The cover art is a composite image. On the left, a person's silhouette is shown pouring soil from a dark container into a large, glowing blue globe that has a motion blur effect. The globe is positioned over a green field of crops. The background is a light beige color with a vertical grey bar on the left side containing horizontal white lines.

Global Agro-ecological Assessment for Agriculture in the 21st Century



ER-01-1
July 2001

Global Agro-ecological Assessment for Agriculture in the 21st Century

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Abstract

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This report 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, and implications for food security.

Key findings

- ◆ More than three-quarters of the global land surface is unsuitable for crop cultivation, suffering severe constraints of being too cold (13%), too dry (27%), or too steep (12%), or having poor soils (40%). Also, multiple constraints occur in some locations.
- ◆ Cultivable land in developing countries totals about 1.8 billion hectares (ha), of which some 20% is only moderately suitable for crop cultivation. At present, over 900 million ha of this land is under cultivation. The corresponding figures for the developed countries are 765 million ha of cultivable land, 35% of which is only moderately suitable, and 595 million ha under cultivation at present.
- ◆ Over 80% of potentially cultivable land reserves are located in just two regions, South America and sub-Saharan Africa. In contrast, most of the cultivable land in Asia is already in use, and the population increase expected by 2050 will reduce per capita availability of cultivable land to below the critical level of 0.1 ha per person.
- ◆ In both the developed and developing worlds, some 1.4 billion ha constitute forest ecosystems, of which 12% and 30%, respectively, have good potential for crop cultivation. However, cultivation in these forest areas would result in severe environmental consequences.
- ◆ Intensification of agriculture will be the most likely means to meet food needs for a world population of some 9.3 billion people in 2050. The study asserts that enough food can be produced on currently cultivated land if sustainable

management principles and adequate inputs are applied. However, this will require substantial improvements of socioeconomic conditions in many developing countries to enable access to inputs and technology.

- ◆ The projected climate change will result in mixed and geographically varying impacts on crop production. About half the developing countries will gain, while the other half will lose. In some 40 poor developing countries with a combined current population of 2 billion, including 450 million undernourished people, climate change production losses may drastically increase the number of undernourished, severely hindering progress against poverty and food insecurity.

Background

In the coming decades of this millennium, the world community of nations will face an enormous challenge concerning food security, environmental conservation, and preservation of genetic resources.

The need for food for an increasing population often threatens natural resources as people strive to get the most out of land already in production or push into virgin territory for new agricultural land. The damage is increasingly evident: water shortages; arable lands lost to erosion, salinity, desertification, and urban spread; disappearing forests; and threats to biodiversity. The situation is likely to be further worsened by the potential impacts of global warming and climate change on growing conditions. Hence, sustainable agricultural development is not just an option, it is an imperative in a world of interdependence, interpenetration, and reciprocity.

Between now and the year 2050, the world's population will most likely increase by some three billion people. Almost all of this growth will occur in developing countries. Currently, some 800 million people go hungry every day and over a billion live on less than US\$1 per day. If no progress is made against hunger, by the year 2050, half the world's population of some nine billion could be living in conditions of malnutrition and extreme poverty.

Thirty years ago, the world faced a global food shortage that experts predicted would lead to catastrophic famines. That danger was averted because an intensive international research effort enabled scientists to develop and farmers to adopt high-yielding varieties of major food crops. This "green revolution" was most effective where soils were fertile and water was plentiful. It also entailed extensive use of fertilizers and pesticides. The lessons learned from this experience indicate that such a strategy may not be biologically, environmentally, or socially viable in the future.

Given the complex and interlinked components of the food security challenge in the 21st century, it is clear that solutions that deal with one part only—for example, crop productivity, land use, water conservation, or forest protection—will not be sufficient. The issues are connected and must be dealt with as an interlinked holistic system to ensure sustainable management of natural resources.

Each country must assign the highest priority to the assessment of land, water, and climate resources and create an integrated spatial information system to apply the best of science, technology, and knowledge for sustainable agricultural development through effective public and private policies and education.



