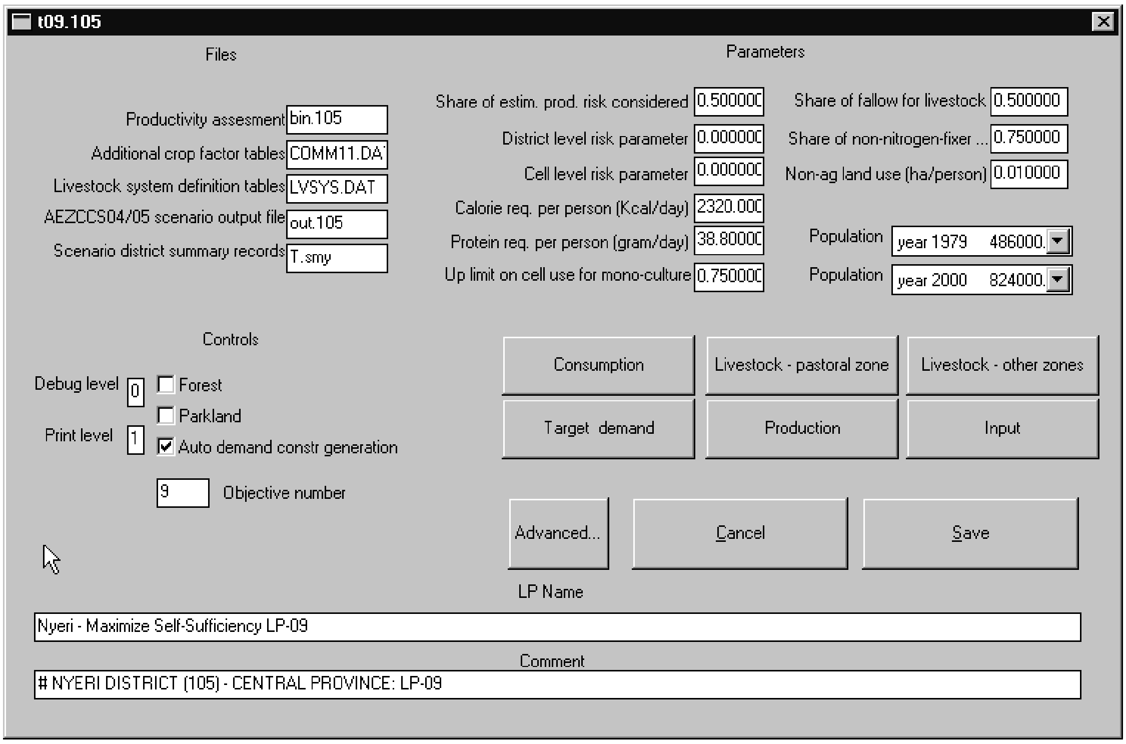


Figure 20: Edit scenario dialog.

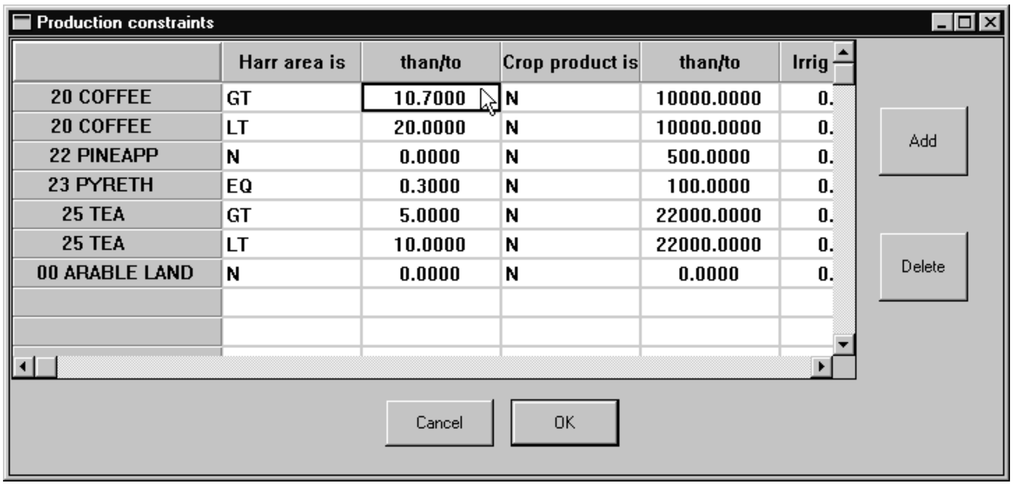


Figure 21: Dialog for modification of production targets.

for Nyeri (with a district code 105). 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 8.5 presents a simple example of a control file for district analysis and describes the contents of the control file.

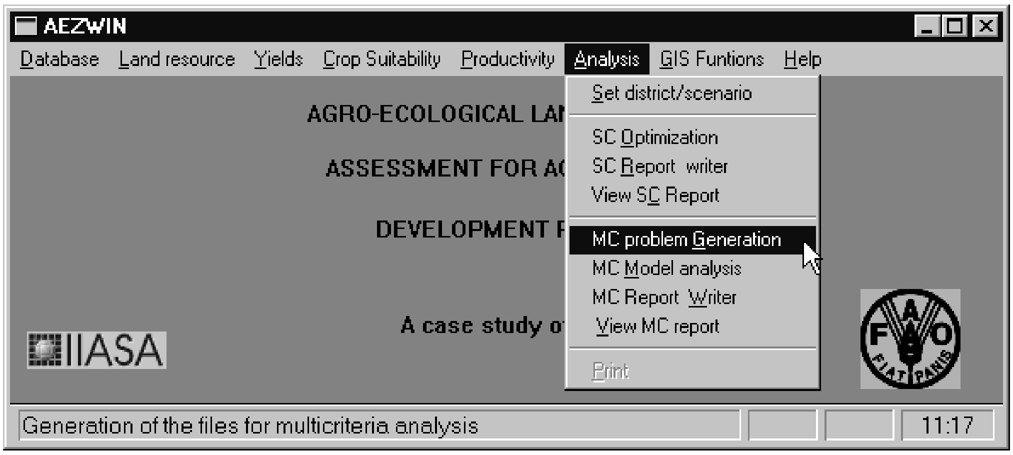


Figure 22: Menu selection for generation of core model for multicriteria analysis.

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

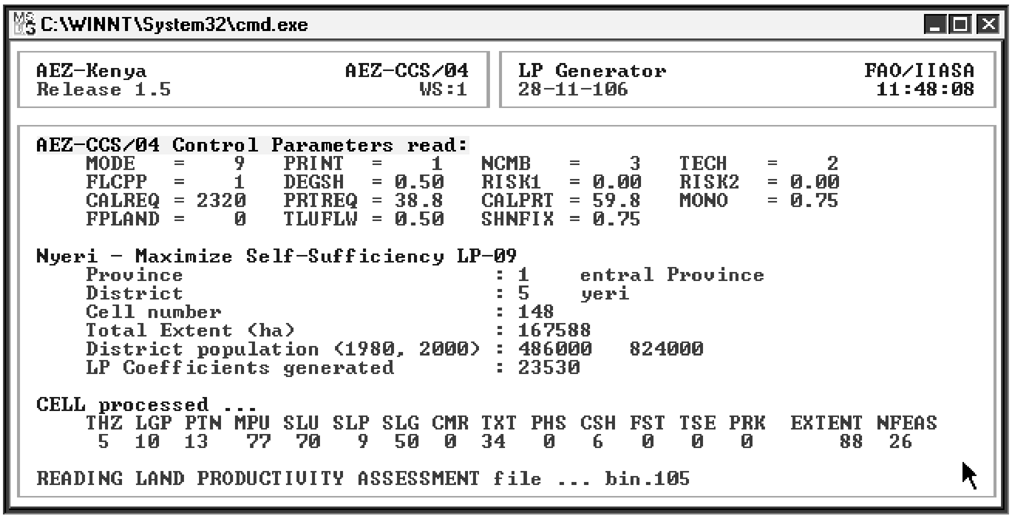


Figure 23: Screen display of the core model generator.

available under the Analysis menu. Single-criterion scenarios were discussed in some detail in (Fischer and Antoine, 1994a). Therefore, we will directly turn to multi-criteria model analysis. The first task to be carried out generates 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 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, we can now turn to the interactive analysis. 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). Next, we open the Problem menu and select New problem (Figure 27) as we have just now created the AEZ model file that is to be processed (there is also an option provided 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.

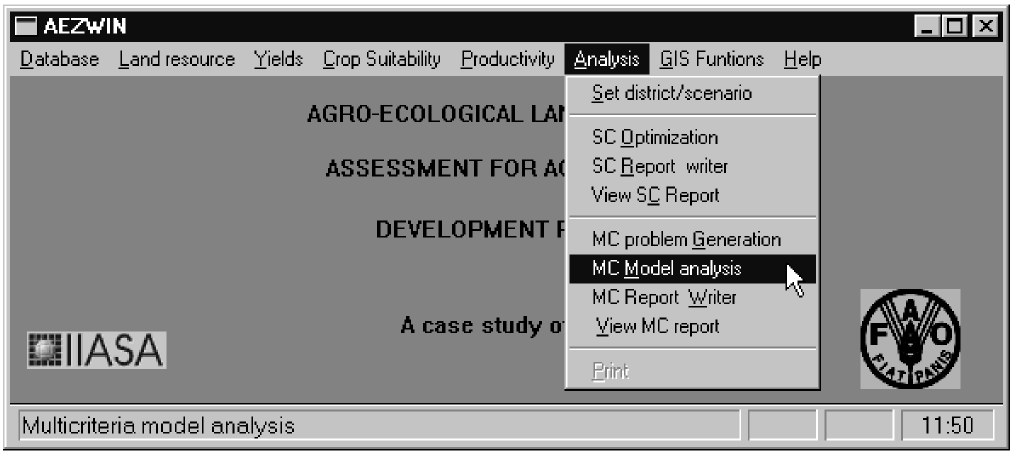


Figure 24: Menu selection for activation of the MCMA for the core model analysis.

