

**AGRO-ECOLOGICAL LAND RESOURCES  
ASSESSMENT FOR AGRICULTURAL  
DEVELOPMENT PLANNING**

**A CASE STUDY OF KENYA**

**RESOURCES DATA BASE AND LAND PRODUCTIVITY**

**Technical Annex 8**

***CROP PRODUCTIVITY ASSESSMENT:  
RESULTS AT DISTRICT LEVEL***



FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS



INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS

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**Crop Productivity Assessment:  
Results at District Level**

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1991

*Any part of the computer programs and the corresponding data sets used in the assessment may be modified in the light of new knowledge and/or new objectives. The model is part of a larger district and national planning tool and is expected to be expanded and refined with use.*

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M-51  
ISBN 92-5-103436-2

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# REPORTS AND TECHNICAL ANNEXES

This work is recorded in a main report and technical annexes.

## Main Report:

Agro-ecological Land Resources Assessment for Agricultural Development  
Planning - A Case Study of Kenya  
Resources Data Base and Land Productivity

## Technical Annexes:

1. Land Resources
2. Soil Erosion and Productivity
3. Agro-climatic and Agro-edaphic suitabilities for Barley, Oat, Cowpea, Green gram and Pigeonpea
4. Crop Productivity
5. Livestock productivity
6. Fuelwood productivity
7. Systems Documentation Guide to Computer Programs for Land Productivity Assessments
8. Crop Productivity Assessment: Results at District Level

# Chapter 1

## Introduction

The 'Agro-ecological Land Resources Assessment for Agricultural Development Planning', is a study concerned with the development and implementation of national level methodology for the determination of land use potentials of land resources of individual districts for policy formulation and development planning. This Kenya case study has been carried out by FAO and IIASA in collaboration with the Government of Kenya (FAO 1984).

The complete work is described in a main report entitled: Resources Data Base and Land Productivity.

This main report are supported by technical annexes which deal with relevant methodological details and analysis.

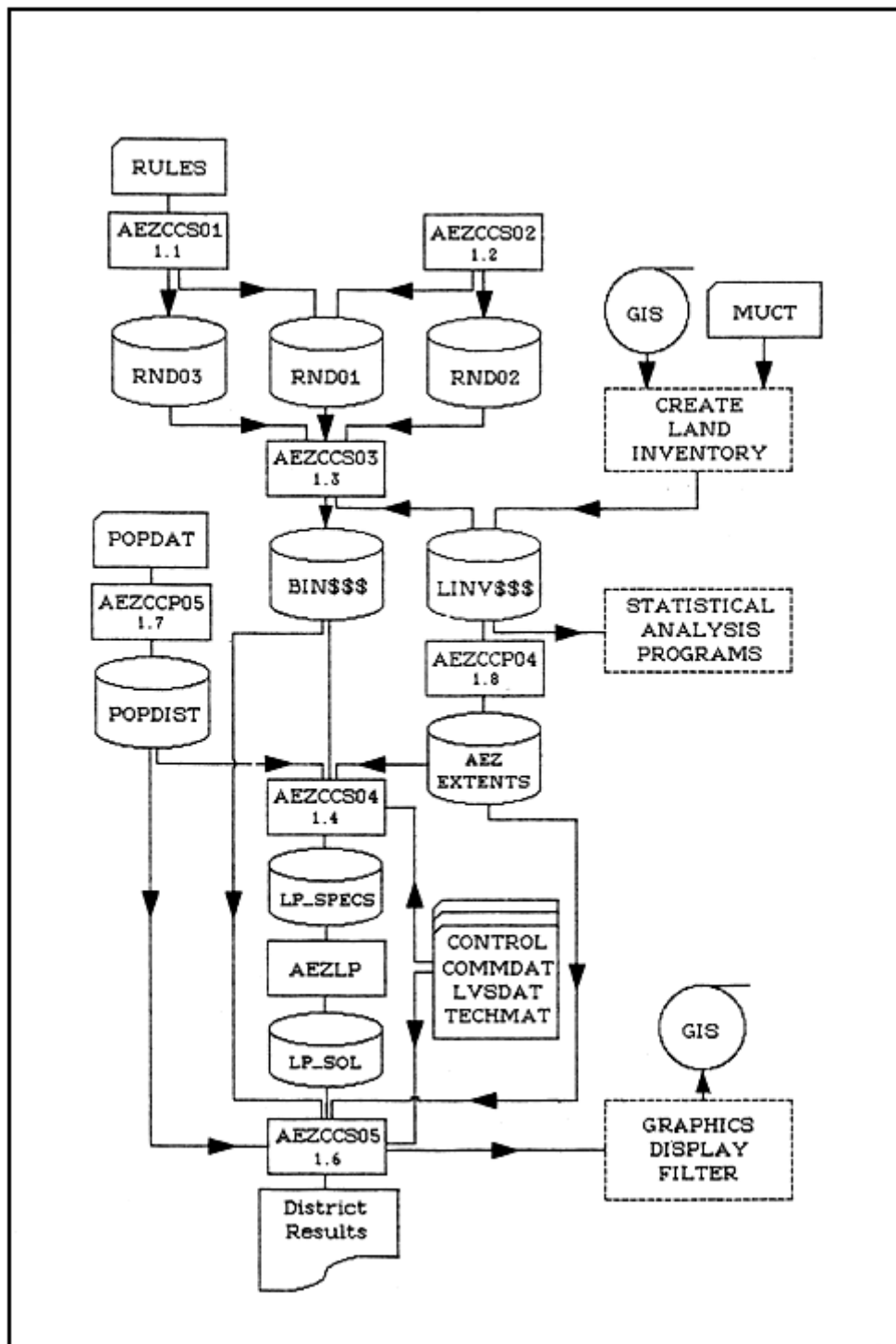
This report, Technical Annex 8, presents quantitative results of the crop productivity assessment for Kenya, carried out at the International Institute for Applied Systems Analysis (IIASA) in the context of the above mentioned work programme. The climatic and soil resources inventory upon which the analysis rests is described in Technical Annex 1. The paper is subdivided into three chapters. Chapter 1 will give a brief overview of the software package. Then, in Chapter 2, the methodology and the resource data base underlying the crop productivity assessment is summarized. Chapter 3 begins with an illustrative example of the computations involved, and briefly discusses and presents crop suitability results at the national level. Additional information regarding the coding schemes used in the presentation can be found in Appendix A. Estimates of rainfed arable land and production potential by crop, according to three sets of assumptions, at national, province and district level are contained in Appendixes B to D.