Land is indispensable for many essential human activities: it provides the basis for agriculture and forest production, biodiversity and wildlife habitat, purification and catchment of water, recreation, and settlement. Land also plays a role in climate regulation mechanisms. Agricultural land uses provide for sequestration of carbon in the soil; at the same time, agricultural activities emit a variety of greenhouse gases that contribute to increased ozone pollution, acid rain, global warming, and reduction of stratospheric ozone.

The range of uses that can be made of land for primary human needs is limited by environmental factors, including climate, topography, and soil characteristics. Uses are to a large extent determined by agronomic viability and level of farm technology and management, as well as demographic, socioeconomic, cultural, and political factors (e.g., population density, land tenure, markets, institutions, and agricultural policies).



*Sustainable agricultural development,
not just an option but an imperative.*

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 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, 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:

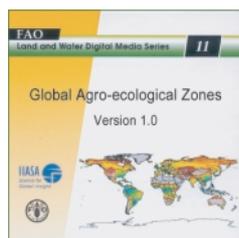
- ◆ Identification of areas with specific climate
- ◆ Soil and terrain constraints to crop production
- ◆ Estimation of the extent of rain-fed and irrigated cultivable land and potential for expansion
- ◆ Quantification of crop productivity under the assumptions of three levels of farming technology 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 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 FAO/IIASA CD-ROM application and IIASA's Research Report on Global Agro-ecological Zones.

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.

The FAO/UNESCO Digital Soil Map of the World (DSMW) has been made the reference for constructing a land surface database consisting of more than 2.2 million grid cells at 5' latitude/longitude within a raster of 2,160 rows and 4,320 columns.



Global Agro-ecological Zones

Environmental resources database including climate, soil, terrain, and land cover comprising 2.2 million grid cells, assessing the agricultural potential of 28 crops at three levels of farming technology.

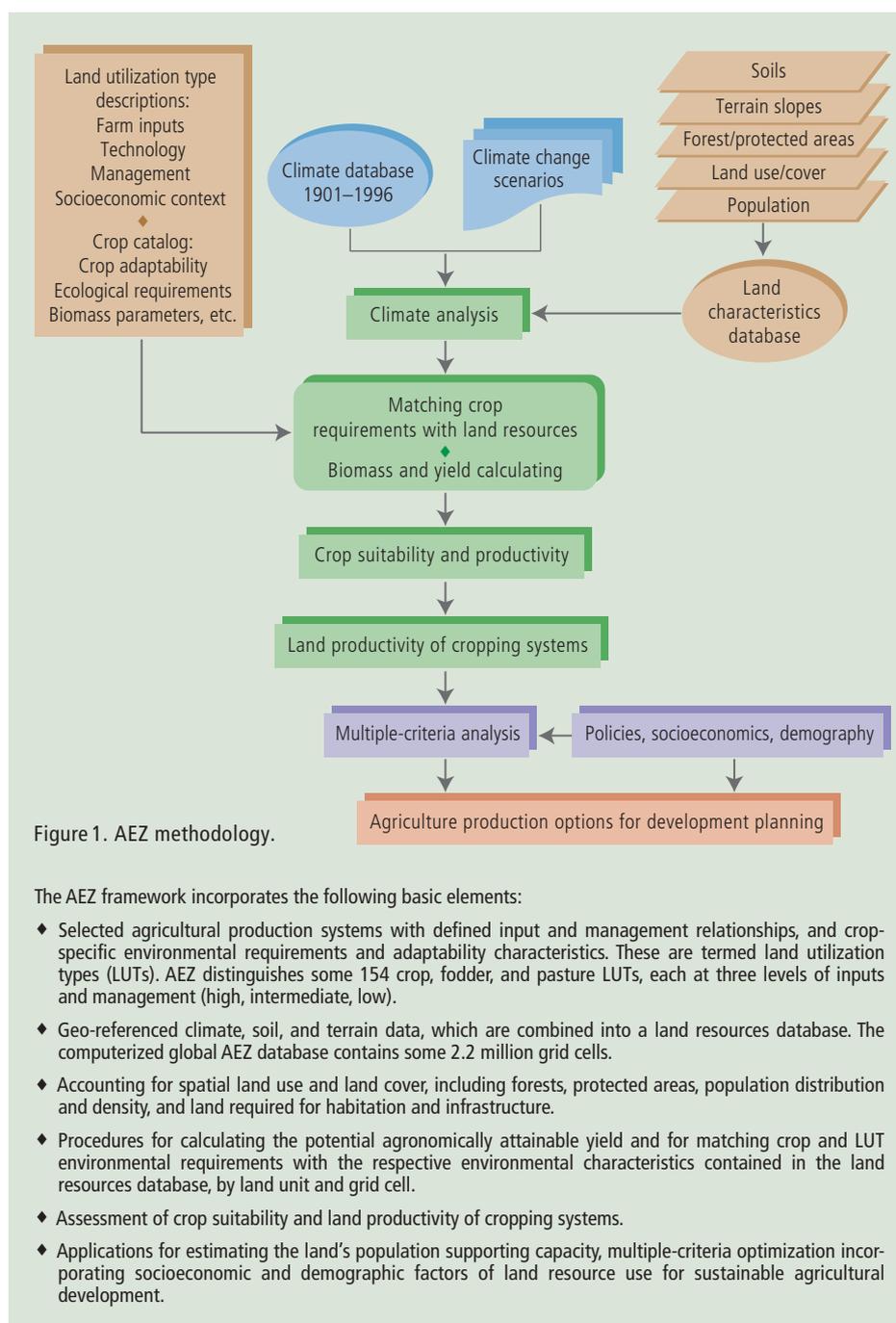
On the input side (see Figure 1), the key components of the database applied in AEZ include the following:

