AGRO-ECOLOGICAL ZONES ASSESSMENTS

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Contents

Summary

This chapter presents a summary of the methodology and results of a comprehensive global assessment of the world's agricultural ecology. The national-level information with global coverage enables knowledge-based decisions for sustainable agricultural development.

The Agro-ecological Zones approach is a GIS-based modeling framework that combines land evaluation methods with socioeconomic and multiple-criteria analysis to evaluate spatial and dynamic aspects of agriculture.

The results of the Global AEZ assessment are estimated by grid cell and aggregated to national, regional, and global levels. They include identification of areas with specific climate, soil, and terrain constraints to crop production; estimation of the extent and productivity of rain-fed and irrigated cultivable land and potential for expansion; quantification of cultivation potential of land currently in forest ecosystems; and impacts of climate change on food production, geographical shifts of cultivable land.

1. Background

The Food and Agriculture Organization of the United Nations (FAO), in collaboration with the International Institute for Applied Systems Analysis (IIASA), has developed the Agro-ecological Zones (AEZ) methodology (FAO 1978-81, FAO/IIASA/UNFPA, 1982) and a worldwide spatial land resources database. Together this enables an evaluation of biophysical limitations and production potential of major food and fiber crops under various levels of inputs and management conditions.

When evaluating the performance of alternative types of land use, a single criterion function often does not adequately reflect the decision-maker's preferences, which are of a multiple-objective nature in many practical problems dealing with resources planning. Therefore, interactive multiple-criteria model analysis has been introduced and applied to the analysis of AEZ models. It is at this level of analysis that socioeconomic considerations can effectively be taken into account, thus providing a spatial and integrated ecological–economic planning approach to sustainable agricultural development.

Future land uses and agricultural production are not known with certainty. For example, what will be the availability and adoption of agricultural technology for various crops in the future? What new genetic crop varieties will be available? How will climate change affect crop areas and productivity? A scenario approach based on a range of assumptions related to such changes in the future enables assessments and a distribution of outcomes that facilitate policy considerations and decision making in the face of future uncertainty.

The AEZ approach, estimated by grid cell and aggregated to national, regional, and global coverage, provides the basis for several applications. These include the following:

- Identification of areas with specific climate, soil, and terrain constraints to crop production.
- Estimation of the extent of rain-fed and irrigated cultivable land and potential for expansion.
- Quantification of crop productivity under the assumptions of three levels of farming technology and management.
- Evaluation of land in forest ecosystems with cultivation potential for food crops.
- Regional impact and geographical shifts of agricultural land and productivity potentials and implications for food security resulting from climate change and variability.

A complete description of the methodology, as well as results detailed for regions across the globe, can be found in the IIASA/FAO CD-ROM application (Fischer *et al*, 2000) and IIASA's Research Report on Global Agro-ecological Assessment - Methodology and Results (Fischer *et al*, 2001, 2002).

2. Methodology

The AEZ methodology follows an environmental approach: it provides a standardized framework for the characterization of climate, soil, and terrain conditions relevant to agricultural production. Crop modeling and environmental matching procedures are used to identify crop-specific environmental limitations under assumed levels of inputs and management conditions. The elements involved in the AEZ framework are described in Figure 1.

FAO's Digital Soil Map of the World (FAO, 1995) has been made the reference for constructing a land surface database consisting of more than 2.2 million grid cells at 5-minute latitude/longitude within a raster of 2160 rows and 4320 columns. On the input side (Figure 1), the key components of the database applied in the AEZ methodology include the following:

- The FAO Digital Soil Map of the World and linked soil association and attribute databases.
- The Global 30 arc-second Digital Elevation Model (EROS Data Center, 1998) was used for elevation and the derived slope distribution database.
- The global climate data set of the Climate Research Unit of the University of East Anglia (CRU) consisting of average data (for the period from 1961 to 1990) and data for individual years from 1901 to 1996 (New *et al*, 1998).
- A layer providing distributions in terms of 11 aggregate land-cover classes derived from a global 1-kilometer land-cover data set (EROS Data Center, 2000).

The AEZ global land resources database also incorporates spatial delineation and accounting of forest and protected areas. A global population data set for the year 1995 provides estimates of population distribution and densities at a spatially explicit sub-national level for each country.

On the output side, numerous new data sets have been compiled at the grid-cell level and tabulated at the national and regional levels. Outputs include: (1) agro-climatic characterizations of temperature and moisture profiles, and (2) time series of attainable crop yields for all major food and fiber crops.