### 1.1 Overview of the AEZ-CCS Software Package

The software package to be applied in detailed AEZ Country Case Studies (AEZ-CCS) consists of a set of five central computer programs which are required for applying the various steps of the AEZ methodology, accompanied by a suite of supplementary computer programs related to various aspects of data preparation, scenario analysis and graphical presentation of results.

The first program, AEZCCS01, converts the coded country specific productivity assessment rules, e.g. soil unit rating, fallow requirement tables, etc., from a format adequate for human use into a file format more suitable for rapid access and processing by computer.

**FIGURE 1**  
**Overview of AEZ-CCS Software Package**





Then, program AEZCCS02 sets up tables of constraint-free attainable potential crop yields in relation to the parameters of the climatic resource inventory, length of growing period zone and pattern of growing period zones. This approach has been chosen to guarantee flexibility and to allow for refinement and adaptation of the methodology when such need arises.

Program AEZCCS03 processes the records of the land inventory and calculates for each location (agro-ecological cell) production potential by primary crop as well as crop combinations according to the AEZ land productivity assessment principles. Application of these rules yields an average productivity factor relative to the maximum attainable yield of a particular crop. For each crop/crop combination and each location a productivity loss factor, accounting for water erosion hazard and soil degradation, is quantified. The program generates an intermediate data file, containing cell information and crop combination records, which forms the basis for assessing district/regional and nation-wide policy scenarios.

Program AEZCCS04 reads the intermediate output file from the land productivity assessment (program AEZCCS03) and generates the input file for a linear program according to the specifications given in a scenario control file. The LP specification file is generated in standard MPS file format.

Finally, program AEZCCS05 re-reads the output file from the AEZ land productivity assessment (program AEZCCS03) and the LP solution file generated by a standard LP package to print out summary tables at a level of detail as indicated in the control file. The LP package is assumed to be available on the respective installation. In our tests of the AEZ-CCS software package a slimmed 'LP only' version of MINOS, a large scale non-linear programming system (see Murtagh and Saunders, 1977), was used to solve for an optimal cropping pattern in relation to the specified scenario objectives and constraints. Formulating and running scenarios using the optimization modules is a subject for a separate report. Figure 1.1 provides an overview of the information flow in the AEZ-CCS software package.

In addition to the above mentioned computer programs there is a growing number of utility programs of various kinds related to :

- compilation of the land resources inventory from GIS
- statistical analysis and cross tabulation of the resource inventory
- aggregation of district level results to province and national level
- crop suitability assessment and production potential
- back-transformation of district/national scenario results to spatial representation
- (GIS)
- color display of results and resource data base in map form

Before turning to more complex tasks as implied by national policy planning, valuable information about the resource endowment of a country regarding agricultural production potential can be obtained by assessing the extents of land and their average suitability to producing individual crops. To this effect, all included crop types, grasses and fuelwood species are evaluated in each of the more than 90000 agro-ecological cells, thereby quantifying potential arable extents in terms of five quality classes and corresponding minimum, average and maximum production. Where possible and relevant, sequential

(mono) cropping sequences are constructed to assess the full production potential in areas with long growing periods. In each agro-ecological cell a 'reasonable' agricultural land use is determined, considering crop suitability and production stability, to derive district level estimates of rainfed arable land. Hence, this Technical Annex is concerned with the fourth item in the above list of utility programs surrounding the AEZ-CCS package, crop productivity assessment and production potential.