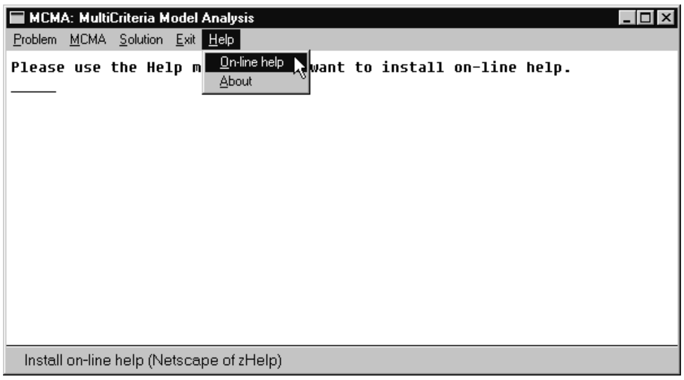


Figure 25: Initial screen of MCMA with select submenu for installation of on-line help.

Figure 26: Dialog for selection of on-line help browser.

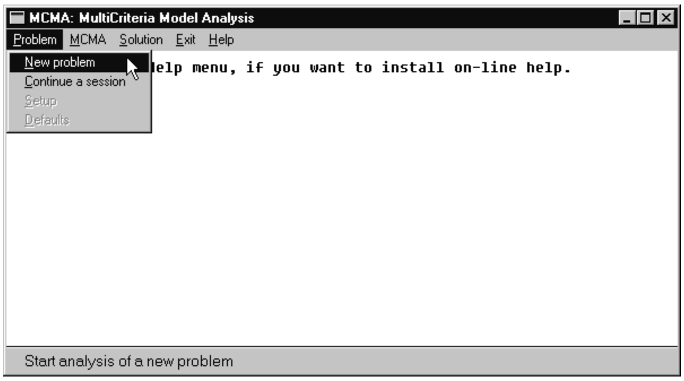


Figure 27: Menu selection for initialization of analysis of a core model.

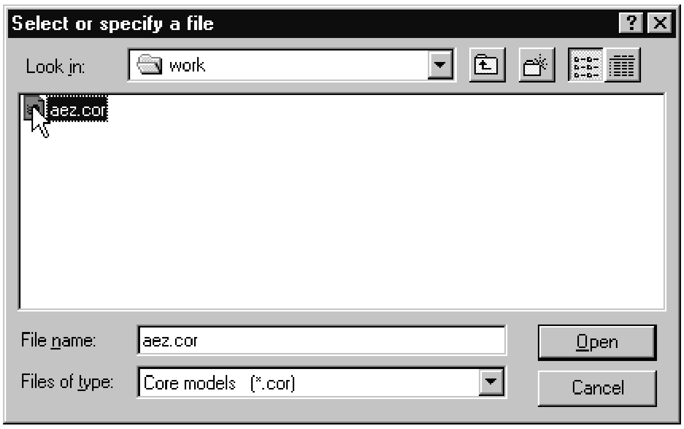


Figure 28: Default selection of AEZ core model.

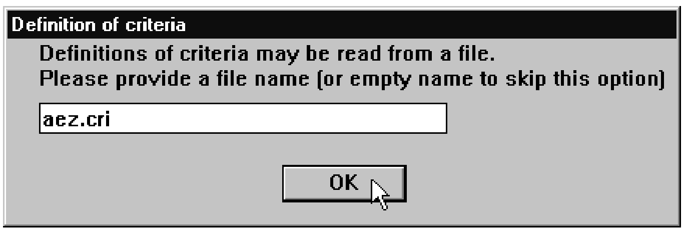


Figure 29: Default selection of a file containing predefined criteria for AEZ core model.

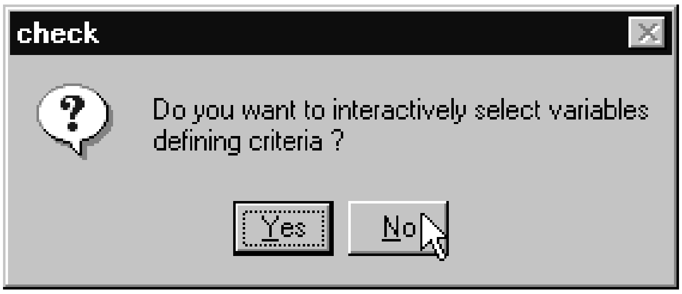


Figure 30: Dialog offering a possibility of selecting outcome variables to be used as criteria.

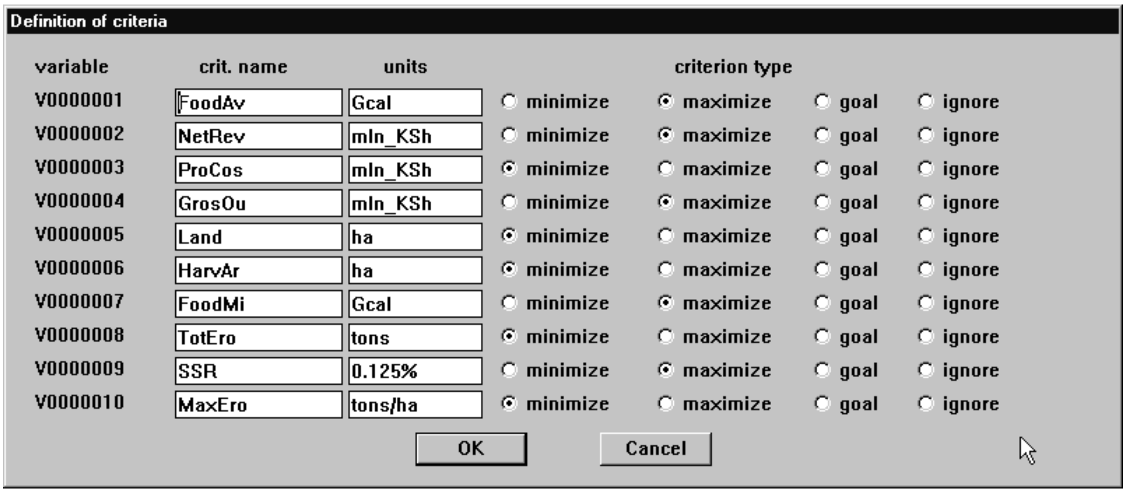


Figure 31: Predefined criteria of AEZ model.

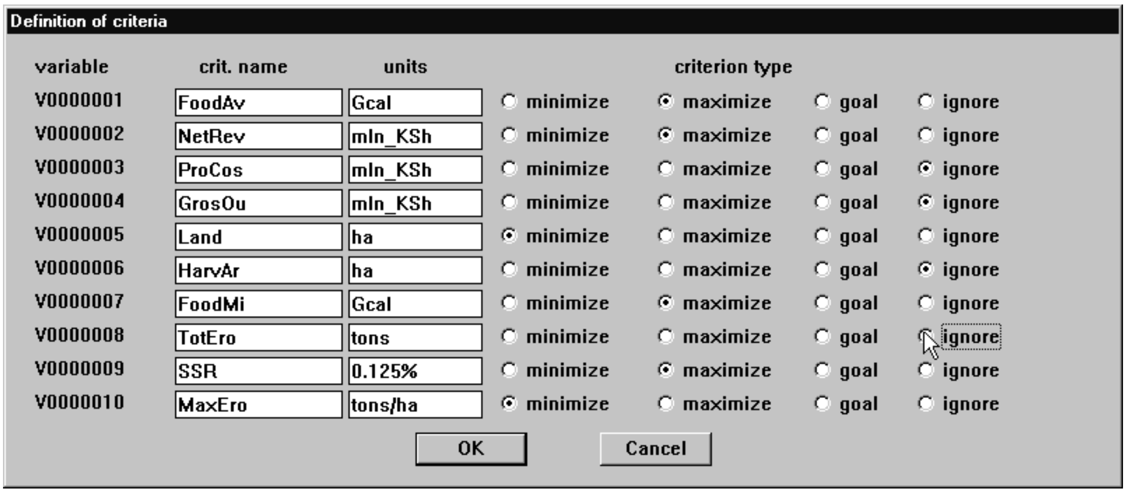


Figure 32: Selection of criteria made for this tutorial.