The AEZ methodology considers the contribution of multiple cropping to land productivity on the basis of the evaluation of thermal and moisture profiles in a grid cell for determination of agronomically meaningful sequential crop combinations.

The AEZ framework incorporates the following basic elements:

- Selected agricultural production systems with defined input and management relationships, and crop-specific environmental requirements and adaptability characteristics. These are termed "land utilization types" (LUTs). The AEZ study distinguishes some 154 crops, fodder, and pasture LUTs, each at three levels of inputs and management (high, intermediate, low).
- Geo-referenced climate, soil, and terrain data, which are combined into a land resources database. The computerized global AEZ database contains some 2.2 million grid cells.

- Accounting for spatial land use and land cover, including forests, protected areas, population distribution and density, and land required for habitation and infrastructure.
- Procedures for calculating the potential agronomically attainable yield and for matching crop and LUT environmental requirements with the respective environmental characteristics contained in the land resources database, by land unit and grid cell.
- Assessment of crop suitability and land productivity of cropping systems.
- Applications for estimating the land's population supporting capacity, multiple-criteria optimization incorporating socioeconomic and demographic factors of land resource use for sustainable agricultural development.

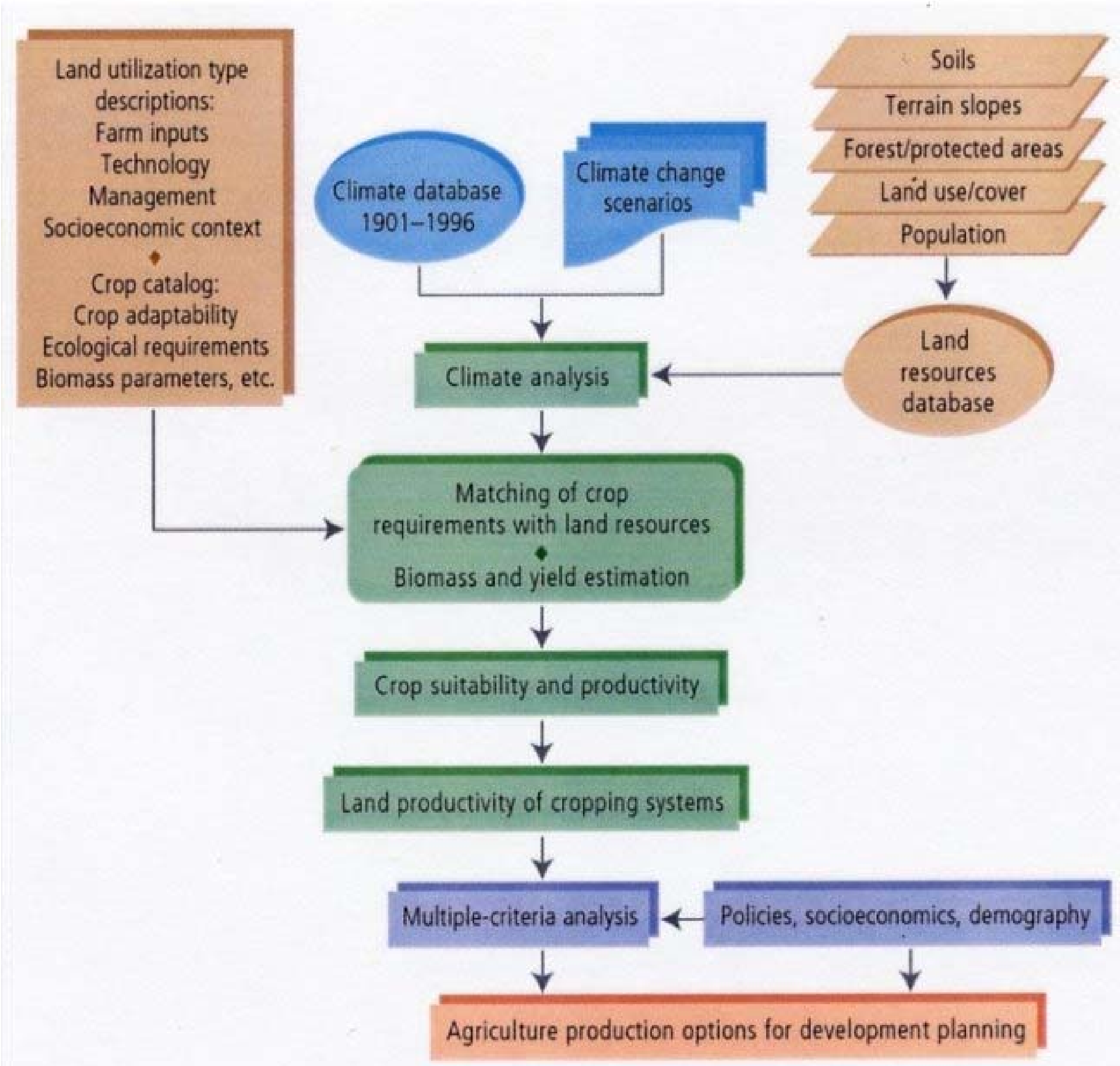

Figure 1. Agro-Ecological Zones (AEZ) methodology.

The AEZ assessments were carried out for a range of climatic conditions, including a reference climate with data on individual historical years, as well as scenarios of a future climate based on various global climate models. Farming technology was considered at three levels: a high level of inputs with advanced management, an intermediate level with improved management, and a low level of inputs with traditional management (Table 1). Hence, the results quantify the impacts on land productivity of both historical climate variability and potential future climate change.

3. Findings

The AEZ results (Fischer *et al*, 2001a) indicate that, at the global level, Earth's land, climate, and biological resources are ample to meet food and fiber needs of future generations, in particular, for a world population of 9.3 billion, as projected in the United Nations medium variant for the year 2050 (United Nations, 1998). Despite this positive aggregate global picture, however, there are reasons for profound concern in several regions and countries with limited land and water resources.

Intensity level	**Characteristics**
HIGH LEVEL OF INPUTS/ADVANCED MANAGEMENT	Production is based on improved high-yielding varieties and is mechanized with low labor intensity. It uses optimum applications of nutrients; chemical pest, disease, and weed control; and full conservation measures. The farming system is mainly market oriented.