## Chapter 2

### Crop productivity assessment - a brief summary of the AEZ approach

This chapter gives a brief summary of the computational steps and data involved in the district-wise AEZ crop productivity assessment followed in this study. Most of the elements touched upon here have been discussed in more detail in some of the other technical annexes which will be referred to as appropriate.

The crop-wise productivity assessment comprises a first appraisal of the detailed Kenya land resources inventory that has been compiled (see Technical Annex 1). It also yields the necessary information and analysis to tackle more complex district planning tasks involving food production targets, crop and livestock interaction, cash crop production objectives, fuelwood requirements, the need to preserve forest and wildlife resources, etc. Scenario formulation for district planning is a subject of a further report.

The procedures introduced here provide detailed estimates of rainfed arable land resources, optionally on a district basis, by province and of the national total. The analysis can be carried out separately for each of the specified levels of technology (low, intermediate and high). The presentation of results, Appendix B to D, concentrates on the intermediate level of inputs which appears to be most realistic in relation to analysis for the year 2000.

In the following we will recapitulate the data elements included in the land resources inventory and their relation to the crop models involved.

#### 2.1 Climatic Inventory

The climatic resources inventory of Kenya quantifies both heat and moisture conditions. The quantification of heat attributes has been achieved by defining reference **thermal zones**. As temperature seasonality effects of latitude are minor due to the equatorial location of Kenya the temperature zones are closely correlated to altitude ranges. To cater for differences in temperature adaptability between crops, nine thermal zones have been distinguished in the climatic inventory in accordance with the four temperature adaptability groups of crops, pasture and tree species discussed in Technical Annexes 3, 5 and 6. Each thermal zone, based on intervals of 2.5 degrees Celsius, relates to an altitude range of about 385 meters.

Quantification of moisture conditions was achieved through the concept of reference **length of growing period** (LGP days). Crop growth is considered possible if moisture supply from rainfall exceeds 1/2 of potential evapotranspiration. The moisture period regime has been inventoried by means of three complementary concepts:

- number of separate 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 Patterns are recognized in the inventory.
- the **mean total dominant length of growing period**, i.e. the sum of mean individual dominant and associated length of growing periods occurring during the year. Fifteen LGP zones, 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 condition.

The map of dominant LGP zones and the map of LGP-Pattern zones together with the associated information (in table form) on length and probability of occurrence of corresponding associated growing periods provide the historical profile of any mean total dominant length of growing period in any of the twenty-two LGP-Pattern zones. A detailed presentation of the climatic inventory, data sources and compilation, is contained in Technical Annex 1.

## 2.2 Soil Inventory

The Exploratory Soil Map of Kenya (Siderius and van der Pouw 1980; Sombroek, Braun and van der Pouw 1982) at a scale of 1:1 million was used to compile the land resources inventory underlying the present assessment. This soil map includes information on distribution and characteristics of soils, landform and geology/parent material.

The digitized map distinguishes 392 different **soil mapping units**. These mapping units describe soil associations or soil complexes composed of dominant soils, associated soils and inclusions (390 mapping units) or relate to water bodies and major urban areas (2 mapping units).

The productivity potential and suitability of different soil units within a mapping unit may vary widely. Therefore, a complete **mapping unit composition table** has been provided (van der Pouw 1983) containing percentage allocation of the mapping units by soil unit, slope class, soil texture and soil phases. The mapping unit composition table also contains information derived from the legend of the soil map regarding landform and geology/parent material. Soil units have been defined in terms of measurable and observable properties of the soil, and specific clusters of such properties are combined into 'diagnostic horizons'. The 123 **soil units** (plus 5 miscellaneous units) inventoried in the Kenya soil resources inventory and the diagnostic horizons are presented in Technical Annex 1.

**Soil texture** is quantified in terms of three major textural divisions (coarse, medium, fine) which have been further subdivided into seventeen textural classes related to contents of clay, silt and sand. The presence of **coarse material** in the soil profile has been inventoried separately from soil texture by means of a coarse material indicator distinguishing six types of stoniness.

**Soil phases** indicate land characteristics which are not considered in the definition of the soil units but bear significance regarding the use, crop suitability and management of land. The nineteen soil phases recognized in this study relate to physico-chemical limitations of the soil, effective soil depth limitations and mechanical hindrance. Up to three soil phases have been combined resulting in some seventy different soil phase combinations occurring in the inventory.