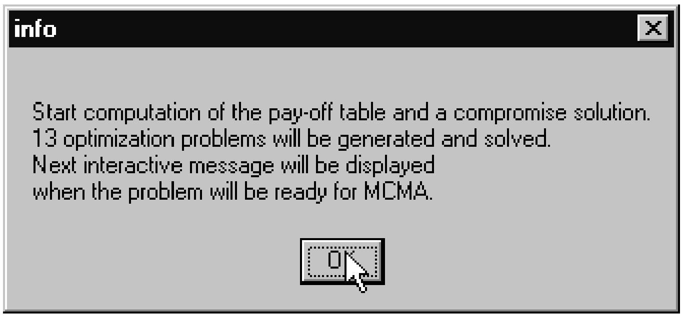


Figure 33: Information about staring computation of the pay-off table.

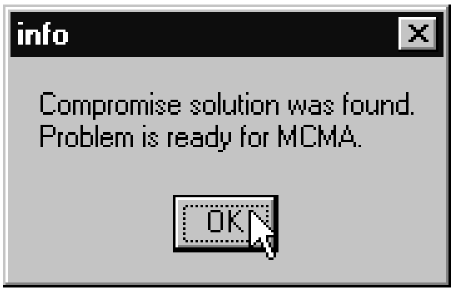


Figure 34: Information about finishing computation of the pay-off table.