- ◆ The FAO DSMW and linked soil association and attribute tables
- ◆ A global elevation and derived slope distribution database
- ◆ The global climate data set of the Climate Research Unit of the University of East Anglia consisting of average data (the period from 1961 to 1990) and data for individual years from 1901 to 1996
- ◆ A layer providing distributions in terms of 11 aggregate land-cover classes derived from a global 1-kilometer land-cover data set.

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 subnational 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 the following:

- ◆ Agro-climatic characterizations of temperature and moisture profiles
- ◆ 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.

Box 1. Farming technology.

High-level inputs/advanced management

Production is based on improved high-yielding varieties and is fully 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. Commercial production is a guiding management objective.

Intermediate-level 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. Production for subsistence plus commercial sale is a management objective.

Low-level 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 and not necessarily market oriented.

The AEZ assessments were carried out for a range of climatic conditions, including a reference climate, individual historical years, and scenarios of 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 of inputs with improved management, and a low level of inputs with traditional management (see Box 1). Hence, the results quantify the impacts on land productivity of both historical climate variability and potential future climate change.

Findings

The AEZ results 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. Despite this positive aggregate global picture, however, there are reasons for profound concern in several regions and countries with limited productive land resources.

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
- ◆ Irrigation impact on crop production
- ◆ Climate change and food production
- ◆ Population change and arable land

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.

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, that is, 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.



*Environmental constraints exclude
three-quarters of global land from crop agriculture:
too cold, too dry or steep, and poor soils.*

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; Figure 4 portrays the situation worldwide.

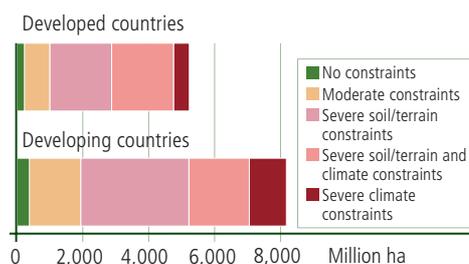


Figure 2. Extent of land with climate and soil/terrain constraints.