Six basic **slope classes**, in twelve combinations, have been employed in the Exploratory Soil Map of Kenya. The six basic slope classes are: 0-2%, 2-5%, 5-8%, 8-16%, 16-30%, and >30%. These have been further refined by forming slope class associations and deriving mean slope quartiles for each of the slope classes. The slope association information, assembled in the form of a slope composition table, has been used to break up extents by soil units into several classes of ranges of slope gradients appropriate for matching to land utilization types and evaluation of soil erosion hazards.

## 2.3 Land Resources Inventory

The land resources inventory combines all the digitized Kenya map overlays that relate to climatic conditions, soil inventory, administrative units and selected properties of

present land use, i.e. cash crop zones, forest areas, irrigation schemes, Tsetse infestation and game parks.

The compilation of the land resources inventory involves the application of the mapping unit composition table and slope composition table to the soil mapping unit overlay and the aggregation of the GIS raster information to agro-ecological cells. The steps involved include:

- creation of a GIS data base file
- sorting of GIS data base file and aggregation to GIS inventory file
- application of mapping unit composition table
- application of slope composition table

The land resources inventory for Kenya eventually contains unique records, holding eighteen fields each, with the following information:

- 1 province code
- 2 district code
- 3 thermal zone
- 4 mean dominant total length of growing period
- 5 pattern of length of growing periods
- 6 soil mapping unit
- 7 soil unit
- 8 slope class
- 9 average slope gradient
- 10 coarse material indicator
- 11 soil texture class
- 12 soil phase combination code
- 13 cash crop zone indicator
- 14 forest land indicator
- 15 irrigation scheme indicator
- 16 Tsetse infestation indicator
- 17 game park indicator
- 18 cell extent (in ha)

The GIS map overlays are based on a grid of one square kilometer pixels covering a rectangle of 1085 by 900 kilometers, i.e. some 976,500 raster points per map (about 575 thousand of which within the country). The compilation sketched above produces a data file of about 91,000 unique (in terms of the combination of the considered land and climate characteristics) records comprising the Kenya land resources inventory. This level of detail ensures that each agro-ecological cell represents a fairly homogenous set of agro-climatic and soil physical conditions, a requirement crucial to adequately matching the cell properties to land utilization types. This will be discussed next.

## **2.4 Crop Climatic Suitability**

A total of twenty-five crop species, divided into sixty-four crop types, are included in the assessment. The full list of crops and crop types is presented in Appendix A. Although the emphasis is on food crops, coffee, cotton, pineapple, pyrethrum, sisal and tea are considered, for their economic relevance to agriculture and to account for reported and/or projected land area occupied by these crops. The remaining nineteen crops are represented in terms of fifty-eight crop types to account for differences in ecotype adaptation and growth cycle within each crop species. In addition, pastures, comprising

some thirty grass and legume species, and two classes of tree species, with and without nitrogen fixing ability, comprising some thirty-one fuelwood species, have been included in the assessment.

Crops have climatic requirements for photosynthesis and phenology both of which bear a relationship to yield. In the FAO AEZ methodology crops are classified into four climatic adaptability groups according to their fairly distinct photosynthesis characteristics. Each group comprises of crops of 'similar ability' in relation to potential photosynthesis.

For example, barley, oat, wheat, phaseolus bean and white potato have a C3 photosynthesis pathway and belong to adaptability group I. They are adapted to operate under cool conditions with less than 20 degrees Celsius mean daily temperature, i.e. an altitude above 1500 meters under Kenyan conditions. Mean daily temperatures of 10 to 12.5 degrees Celsius and below, i.e. the altitude range of 2700 to 3100 meters and above, are assumed to pose a risk of frost damage too great for successful cultivation of these crops. At altitudes between 1500 m and 2700 m (thermal zone 4, 5 and 6) the length of the growth cycle of these crops increases by 5 to 6 days for each 100 m increase in altitude.

Similarly, for each of the 64 crop types considered, for pastures and fuelwood species, the relation between crop growth cycles, thermal requirements and inventoried thermal zones in Kenya has been assessed and rated. Five suitability classes are employed, i.e. S1 to S4 and N, and the ratings apply to all three levels of input. A rating of S1 indicates that the temperature conditions for growth and yield physiology and phenological development are optimal and that thermal conditions do not hinder achievement of maximum yield potential. Ratings of S2, S3 and S4 indicate that temperature conditions for growth and development are sub-optimal resulting in suppression of yield potential by 25, 50 and 75 percent, respectively. A rating of N indicates that temperatures are not suitable for cultivation of the crop.

Potential yields when considering moisture related constraints, i.e. water stress, weeds, pests and diseases, workability, for individual LGPs were estimated according to the AEZ method (FAO 1978-81) for all crops (excluding the cash crops, coffee, cotton, pineapple, pyrethrum, sisal and tea; see below), pastures and fuelwood species. Yields refer to single crops which act as building blocks in the formulation of annual cropping patterns and crop rotations.