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 which is provided with the installation. To accept the default (which is strongly recommended), click the OK button (Figure 29). In file aez.cri all of the ten pre-defined criteria are included. The user is given the option to interactively select outcome variables among 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. 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 GrosOu    max   mln_KSh
V0000005 var Land      min   ha
V0000006 var HarvAr    min   ha
V0000007 var FoodMi    max   Gcal
V0000008 var TotEro    min   tons
V0000009 var SSR       max   0.125%
V0000010 var MaxEro    min   tons/ha
```

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 the example, we restrict the analysis to six criteria (FoodAv, NetRev, Land, FoodMi, SSR, and MaxEro) and disable the remaining predefined criteria (ProCos, GrosOu, HarvAr, TotEro) 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).

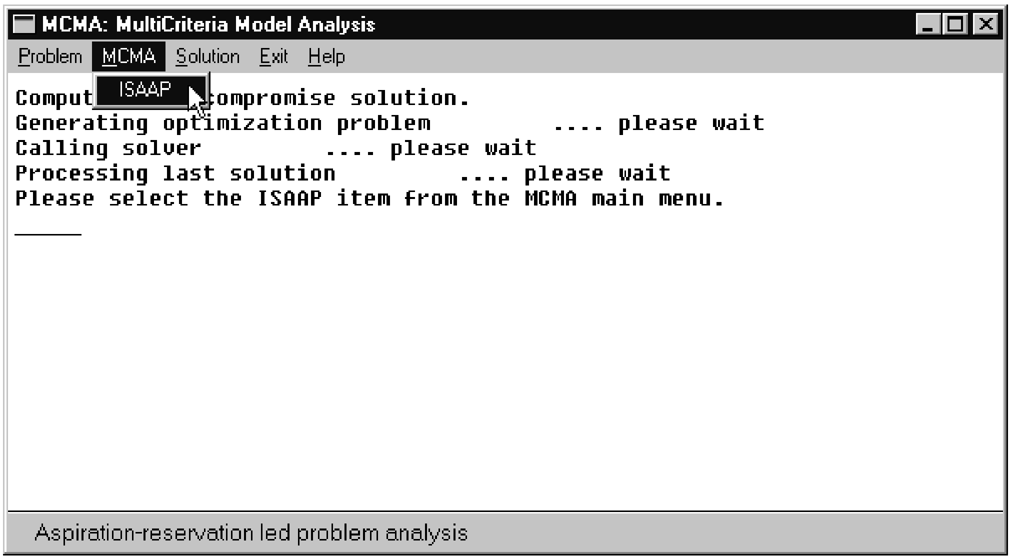


Figure 35: Screen with information about computed compromise solution and selected submenu to activate ISAAP.

The user is now requested to select the ISAAP item from the MCMA menu (Figure 35). The ISAAP tool provides a graphical interface to interactively specifying 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

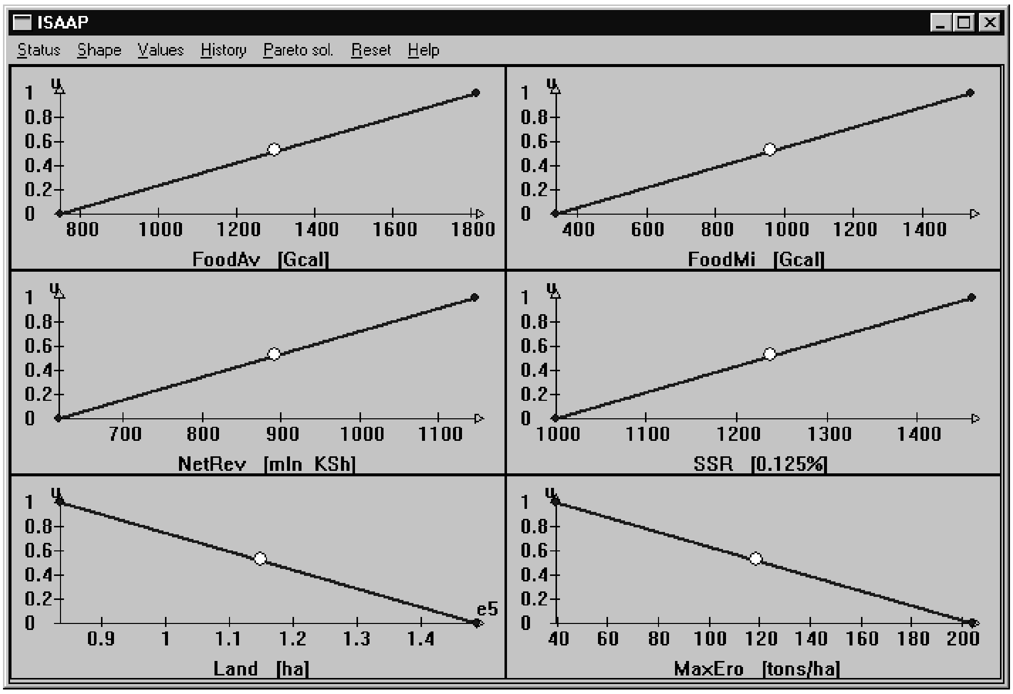


Figure 36: ISAAP screen with a compromise solution.

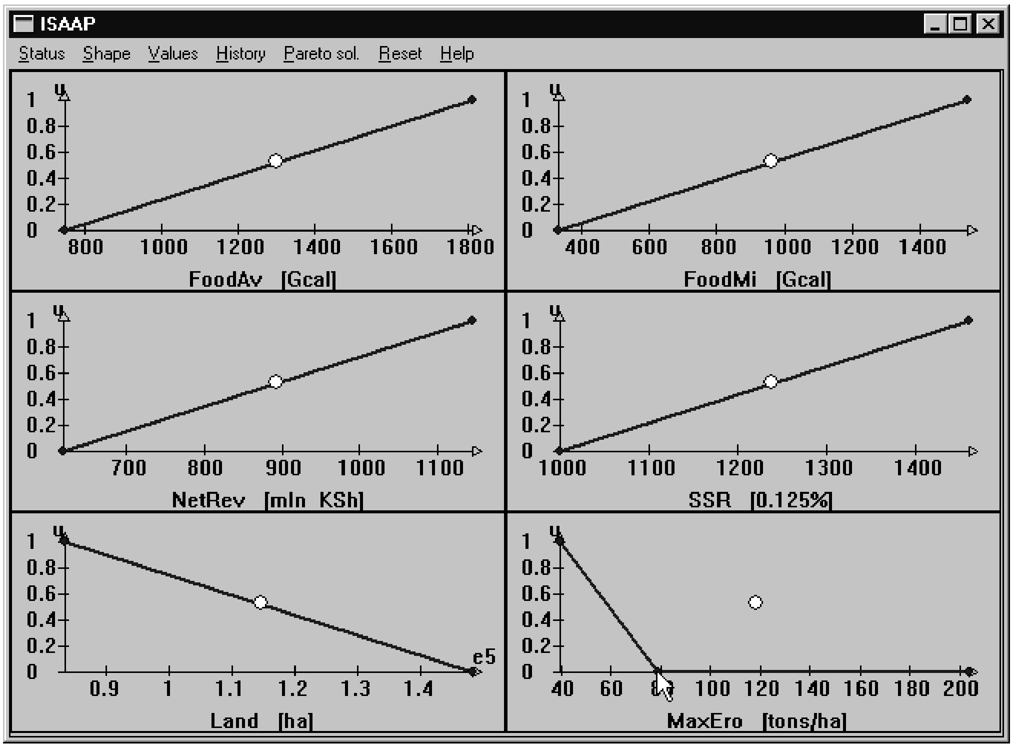


Figure 37: ISAAP screen after a change of reservation level for criterion MaxEro.

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 Land, and the maximum level of soil erosion estimated for any cultivated land unit MaxEro. 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 an unacceptably high level of erosion, we demonstrate the ease-of-use of ISAAP 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.

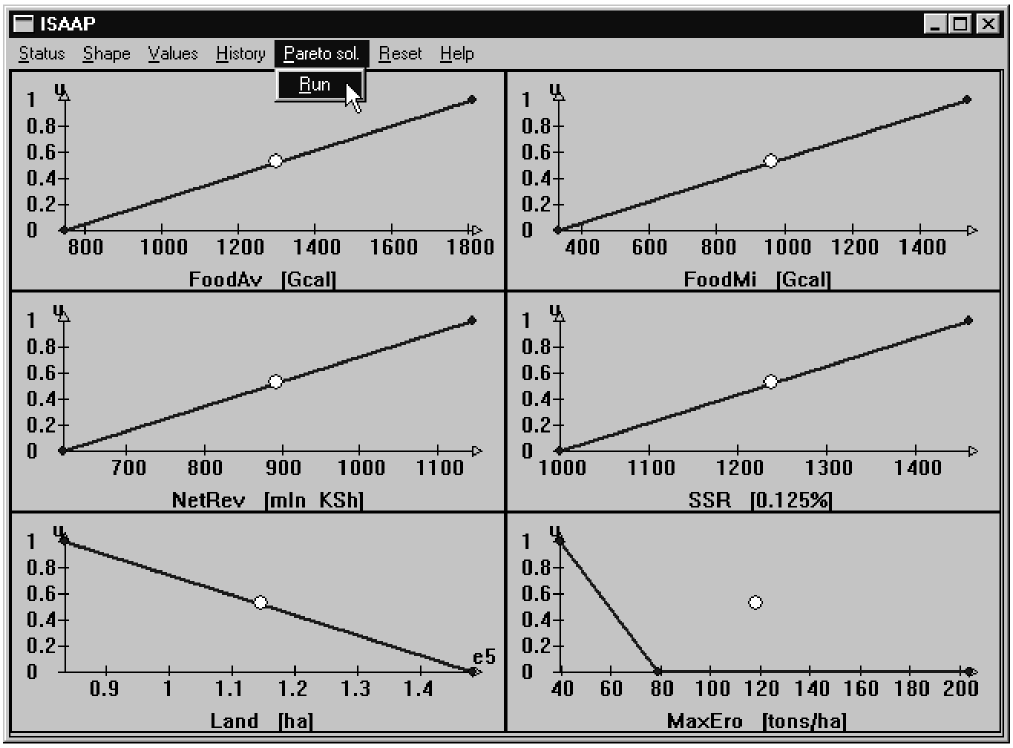


Figure 38: Selection of submenu activating computation of Pareto-optimal solution for current selection of aspiration and reservation levels.

As we are interested in the overall impact of improving merely this particular criterion, we 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, we now work on all criteria

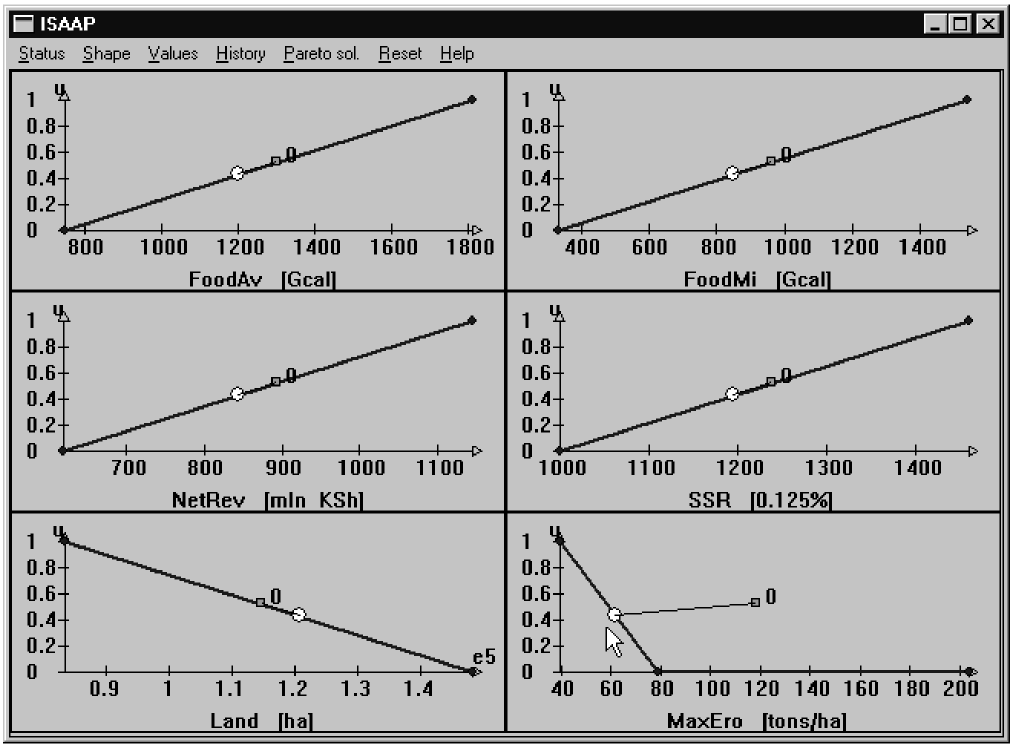


Figure 39: Visualization of Pareto-optimal solution for the first modification of preferences.

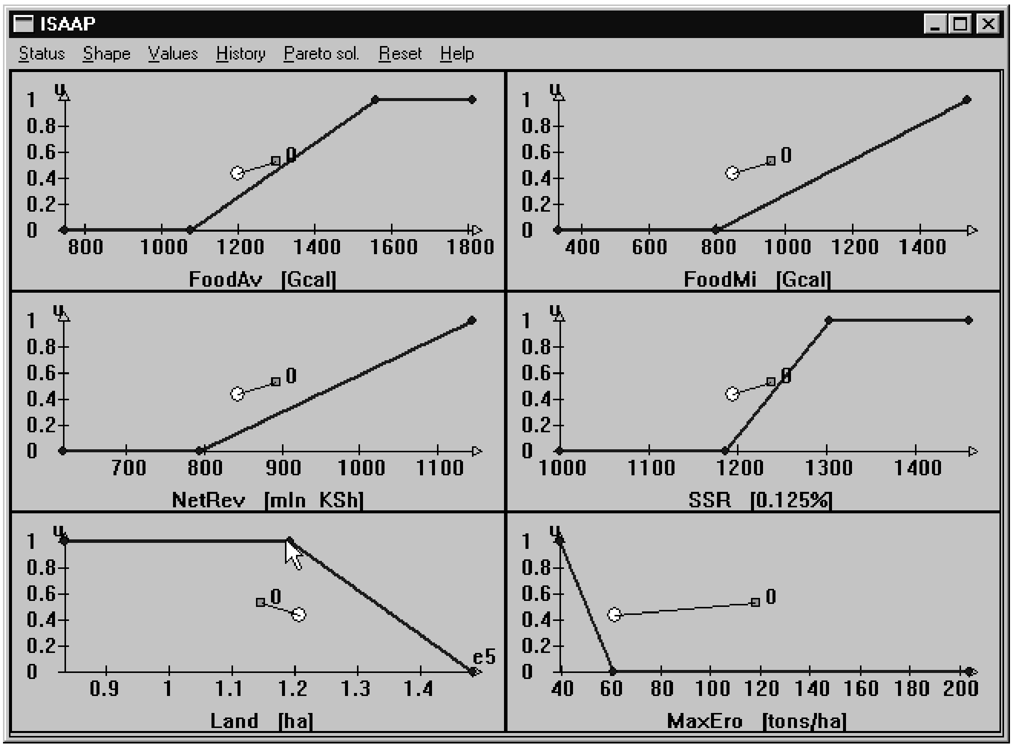


Figure 40: Second specification of aspiration and reservation levels.