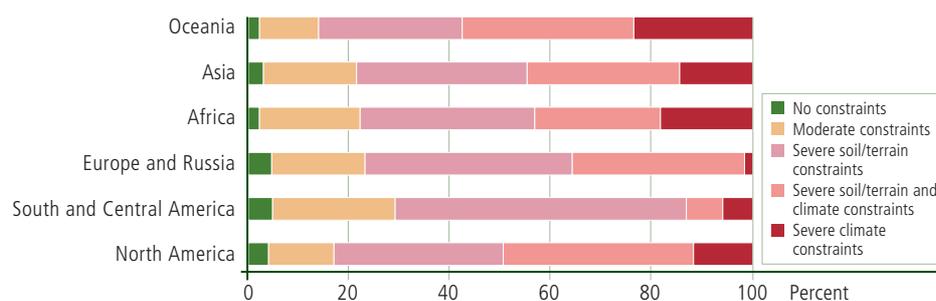
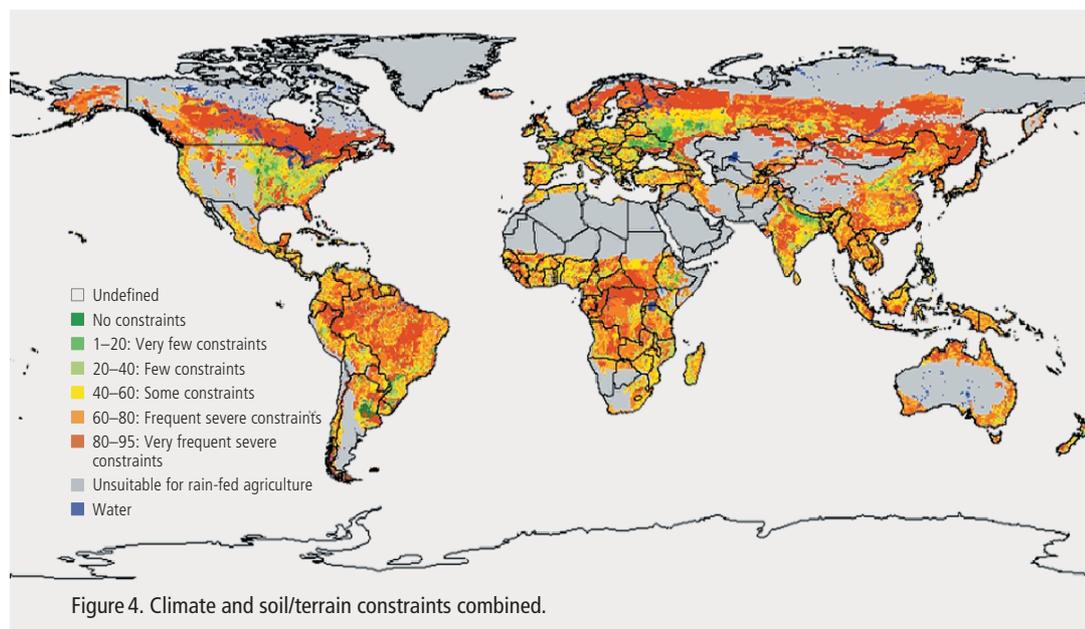


Figure 3. Distribution of climate and soil/terrain constraints by region.

At the global level, almost 40% of the soils suffer 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.



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 aluminium, thus countering soil toxicity problems common in some tropical areas.



Land with cultivation potential

There are various ways to estimate the extent of land with cultivation potential for rain-fed crops. Any quantification depends on a variety of assumptions concerning the range of crop types considered; the definition of what level of output qualifies as acceptable; and the social acceptance of land-cover conversions (of forests in particular) and what land constraints may be alleviated with farming technology, management, and investment.

The AEZ assessment considers a total of 24 crop species, two pasture types, and two fodder crops. Altogether, 154 crop/land utilization types are considered, each at three defined levels of inputs and management.