All annual crops are matched to individual component length of growing periods. The LGP-Pattern evaluation takes into account the probability weights associated with the historical pattern of occurrence of length of growing periods. This provides a measure of the variability of the yields, quantifying potential yields under average, best and worst historical moisture conditions.

Perennial crops, including cassava, banana, oil palm and sugar cane, are evaluated with respect to mean total dominant length of growing period with yield potentials adjusted according to LGP-Pattern group to account for moisture stress where appropriate.

For the cash crops, coffee, cotton, pineapple, pyrethrum, sisal and tea, for which agro-climatic yield potential has not been estimated, an allocation rating table relating crop suitability to LGP and LGP-Pattern has been formulated to identify appropriate climatic zones for consideration in the crop productivity and resource optimization algorithms.

The above procedures apply to the climatic inventory on all soils except Fluvisols, where intensity and duration of flooding governs potential cultivation rather than local precipitation. In addition, cultivation of these soils is normally confined to post-flood periods. For these reasons, Fluvisols were rated separately for all crops, combining agro-climatic and agro-edaphic considerations.

## 2.5 Crop Edaphic Suitability

To assess the suitability of soils for crop production, soil requirements of crops must be known and compared to chemical soil properties and physical limitations imposed by landform, such as slope, texture and coarse material. The basic soil requirements of crop plants can be summarized under broad topics related to internal and external soil characteristics:

- soil temperature regime
- soil moisture regime
- soil aeration regime
- natural soil fertility regime
- effective soil depth for root development and foothold
- soil texture regime
- soil salinity and toxicity harmful to crop growth
- soil slope and topographic characteristics
- occurrence of flooding
- soil accessibility and trafficability

Many soil characteristics, e.g. natural fertility, salinity, pH, gypsum content, etc., can be defined in a range that is optimal for a given crop, a range that is critical, and a range that is unsuitable under present technology (see Technical Annex 3, and FAO 1978-81, 1980). These relationships have been applied in the matching of the inventoried soil units with the soil requirements of crops.

The **soil unit evaluation**, expressed for each crop in five suitability classes, S1 to S4 and N, relates soil properties to the degree to which crop requirements can be met under a given management practice, i.e. level of inputs. Where appropriate, the soil unit rating is modified according to limitations implied by **texture evaluation**, **stoniness** and **phase evaluation**. For further detail refer to Technical Annex 4.

## 2.6 Slope Evaluation

Limitations imposed by slope are taken into account in a threefold manner. As explained earlier, the original mapping units are split up, with regard to the inventoried slope class, into uniform slope ranges according to a slope composition table. Seven slope ranges have been considered as appropriate for LUT matching: 0-2%, 2-5%, 5-8%, 8-16%, 16-30%, 30-45% and >45%. For example, mapping units with an attached slope class code 7, slope symbol CD, 5-16 %, are assumed to involve slope ranges of 2-5%, 5-8%, 8-16% and 16-30% with 5, 20, 70 and 5 percent of the mapping unit falling into the respective slope ranges.

Secondly, a slope-cultivation association screen defines those slope ranges which are permissible for cultivation in relation to crop type, land use practice and level of inputs.

The computation of the land productivity assessment also involves the calculation of potential topsoil loss as well as relating topsoil loss to productivity loss. In the analysis, topsoil loss is estimated for each permissible crop combination and level of

inputs using a modified Universal Soil Loss Equation (see Technical Annex 2). In the specification of the USLE, slope gradient is an important explanatory variable in estimating topsoil loss. Yield loss is associated to the estimated topsoil loss through a set of linear relationships accounting for soil properties (susceptibility to erosion), climatic conditions (regeneration capacity of topsoil) and level of management.

## **2.7 Crop Productivity Assessment and Production Potential**

The techniques outlined so far comprise the suitability assessment part of the land productivity model. All three assessments, the climatic suitability, the edaphic suitability and the evaluation of slope limitations are carried out for each agro-ecological cell to estimate crop performance. Land that is reserved for other uses, e.g. forest areas and game parks, can - but need not - be excluded from the analysis. The results of the suitability assessment in Kenya are presented in chapter 3 in the form of generalized maps, Figure 3.1 to Figure 3.3, for crops, pastures and fuelwood species, respectively. Information by district and province can be found in Appendix B.

Six suitability classes have been defined relating average cell suitability to maximum attainable yield. Classes C1 to C5 relate to average attainable yields of >80%, 60-80%, 40-60%, 20-40%, and 5-20% compared to maximum yields. Note that extents in suitability class C5 will not be considered among the viable crop options, but have been included here to indicate the scope of production in very marginal areas. A sixth class accounts for areas that are entirely unsuitable or allow only for less than 5 percent of maximum yield. Data for the non-suitable class are not explicitly included in the tabulated results. The assessment in Appendix B assumes that cells marked as belonging to an irrigation scheme, forest zone or game park cannot be considered for rainfed production of crops, pastures or fuelwood species.