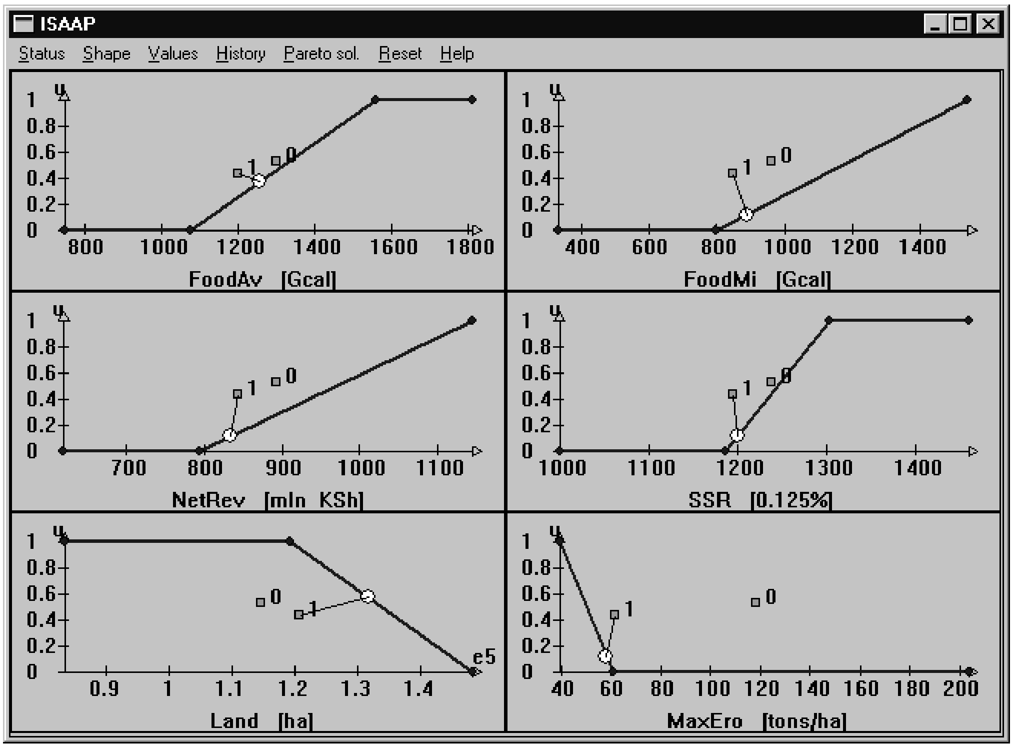


Figure 41: Pareto-optimal solution for the second specification of preferences.

simultaneously. We increase the reservation levels for the food output, revenue and self-sufficiency criteria, relax the criterion on cultivated land, and try to further improve the level of maximum erosion. At the same time, we relax the aspiration levels for average food output and SSR. 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, we increase the reservation level of FoodMi (i.e., we are asking for more food output in 'bad' years), demand a self-sufficiency level SSR of 100% (reservation level of SSR indicator set to 1250), and reduce the aspiration level of MaxEro from 60 to 50 tons/ha (Figure 42). After again 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 multicriteria model analysis: there is no risk in a specification of reservation levels 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

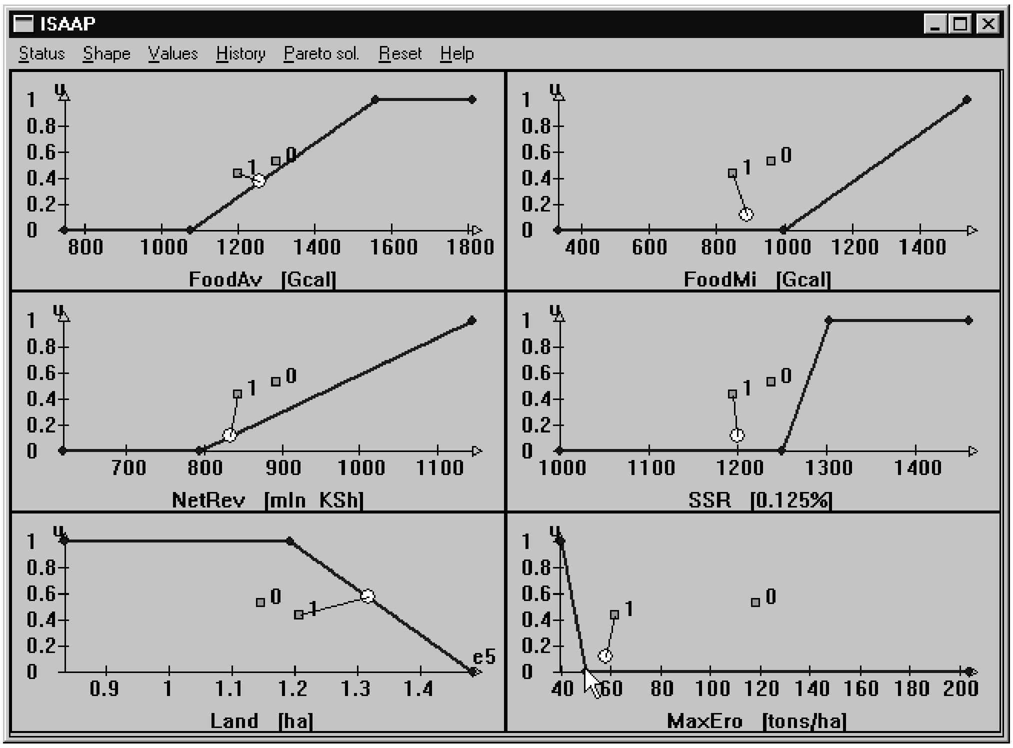


Figure 42: Illustration of setting very tight aspiration and reservation levels.

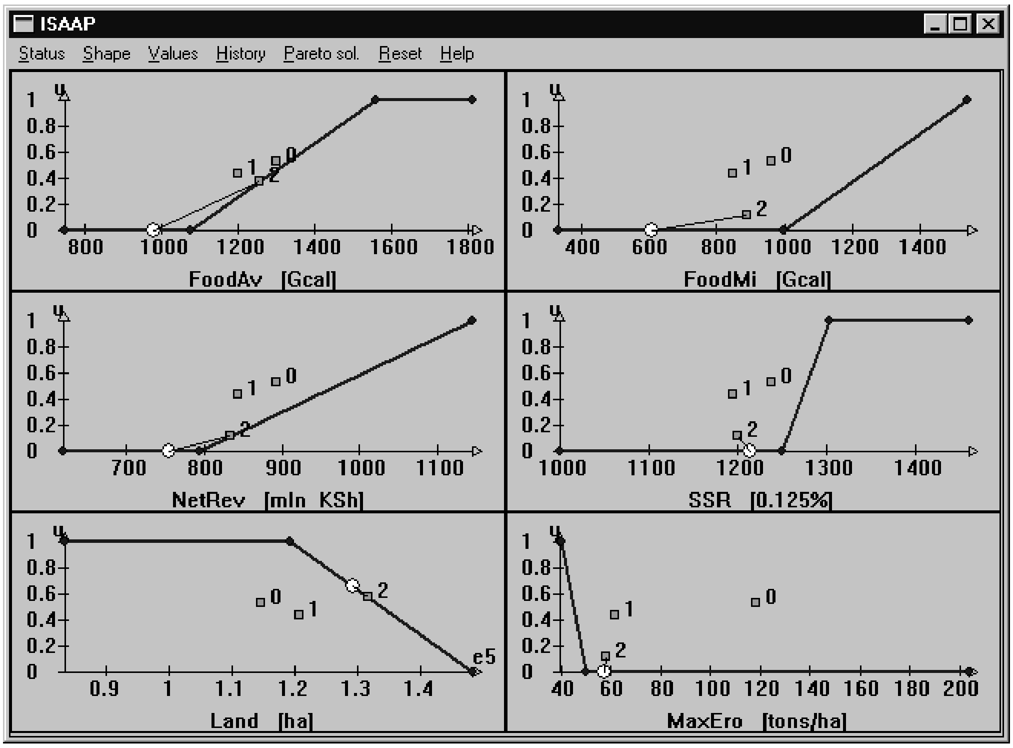


Figure 43: Pareto-optimal solution for unattainable reservation point.

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).

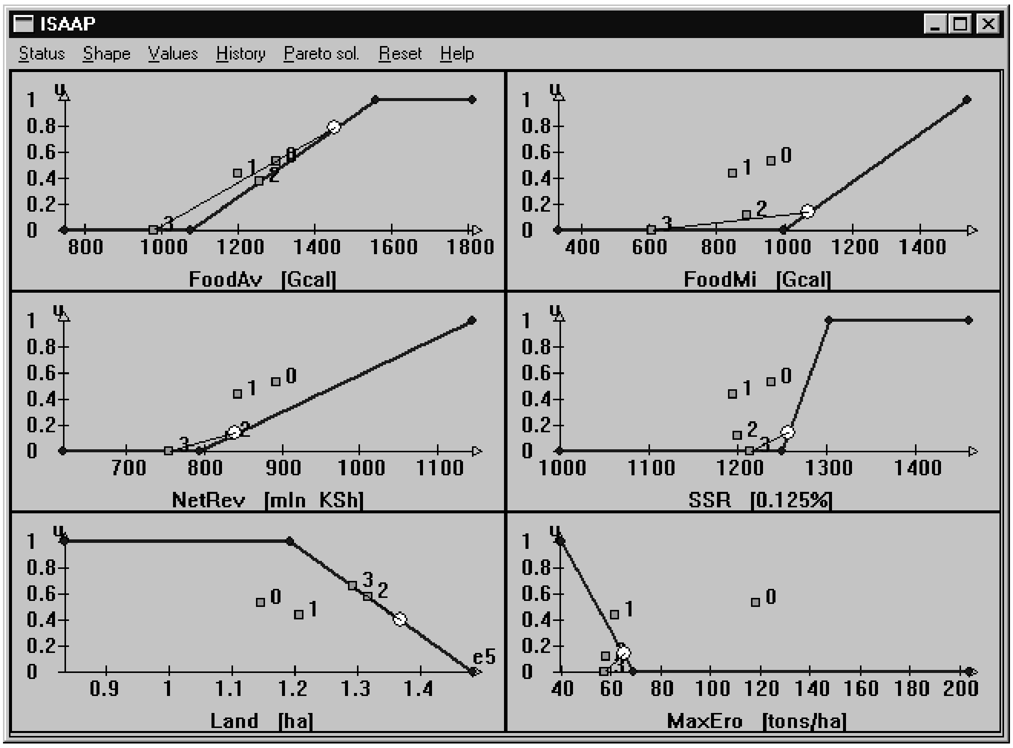


Figure 44: Illustration of relaxation of reservation levels.

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 infeasible.

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 level 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). 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,

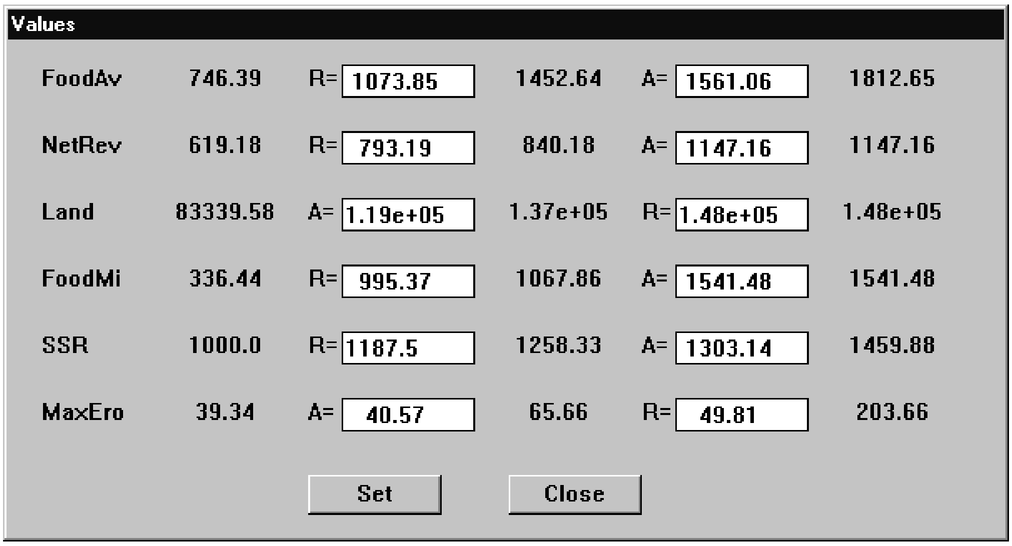


Figure 45: Dialog for setting values of aspiration and/or reservation levels from the keyboard.

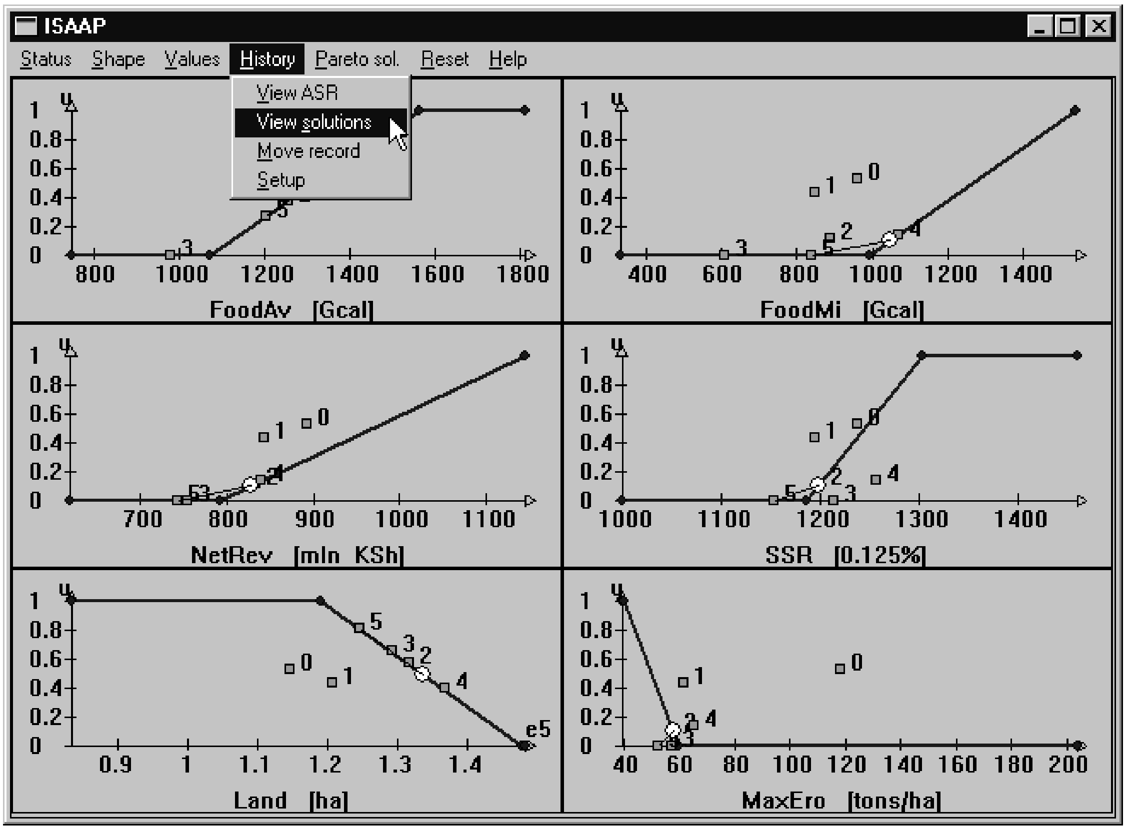
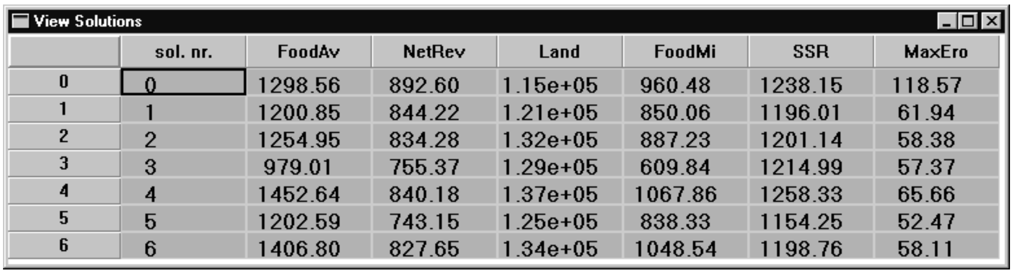


Figure 46: Submenu selection for viewing solutions in form of a spreadsheet.



	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

Figure 47: Solution (criteria values) in form of a spreadsheet.

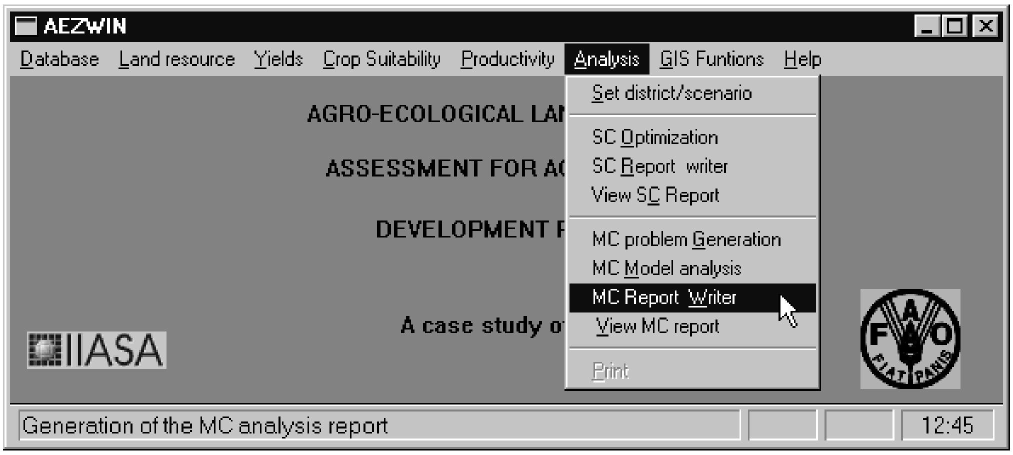


Figure 48: Selection of submenu for invoking the AEZ report writer.

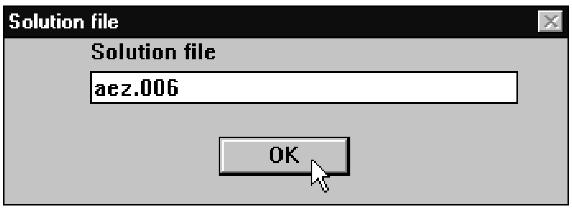


Figure 49: Selection of a solution to be analyzed by the AEZ report writer.

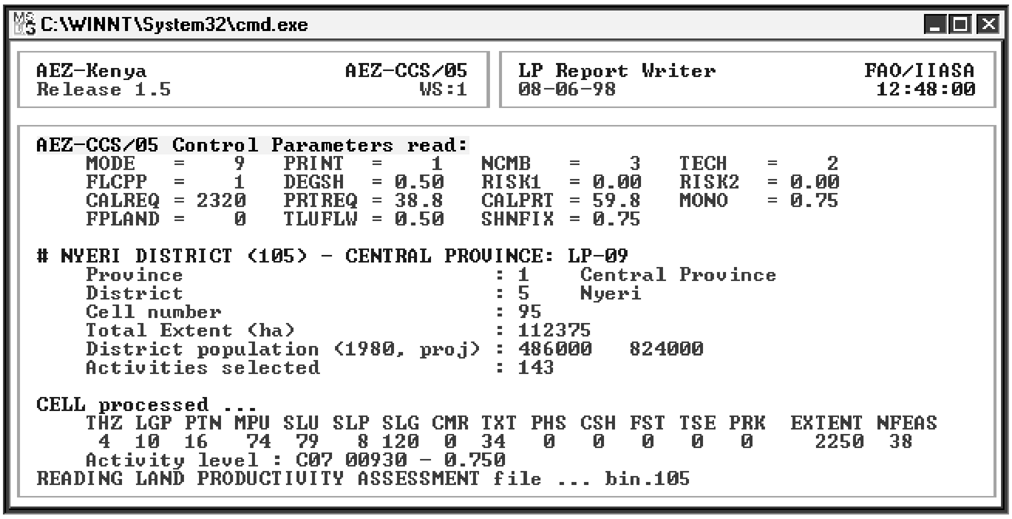


Figure 50: Screen display screen of the AEZ report writer.

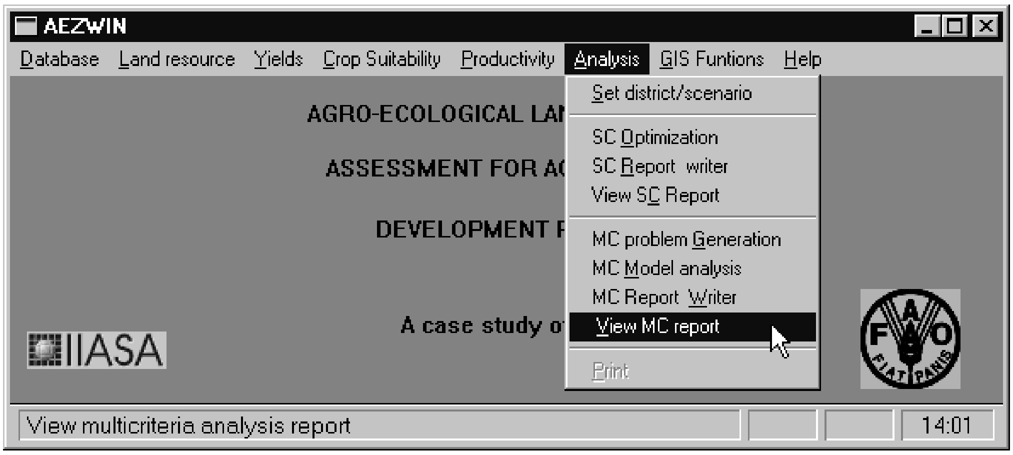


Figure 51: Selection of submenu for loading last report into *Notepad*.