The results of the estimation of extent of land with cultivation potential for major crops show that at the global level about 2.7 billion ha are suitable for cereal cultivation with high-level inputs and management, and about three-quarters of this land is very suitable or suitable. The land area suitable for roots & tubers and pulses is some 30% to 40% smaller than that suitable for cereal (see Table 1).

Table 1 also shows that the cultivable land for each of these major crop groups is reduced by 10% to 20% at the intermediate level of inputs compared with the high level of inputs. The exclusion of land that is in forest ecosystems and land used for settlement and infrastructure would further reduce the cultivable land area for each of these crop groups by a similar proportion.



*Potential agricultural land
is ample to meet future world food needs,
but profound concern exists
for many countries with land and water scarcity.*

It should be emphasized that these results indicate the potential area suitable for each of these individual crop groups. In reality, the demand mix for domestic consumption and trade will drive allocation to particular crops.

The total extent of potential rain-fed land is estimated for each grid cell. When considering all modeled Global AEZ crop types excluding silage maize, forage

Table 1. Extent of land with rain-fed cultivation potential for major crop groups (million ha).

Level of inputs	Suitability of land	Cereals	Roots & tubers	Pulses	Oil crops	Sugar crops	Cotton
High	VS+S	2,000	1,145	1,050	1,495	535	440
	VS+S+MS	2,725	1,865	1,720	2,410	1,150	755
Intermediate	VS+S	1,590	795	725	1,105	385	280
	VS+S+MS	2,500	1,515	1,495	2,035	900	580
Intermediate, excluding forests, land for settlement and infrastructure	VS+S	1,255	595	645	890	270	270
	VS+S+MS	1,960	1,130	1,255	1,585	595	550

Note: VS=very suitable; S=suitable; MS=moderately suitable.

legumes, and grasses, mixing all three input levels, and assuming no restrictions for land-cover conversion, the results show that about one-quarter of the global land surface, excluding Antarctica, can be regarded as potentially suitable for crop cultivation.

The total extent of land suitable for at least one crop amounts to some 3.3 billion ha. Of this, about 23% are in land classified as forest ecosystems. If only the very suitable and suitable land area is considered, then the corresponding extent of land is 2.5 billion ha, with some 24% in forest ecosystems (see Table 2).

In developed countries, about one-fifth of the total land has rain-fed cultivation potential. In developing countries, this proportion is slightly less than 30%. The estimate of cultivable rain-fed land potential is more than twice the area reported by the FAO as land actually in use for cultivation in 1994–1996. These AEZ estimates are high, since all land suitable for at least one crop is included in the assessment and crop choice is not constrained by current demand mix. Figure 5 displays the land suitable for rain-fed crops across the world.