Consequently, this information is used to determine crop productivity potential. To this effect further considerations have to be taken into account including multiple cropping, in space and time, fallow requirements to maintain soil fertility, and production stability constraints to reflect consequences of rainfall variability.

Multiple cropping refers to the intensification of arable land use, both in time and space. The principles of yield increases resulting from a better use of time with crops in sequence is complementary to increases arising from a more efficient use of space with crops in mixture.

**Sequential cropping** is possible in areas where climatic conditions, temperature and moisture supply, permit crop growth beyond the duration of one crop. This mostly applies to areas in Kenya with a length of growing period above 210 days. The sub-humid and humid zones account for only 12 percent of Kenya's land area but some 60 percent of the rainfed arable land resources. The algorithms implemented for land productivity assessment explicitly construct and evaluate all feasible sequential crop combinations, both multiculture and monoculture, by matching individual crop cycle requirements to the relevant component length of growing periods implied by the LGP-Pattern. In this Technical Annex, however, we present arable land estimates and production potential for individual crops only (including sequential monoculture of crop types belonging to the same crop species).

**Intercropping increments**, i.e yield advantages from practices like strip, alley and relay cropping, are assumed to increase with length of growing period. No yield advantage is adjudged in LGPs with less than 120 days. Also, it is stipulated that advantages would be largest with mixtures where the individual component crops are rated



as very suitable. The relative contribution of intercropping is assumed to be most pronounced under low level of inputs. No increment is applied under high level of inputs, since the mechanization requirements associated with this management level are generally regarded as being incompatible with intercropping practices. For wetland rice, sugarcane, banana, oil palm, pastures and fuelwood species no intercropping increments were applied.

To make the assessment more realistic, the model includes, as a scenario variable, a parameter stating the required minimum level of production stability. As the objective function of the planning scenarios is usually formulated in terms of average production conditions, i.e. yields attainable under different patterns of growing periods weighted by their historical profiles of occurrence, the **production stability constraint** stipulates that in each agro-ecological cell the selected activities would satisfy the condition that the minimum production levels, i.e. output in climatically worst years, would lie within a tolerable range to the best alternative under worst conditions. The trade-off is between loss in average productivity and risk aversion. The tolerance parameter can be varied with level of inputs. In the results presented, a production stability constraint has been imposed only when determining total arable land potential, but not when quantifying productivity potential of individual crop types. The estimates of potentially arable land by crop type, listed in Appendix D, therefore possibly include areas where production may not be feasible when imposing a production stability constraint.

The AEZ assessment is concerned with sustainable agricultural practices. In their natural state, many soils cannot be continuously cultivated without undergoing degradation manifesting itself in decreasing crop yields and deterioration of physico-chemical soil properties. The assumptions on **fallow requirements** incorporated into the model are formulated for four main groups of crops - cereals, legumes, roots and tubers, banana and sugar cane - and relate to soil unit, thermal zone and moisture regime. For details refer to Technical Annex 4. In the results, Appendix B to D, however, fallow requirements were not deducted in calculating crop-wise potentially arable land and implied production.

## Chapter 3

### Crop productivity assessment - results at national level

This chapter illustrates the suitability assessment and calculation of rainfed production potential with an example, followed by tabulated results of crop productivity assessment

#### 3.1 Patting It All Together - An Example

We pick a record from the land resource inventory, an agro-ecological cell in Meru district, and look at maize productivity. The cell data record reads:

```
3 6 11113224 33034 0 2 35 00 000 1150
```

```
--+-----+-----+-----+-----+-----+-----+
```

The line underneath the data record indicates the individual fields, the cross marking the end of each field. The record contains the following information:

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 Centigrade
4	7 - 8	11	mean total LGP	growing period of 270 to 299 days
5	9 - 10	13	LGP-Pattem	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	170	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 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	cell extent	size of agro-ecological cell (ha)

A few remarks may be helpful: Mapping unit Pn1 belongs to the landform of non-dissected erosional plains. In the legend of the soil map it is described as: 'well drained, very deep, dark reddish brown to dusky red, friable clay; in places bouldery (nito-rhodic FERRALSOLS)'. The land extent under consideration falls into thermal zone 1, i.e. a mean daily temperature >25 Centigrade 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 whole 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 inventoried mean total dominant length of growing period for the cell, located in the north-east of Mount Kenya, is LGP code 11, i.e. sufficient moisture supply for a total growing period of 270 - 299 days, quite favorable conditions.