INTERMEDIATE LEVEL OF INPUTS/IMPROVED MANAGEMENT	Production is based on improved varieties and on manual labor and/or animal traction and some mechanization. It uses some fertilizer application and chemical pest, disease, and weed control, and employs adequate fallow periods and some conservation measures. The farming system is partly market oriented.
LOW LEVEL OF INPUTS/TRADITIONAL MANAGEMENT	Production is based on the use of traditional cultivars (if improved cultivars are used, they are treated in the same way as local cultivars) and labor-intensive techniques, with no application of nutrients. It uses no chemicals for pest and disease control and employs adequate fallow periods and minimum conservation measures. The farming system is largely subsistence based.

Table 1. Farming technology.

Socioeconomic development will inevitably infringe on the current and potential agricultural land resource base, as the need to expand industrial, infrastructure, and habitation land use increases. Furthermore, global environmental changes, particularly climate change, are likely to alter the conditions and distribution of land suitability and crop productivity in several countries and regions.

The presentation of results is organized as follows:

- Climate, soil, and terrain limitations to crop production.
- Land with cultivation potential.
- Potential for expansion of cultivated land.
- Cultivation potential in forest ecosystems.
- Yield and production potentials.
- Temperature and rainfall sensitivity.

It should be noted that the AEZ results have been aggregated to the national, regional, and global levels. Furthermore, the farming technology and input assumptions are based on present-day knowledge. Research and scientific developments in the future could alter the projection outcomes.

3.1. Climate, Soil and Terrain Limitations to Crop Production

Climate constraints are classified according to the length of periods with cold temperatures and moisture limitations. Temperature constraints are related to the length of the temperature growing period, i.e. the number of days with a mean daily temperature above 5 °C. For example, a temperature growing period shorter than 120 days is considered a severe constraint, while a period shorter than 180 days is considered to pose moderate constraints to crop production. Hyper-arid and arid moisture regimes are considered severe constraints, and dry semi-arid moisture regimes are considered moderate constraints.

Soil constraints are classified into moderate and severe limitations imposed by soil depth, fertility, and drainage; soil texture/structure/stoniness; and specific soil chemical conditions. Limitations imposed by terrain slope have been classified similarly. The extent of land with climate and soil/terrain constraints is shown in Figure 2.