land resources allocation, and resulting food supply levels. 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).

6.5 Continuing the district analysis

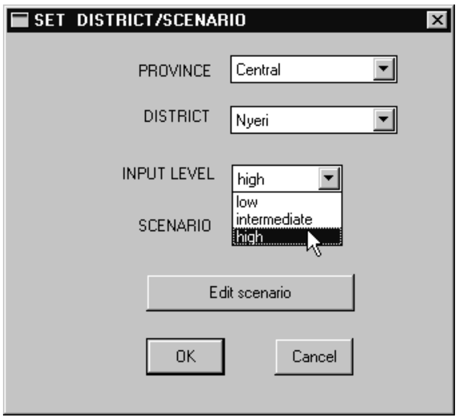


Figure 52: Dialog for selecting the input level.

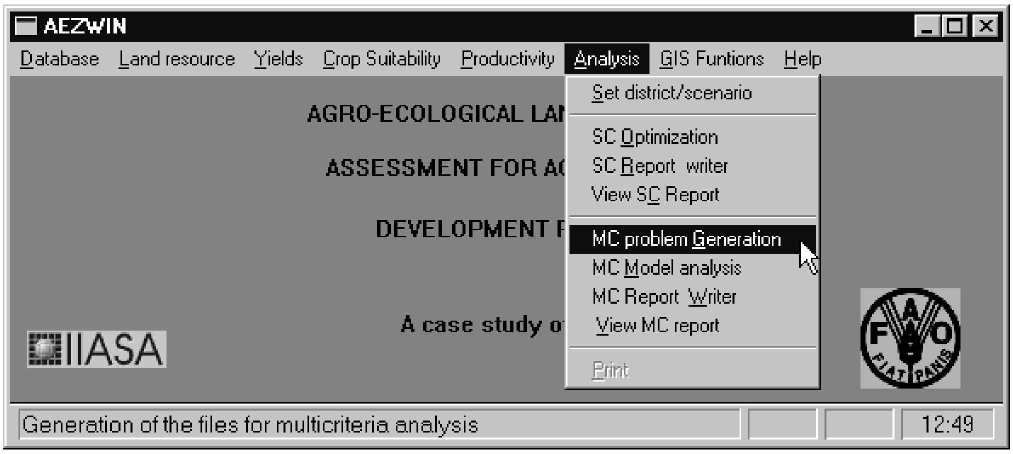


Figure 53: Subenu selection for generation of another AEZ core model (that corresponds to the new selection of input level).

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

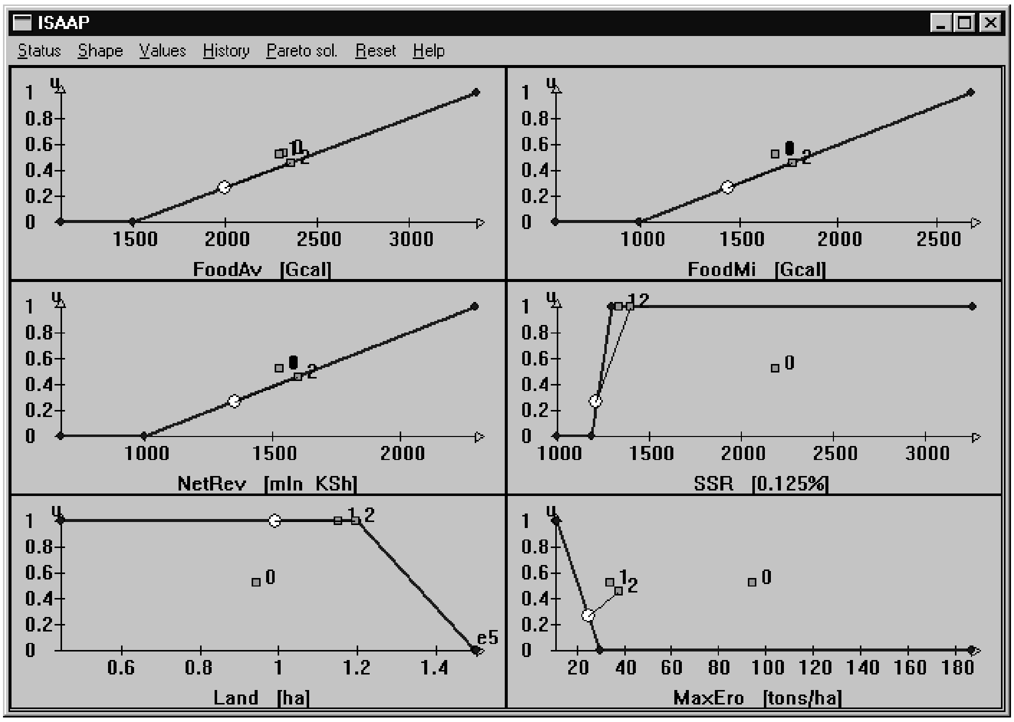


Figure 54: A sample of Pareto-optimal solution for the high input level.

interactive analysis using ISAAP. An example for Nyeri at the high level of input, with 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.

7 Exploring AEZ

The previous sections gave an overview of the software installation, introduction to menu options available in AEZWIN, and a brief tutorial explaining the sequences of steps aimed at preparing and analyzing a district scenario. Now we will start to explore the database and software system by doing some practical exercises.

7.1 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^o Celsius.

Quantification of moisture conditions was achieved through the concept of reference length of growing period (LGP). Reference LGP is defined as 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 inventorized 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 (LGP-pattern). Twenty-two such LGP-pattern classes are recognized in the 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 information (in table form) on length and probability of occurrence of associated growing periods, provide the historical moisture profile, 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 are distinguished, describing soil associations or soil complexes composed of dominant soils, associated soils and inclusions (390 map units) or relate to water bodies and major urban areas (2 map units). 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 derived from the legend of the soil map regarding land form and geology/parent material.

In addition to the soil and climate information, six other layers of information have been incorporated in the land resources database, providing information on cash crop zones, forest zones, parkland areas, location of irrigation schemes, tse-tse 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 and creation of a GIS database file, and