LGP-Pattern code 13 indicates that there are usually two (shorter) growing periods, in seven out of ten years according to historical profiles, and one growing period in about 1/3 of the years. The reference table relating the mean total dominant LGP to the corresponding mean total associated LGPs (see Technical Annex 1.1) lists the following for the bimodal case: the first associated LGP, LGP<sub>21</sub> with code 7, is 150 - 179 days, the second associated LGP, LGP<sub>22</sub> with code 5, lasts 90 - 119 days.

The list of crop types considered in the AEZ assessment for Kenya (see Appendix A), includes nine maize crop types, with crop sequence numbers 4 to 12. Maize types with crop codes 031 to 036, i.e. crop sequence numbers 7 to 12, are highland maize types adapted to cooler conditions and have therefore been rated as not suitable in the thermal zone suitability screen. This leaves us with three lowland maize types, crop codes 021 to 023, crop sequence numbers 4 to 6. Agronomically attainable yield potentials for the relevant LGPs (in kg dry weight per hectare), i.e. on suitable soils and terrain, at intermediate level of inputs, and the corresponding crop cycle lengths are as follows:

Code	Crop	Growth Cycle (days)	Length of Growing Period (days)						
			90	120	150	180	210	240	270
			-	-	-	-	-	-	-
			119	149	179	209	239	269	299
021	Maize 1	70-90	1000	1860	2570	2540	1790	1260	1030
022	Maize 2	90-110	1300	2530	3510	3450	2500	1730	1370
023	Maize 3	110-130	0	3200	4450	4350	3200	2200	1700

The maximum unconstrained yields are 2.6, 3.5 and 4.5 t/ha, respectively. For all three crop types, the highest yields can be achieved in the LGP with 150 to 179 days (LGP code 7). In shorter LGPs water stress constrains attainable yields, in longer LGPs pests, weeds and workability constraints are assumed to increasingly limit attainable maize yields. From the LGP-Pattern weights we derive average attainable yields of 2.1 t/ha (min 1.0 t/ha, max 2.6 t/ha) for the shortest maize type (code 021), 2.9 t/ha (min 1.4 t/ha, max 3.5 t/ha) for the second maize type (code 022), and 3.6 t/ha (min 1.7 t/ha, max 4.5 t/ha) for the third lowland maize type (code 023).

The soil unit rating of nito-rhodic Ferralsols for maize is S2, like with most Ferralsols, i.e. suitable with some limitations depressing yields by 25 percent. The clay texture does not affect the rating. Combining agro-climatic and agro-edaphic suitability rating we arrive at average yields of 1.7, 2.4 and 3.0 t/ha respectively. 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 %.

In a relatively long growing season, as we are considering here, additional yields from multicropping must be considered. The intercropping increment, as explained earlier, depends on the level of inputs, the length of the growing period and the overall crop suitability. At the intermediate level of inputs, with moisture availability well above 120 days the intercropping increment for maize is estimated at around 10 percent, i.e. a LER (land equivalent ratio) of 1.1.

The length of the growing period allows also for two or even three crops to be grown each year. Since we consider only lowland maize in this example, the optimal

sequential crop combination with two crops grown in sequence involves crop code 023, the maize type with the longest cycle, as the first crop, followed by the medium maize type, crop code 022, with a growth cycle of 90 to 110 days. The maize crop with the shortest growth cycle, lowland maize crop code 021, requires 80 days on average (growth cycle 70 - 90 days). Assuming a 10 day turn-around time, three sequential crops can be grown within 270 days. In the dominantly bimodal LGP-Pattern (code 13), two maize crops (crop codes 022 and 021) could be grown in the first growing season, 150 - 179 days, a third maize crop (code 021) in the shorter second growing season of 90 - 119 days. Table 3.1 summarizes the best performing sequential maize crop combinations in the given cell, as also for LGPs of 240 - 269 and 210 - 239 days, when one, two or three crops are grown. The results have to be understood as an illustration of the crop combination algorithm rather than a likely or even viable option. In fact, the crop combination requirement constraints imposed to avoid continuous mono-cropping would normally rule out the sequential cropping patterns described in Table 3.1. For the quantification of maximum potential crop production, including multiple mono-cropping, as in the results presented in Appendix C and D, these combinations would however be acceptable.

Fallow requirements to maintain soil fertility and ensure sustainable production, under given conditions and input level, are set at 25 percent, i.e. 5 out of 20 years the land would not be permitted to be under maize cultivation.