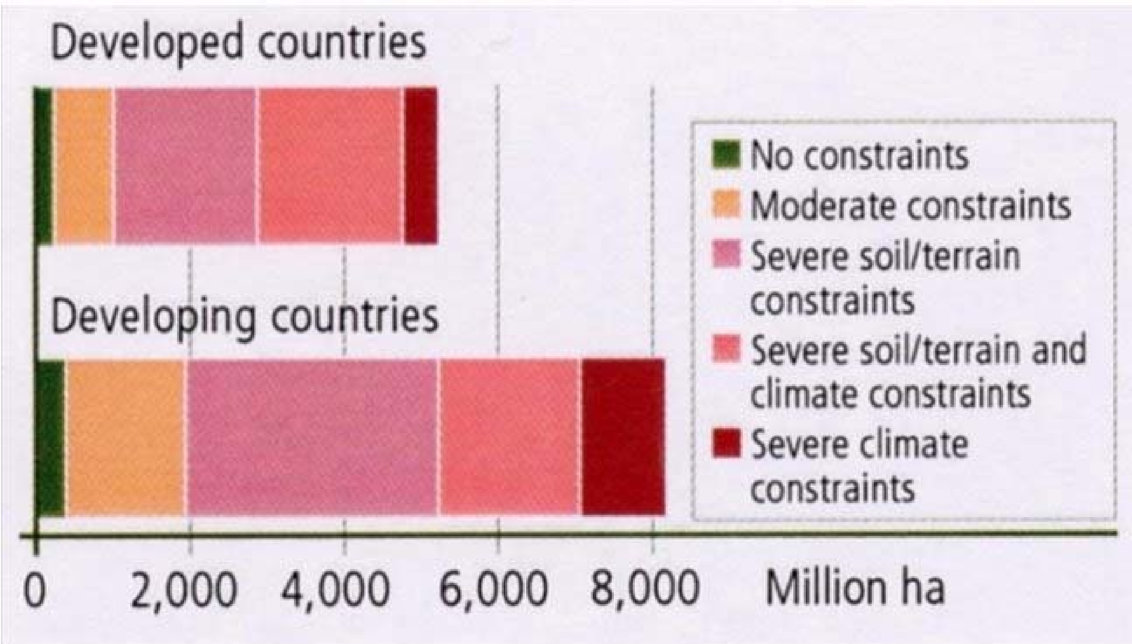

Figure 2. Extent of land with climate and soil/terrain constraints.

On the basis of currently available global soil, terrain, and climate data, the AEZ estimates indicate that 10.5 billion hectares (ha) of land—more than three-quarters of the global land surface, excluding Antarctica—suffer rather severe constraints for rain-fed crop cultivation. Some 13% of the surface is too cold, 27% is too dry, 12% is too steep, and about 65% is constrained by unfavorable soil conditions, with multiple constraints coinciding in some locations. Figure 3 shows the distribution of land constraints by region, and Figure 4 portrays the situation worldwide.

At the global level, almost 40% of the soils suffer from severe fertility constraints and about 6% are affected by limitations resulting from salinity, sodicity, or gypsum constraints. The respective regional figures are 43% and 1% for North America; 46% and 5% for South and Central America; 56% and 4% for Europe and Russia; 30% and 3% for Africa; 28% and 11% for Asia; and 31% and 18% for Oceania.

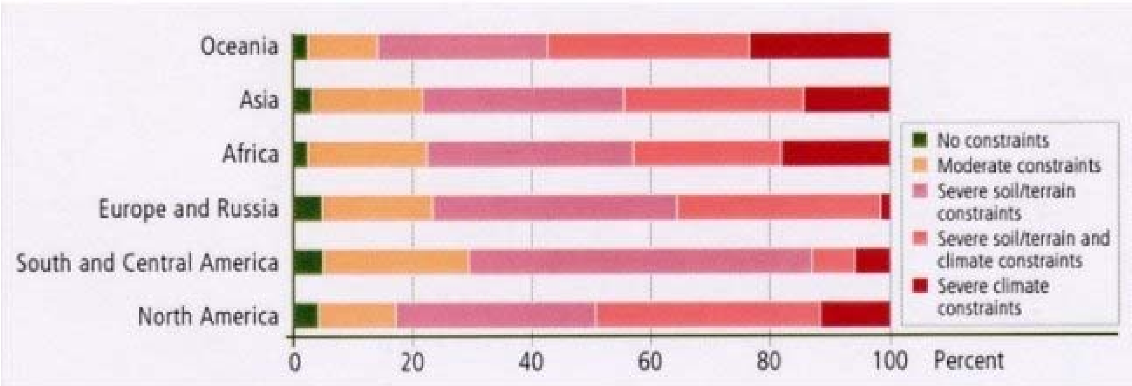

Figure 3. Distribution of climate and soil/terrain constraints by region.