(ii) application of soil mapping unit composition and slope composition tables.

This process produced a collection of about 91000 data records, termed agro-ecological cells. These data records are unique in terms of the combination of their soils, land form and climate attributes. This level of detail permits that each agro-ecological cell represents a fairly homogeneous set of agro-climatic and soil physical conditions, as is crucial to adequately matching land unit properties with crop requirements.

From the information contained in a land inventory record it is possible to identify the respective grid-cells in the GIS 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 set of grid-cells. Therefore, the results must be aggregated to average values per raster point before transferring to GIS. There are 18 attribute fields distinguished 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 resource inventory file is created by superimposing administrative, climatic, soil and land-use data contained in ten base maps. The maps are stored in raster format, i.e., data arranged in 1085 rows and 900 columns of square pixels, each 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, usually stored as one-byte values each, of which about 40 percent falls outside the national boundaries (coded as pixel value zero). Note that the LRI must be recreated whenever one of the ten base 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, allows for viewing the resource inventory, for compiling 2-way and 3-way cross-tabulation statistics, and viewing and printing these tables.

Example 1: Cross-tabulation provides statistics on the coincidence of pairs of classes of different resource inventory attributes. For instance, we may ask about the occurrence of forest zones according to different thermal zones. Proceed as follows:

Step 1: From the main menu choose Land resource.

Step 2: In the sub-menu presented to you, 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 table[10]

Now, the program will start processing the land resource inventory and report on progress. Note that 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. From the column-normalized table we conclude 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 column of the tables indicate the percentage of area of classes of attribute 2 and attribute 1, respectively. For

[10]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.

Table 2: AEZ cross-tabulation, thermal zones vs. forest zones