**TABLE 3.1**  
**Maize production potential (t/ha) - an example**

LGP (days)	Crop Code	One Crop			Two Crops			Three Crops				
		min	avg	max	Crop Code	min	avg	max	Crop Code	min	avg	max
210-239	023	2.6	2.9	3.5	023 021	2.8	3.5	5.1	n.a.	0.0	0.0	0.0
240-269	023	1.8	3.4	3.6	023 022	2.6	4.0	4.7	021 021 021	2.4	3.8	4.5
270-299	023	1.4	3.0	3.7	023 022	2.2	3.9	4.6	022 021 021	2.4	4.0	4.7

The soil erosion hazard is quantified by means of a modified Universal Soil Loss Equation (USLE), involving estimates of rain erosivity, soil erodibility, slope effect (slope length factor), crop cover factor and protective management practices. An average growing period of 285 days implies a mean average rainfall of about 1550 mm, resulting in an estimated rainfall erosivity factor of 600. Nito-rhodic Ferralsols with clay texture are considered to be of low erodibility. Hence, they are grouped into the second (out of seven) soil erodibility class with an average soil erodibility factor of 0.11. With a slope length factor of 0.8 and a crop cover factor of 0.4, adjusted to 0.36 for an assumed crop/fallow cycle - the fallow requirement is 25 percent) - finally results in an estimated annual soil loss of 19 t/ha/year, corresponding to about 1.6 mm topsoil loss per year. The regeneration capacity of topsoil, a function of thermal zone and length of growing period, stipulates an annual addition of topsoil of 1.7 mm, making up for the estimated erosion losses. Therefore, maize productivity is not assumed to be adversely influenced by water erosion in the given agro-ecological cell.

### 3.2 National Level Results

The calculation procedures outlined above have been performed for all crop types, pastures and fuelwood species in all agro-ecological cells of Kenya. As a result, the extent and quality of arable land and production potential of each crop type was determined in all locations. The information was then aggregated to district level,

province level and national total. The results are also aggregated over crop types to indicate production potential of crop species, e.g. arable land and production potential for maize rather than nine individual maize types.

Three sets of results are presented. The first set, Assumption Set A, refers to single crop suitability and production potential on all land that is not indicated as forest zone, game park, or as belonging to an irrigation scheme.

The second round of computations, Assumption Set B, looks at productivity allowing sequential (mono) crop combinations, where feasible. Also, crop types can be combined, e.g. a first maize crop with a growth cycle of 110-130 days and a second maize crop of 70-90 days. The resulting crop production is included with the crop type that comes first in the crop combination, the primary crop.

Finally, in Assumption Set C, it has been attempted to determine the utmost crop potential by including all rainfed land in the assessment, regardless of any other land use indicated in the land resources inventory.

Six suitability classes have been defined, relating average single-crop suitability in a cell to maximum attainable yield. The classes C1 to C5 relate to average attainable yields of >80 %, 60-80%, 40-60%, 20-40%, and 5-20% compared to maximum yields. Note, that extents in suitability class C5 are usually not considered among the viable crop options, but have been included here to indicate the scope of production in very marginal areas. A sixth class accounts for areas that are entirely unsuitable or allow for only less than 5 percent of maximum yield. Data for the non-suitable class are not explicitly included in the result tables. Production potential is calculated from land extents in suitability classes C1 to C4 only. Average, minimum and maximum production potential and yields are determined according to the LGP-Pattern and associated probabilities. Multiple land use in time (sequential mono-cropping) is indicated by means of a multicropping index (MCI).

Each table shows an estimate of arable land by productivity class. The algorithm used to determine arable extents in an agro-ecological cell comprises of a two stage procedure. In a first step, the crop or (mono) crop combination that performs best under worst climatic conditions is determined. Then, all crop combinations which meet the production stability constraint, i.e. fall within a tolerable neighborhood of the best performing crop, are considered in the final selection. Finally, among all qualifying crops, the crop type that maximizes the weighted sum of extents in land suitability classes C1 to C4 is selected as describing the cell's arable land potential. Suitable extents of the primary crop type in the chosen crop combination, i.e. the first crop to be grown in the sequential cropping pattern, are recorded in the relevant totals of arable land resources.

The estimates of arable land have been grouped according to four broad climatic zones: the arid zone, areas inventoried with mean total dominant length of growing periods less than 120 days, the semi-arid zone, comprising of areas with LGPs of 120 to 179 days, the sub-humid zone, referring to LGPs in the range of 180 to 270 days, and a humid zone, where growing periods exceed 270 days. For information, the sum total of all land resources inventory records processed is also included in the table. Total arable land is then expressed as percentage of total zone area, as a relative measure of quality of land in the zone.

From the coded information contained in a land inventory record it is possible to identify the respective grid raster points 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 will refer to the same set of grid points. Therefore, the results to be transferred to the GIS must be aggregated to average values per raster point. Aggregation of crop suitability assessment by agro-ecological cell to GIS raster points (100 ha each) has produced the results shown in Figure 3.1, for crops, Figure 3.2, for pastures, and Figure 3.3, for fuelwood species. Similar maps can be produced for each crop type in the study.

**FIGURE 3.1**  
**Generalized land suitability for rainfed crop production**