Climate change is likely to have both positive and negative effects on extent and productivity of arable land resources. In some areas, prevailing constraints may be somewhat relieved by climate change, thus increasing the arable land resources. In other areas, however, currently cultivated land may become unsuitable for agricultural production.

The extent to which specific constraints like low fertility and toxicity can be overcome will also depend on the outcomes of agricultural and scientific research. For example, agricultural research in Mexico has resulted in the application of biotechnology to increase plant tolerance to aluminum, thus countering soil toxicity problems common in some tropical areas.

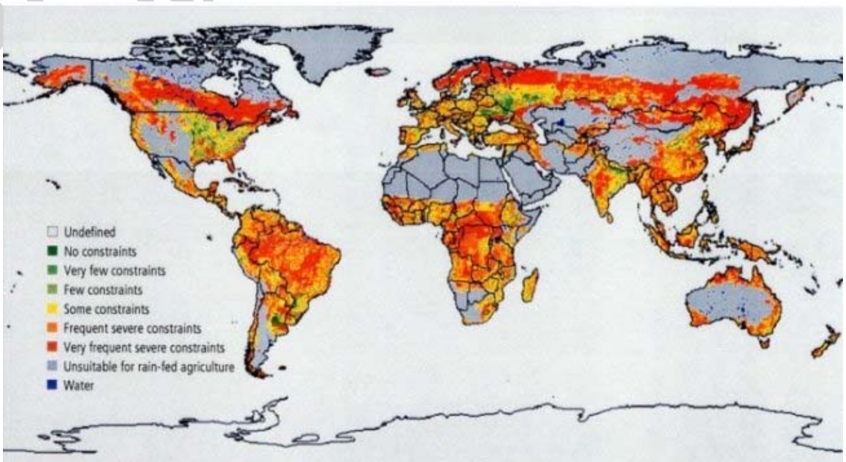

Figure 4. Climate and soil/terrain constraints combined at worldwide level.

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Biographical Sketches

Günther Fischer is a senior scientist at the International Institute for Applied Systems Analysis (IIASA), leading a major research project on *Modelling Land Use and Land Cover Changes (LUC)*, developing a GIS-based modelling framework, which combines economic theory and advanced mathematical methods with biophysical land evaluation approaches to model spatial and dynamic aspects of land and water use. Since 1980 he has been collaborating with FAO on the development, implementation and application of the AEZ methodology to global, national and regional resource appraisals for decision support.

Mahendra Shah specializes in sustainable development, economic planning, and emergency relief operations. He was special advisor to UNCED and prepared the Earth Summit report "The Global Partnership for Environment and Development - A Guide to Agenda 21". Shah also served as Executive Secretary of the CGIAR system review and co-authored with Maurice Strong, "Food in the 21st century―from Science to Sustainable Agriculture". Shah joined IIASA as a senior scientist in January 2001 to work on climate change and agricultural vulnerability. He is also the coordinator of IIASA―UN relations.

Harrij van Velthuizen is land resources ecologist and specialist in agro-ecological zoning. He was member of the working group that developed FAO's agro-ecological zones (AEZ) methodology. With support of FAO he initiated, in 1995, at IIASA the Global AEZ study. In 2001, he joined IIASA's *Modeling Land Use and Land Cover Changes (LUC)* project, to focus on expanding and enhancing AEZ models and applications.

Freddy Nachtergaele is a Doctor in agronomy who has been working for the Food and Agriculture Organization of the United Nations in Rome as a Technical Officer for Soil Resources and Land Classification with the Land and Water Development Division since 1989. Prior to that he was a land resources expert for FAO in field projects in North and East Africa and in Southeast Asia. He is co-author of the Global Agro-ecological Zones study, vice-Chairman of the IUSS working group on the World Reference Base for Soil Resources, and he coordinates the update of the FAO/UNESCO Soil Map of the World at FAO under the Global SOTER programme. He is the author of numerous scientific articles in the field of agro-ecological zoning, land evaluation, land-use planning and soil classification.