```
Field  3 ( Thermal_Zone ) versus Field 14 ( Forest_Zone )
==========================================================

After ROW - Normalization
=========================
FOREST   |     --       F1       F2       F3   |  Total
THZ      |                                     |
--------------------------------------------------------
 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   |     --       F1       F2       F3   |  Total
THZ      |                                     |
--------------------------------------------------------
 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
```

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).

7.2 Generating yield tables

Program AEZCCS02 generates tables of agronomically attainable primary[11] 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 easy look-up in the land productivity assessment, program AEZCCS03.

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 days[12]. A small fraction of the area is indicated as having a mean total LGP of 210-239 days (LGP code 9). Let us consider, for instance, maize yields in that zone. According to the LGP-pattern rule table, we find for LGP code 9 in LGP-pattern zone 13:

(a) 2 growing periods in 70 percent of years, with a longer component growing period, LGP_{21}, of 120-149 days (component LGP code 6), and a shorter component growing period, LGP_{22}, of 60-89 days (component LGP code 4).

(b) 1 component growing period in 30 percent of years, LGP_{11}, of 180-209 days (component LGP code 8).

In program AEZCCS02, both these situations are evaluated and average yields are derived. Table 3[13] summarizes the relevant information on maize yields in LGP-pattern zone 13 (dominantly bimodal), mean dominant LGP zone 9 (210-239 days),

---

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

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

[13]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.

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

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 pattern component. In this example, the dominant pattern component is bimodal (70 percent of years), the longest component LGP is LGP_{21} with 120-149 days. From Table 3 we conclude that in low-land areas (thermal zone T1-T3, i.e., at an altitude < 1550 meters), Maize 3 performs best; in thermal zone T4 (approx. 1550-1950 meters altitude) only the shortest high-land maize types, Maize 4 with 120-140 days growth cycle, could be cultivated.

7.3 Land productivity assessment

Program AEZCCS03 processes each record of the land 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

Application of these rules results in a productivity factor 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 erosion (only water erosion is considered).

A record from the land 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 on page 22) 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 center-piece of AEZ. 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.

For that purpose, we pick a record from the land resource inventory, an agro-ecological cell in Meru district, and look at production options generated by the above procedure. 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

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)

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 $> 25^o$ Celsius applies, corresponding to an altitude below 800 m.

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.

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 we have chosen refers to the latter with an average slope gradient of 3.5%.

The inventorized 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, LGP_{21} with code 6, is 120-149 days, the second associated LGP, LGP_{22} 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 requirement of all 64 crop types are tested against the length of the dominant component LGP; in this example, LGP_{21} with a length of 120-149 days[14]. For the land unit under consideration above, (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.

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 low-land 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

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

Table 5: Selected crop combinations, in land unit of example 3

Nr	First Crop type	Growth Cycle	Nr	Second Crop type	Growth Cycle	Rank by Criterion V1	V2	V3	V4	Combined Rank
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								

(criterion V2). A crop combination is retained for later use if it is reasonably[15] competitive in at least one of the four criteria. Table 3 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):

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

which involves estimates of rain erosivity (factor R), soil erodibility (factor K), slope effect (slope length factor LS), crop cover (factor C*), management, (factor M), and protective measures (factor P). Each of the factors making up the USLE is quantified in each agro-ecological cell, for all viable crop combinations, for pastures and selected fuelwood species. Details of the parameterization used in the Kenya study are described in FAO/IIASA (FAO/IIASA, 1991).

[15]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.

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 susveptible 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 our 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 0.5. This is further adjusted to 0.4 for increased[16] 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:

$$A_{P=1.0} = 369 \times 0.11 \times 0.8 \times 0.4 = 13\text{t/ha/year} \tag{2}$$

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

$$A_{P=.067} = A_{P=1.0} \times 0.067 = 1t/ha/year \tag{3}$$

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

[16] Note that lower cover factors indicate better ground cover.

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) C1 >80	C2 60-80	C3 40-60	C4 20-40	Total C1-C4	2nd Harv.	Total Harv.	Total 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			

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 yield[17]. Classes C_1 to C_4 represent average yields of >80 % (very productive), 60-80% (productive), 40-60% (moderately productive), 20-40% (marginally productive), respectively, compared to maximum attainable yields.

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

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).

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 above[18], amounts to some 6.6 million ha. About 2.6 million ha are adjudged very good or good potential (classes C_1 and C_2), 2.0 million ha are rated moderately productive (class C_3). The balance, another 2.0 million ha, is of low potential (class C_4).

The arable extents in classes C_1 to C_4 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.

8 The land use allocation model (LUAM)

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 by-products), 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).

[18]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).

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 trade-offs between several objectives within the given set of constraints. In the Kenya study, the criteria are selected out of the set of outcome variables (cf Section 8.3). 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.

8.1 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.

8.2 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.

8.3 Outcome variables

Typically, six to eight variables are interactively selected from the set of outcome variables (defined in the core model outlined in Section 8.4) to serve as criteria in multicriteria 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 consuption 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.

8.4 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 l80-270 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.

8.5 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 (cf Figure 22 on page 25) 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 */
SCR0104 /* temporary file, LP matrix coefficients       */
SCR0204 /* temporary file, LP right hand sides  */
SCR0304 /* temporary file, crop combination data        */
SCR0404 /* 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    */
2320.   /* CALREQ: calorie requirement per person (Kcal per day)        */
38.80   /* PRTREQ: protein requirement per person (gram per day)        */
0.750   /* UMONO : upper limit on cell use for mono-culture     */
0.500   /* TLUFLW: share of fallow used for livestock   */
0.750   /* SHNFIX: share of non-nitrogen-fixer species admitted */
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 (on page 64) 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.

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.

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 flag :
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 flag 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 ($0 \leq \text{TLUFLW} \leq 1$).

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

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.

9 Trouble-shooting

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 paper. 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: `_l1.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.

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 sites[19] and down-load updates, when those will be available. For users of AEZWIN a version of the `lpgen2.exe` utility that matches

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

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 a 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 it 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 server [20] 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.

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, Somlyódy and Watkins, 1995; Makowski, Somlyódy 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 (Matsuhashi, 1997).
- A number of engineering applications in mechanics, automatic control and ship navigation, summarized, see (Wierzbicki and Granat, 1997).

There is 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.

[20] The URL of IIASA's Web server is: `http://www.iiasa.ac.at`

12 Acknowledgment

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- Mr Grzegorz Wójcik of the Warsaw University of Technology, who has developed a tool for converting a single source documentation in the form of LaTeX (with additional styles) into three types of documents, namely a standard LaTeX document, the HTML files, and the restricted HTML files accepted by a portable *zHelp* utility. The tool generates also a dictionary which makes it possible to implement a convex sensitive help in a C++ program.

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A Kenya case study coding schemes

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 Appendix contains the coding schemes relevant in the context of the Kenya Case Study:

A.1 Kenya district codes

Code	Nr	District	Province
01	01	Kiambu	Central Province
02	02	Kirinyaga	
03	03	Muranga	
04	04	Nyandarua	
05	05	Nyeri	
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	

A.2 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	CASSSIA	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.

A.3 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	1.00	8840	0	5.0
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)

A.4 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

A.5 Thermal zone coding

Code	Temperature (Celsius)	Altitude (meters)	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

A.6 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

A.7 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+

A.8 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)

A.9 Forest land coding

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

A.10 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

A.11 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

A.12 Tsetse area coding

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

A.13 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

A.14 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

A.15 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

A.16 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

A.17 Soil unit coding

Code	Symbol	Explanation
001	A	Acrisols
002	Ac	Chromic Acrisols
003	Ag	Gleyic Acrisols
004	Ah	Humic Acrisols
005	Aic	Ferralo-chromic Acrisols
006	Aif	Ferraloferric Acrisols
007	Aio	Ferralo-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	Ferralic 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 Renzinas
028	Eo	Orthic Rendzinas
029	F	Ferralsols
030	Fa	Acric Ferralsols
031	Fh	Humic Ferrasols
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	Luvisols
061	La	Albic Luvisols
062	Lc	Chromic Luvisols
063	Lf	Ferric Luvisols
064	Lg	Gleyic Luvisols
065	Lic	Ferralo-chromic Luvisols
066	Lif	Ferralo-ferric Luvisols
067	Lio	Ferralo-orthic Luvisols
068	Lk	Calcic Luvisols
069	Lnc	Nito-chromic Luvisols
070	Lnf	Nitoferric Luvisols
071	Lo	Orthic Luvisols
072	Lv	Vertic Luvisols
073	M	Greyzems
074	Mo	Orthic Greyzems
075	Mvo	erto-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	Histosol
085	Od	Dystric Histosols
086	Q	Arenosols
087	Qa	Albic Arenosols
088	Qc	Cambic Arenosols
089	Qf	Ferralic Arenosols
090	Qk	Calcaro-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	Solonetz
098	Sg	Gleyic Solonetz
099	Slo	Luvo-orthic Solonetz
100	Sm	Mollic Solonetz
101	So	Orthic Solonetz
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

A.18 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

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