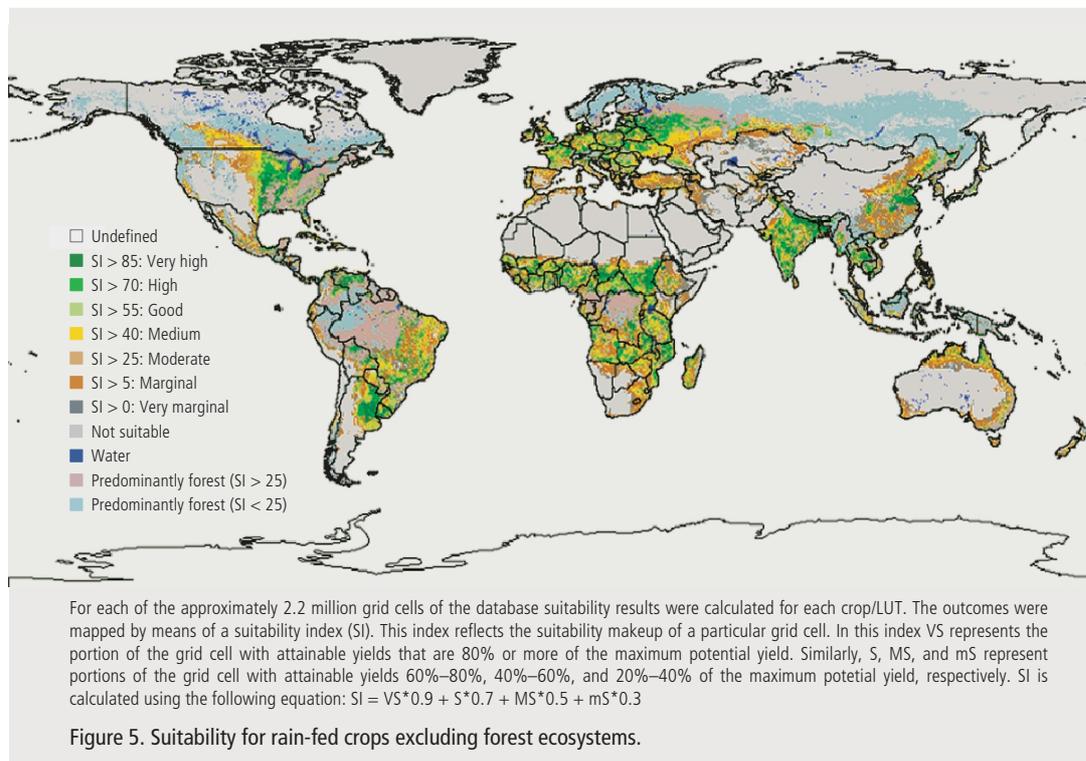
The results highlight that in Asia, Europe, and Russia, the rain-fed land that is currently cultivated amounts to about 90% of the potential very suitable and suitable land. Hence there is little room for agricultural extensification. In the case of North America, some 75% of the very suitable and suitable land is currently under cultivation. By contrast, Africa and Latin America are



Table 2. Rain-fed cultivated land in 1994–1996 and rain-fed cultivation potential for major food and fiber crops, mixed inputs (million ha).

Region	Total land	Cultivated land, 1994–1996		Land with cultivation potential				Settlements and infrastructure
				VS+S		VS+S+MS		
				Total	In forest ecosystems	Total	In forest ecosystems	
Oceania	850	50	3	76	12	116	17	1
Asia	3,113	376	180	406	36	516	47	83
Africa	2,990	185	12	767	114	939	132	26
Europe & Russia	2,259	289	25	328	61	511	97	21
South & Central America	2,049	141	18	697	281	858	346	16
North America	2,138	203	22	266	96	384	135	9
<i>Developing countries</i>	8,171	702	208	1,872	433	2,313	527	124
<i>Developed countries</i>	5,228	543	53	669	168	1,012	247	33
<i>World</i>	13,400	1,245	260	2,541	601	3,325	774	156

Note: VS=very suitable; S=suitable; MS=moderately suitable.



estimated to have some 1.1 billion ha of land in excess of currently cultivated land; of this, about 36% is in forest ecosystems. In these two regions there is clearly scope for further expansion of agricultural land, even assuming that current forests are maintained.

Potential for expansion of cultivated land

Despite the fact that currently reported cultivated land in official statistics is likely to underestimate actual use by some 10% to 20% in several developing countries, the



results indicate that there is still a significant potential for expansion of cultivated land in Africa and South and Central America (see Figure 6a). More than 70% of additional cultivable (very suitable, suitable, and moderately suitable) land is located in these two regions, and about half of this land is concentrated in just seven countries—Angola, Democratic Republic of Congo, Sudan, Argentina, Bolivia, Brazil, and Colombia.

In other regions, this potential is either very limited, as in Asia, or is unlikely to be used for agriculture in the future, as in Europe and Russia, North America, and Oceania (see Figure 6b).



*Major land expansion is possible in Africa and South America,
but with substantial environmental and development costs.*

Agronomic suitability is by no means the only determinant of future land development. The potential expansion of cultivable land will be limited by the constraints of ecological fragility, degradation, toxicity, and incidences of diseases, as well as by a lack of financial resources and infrastructure. These issues will need to be explicitly considered in agricultural extensification at the national level.

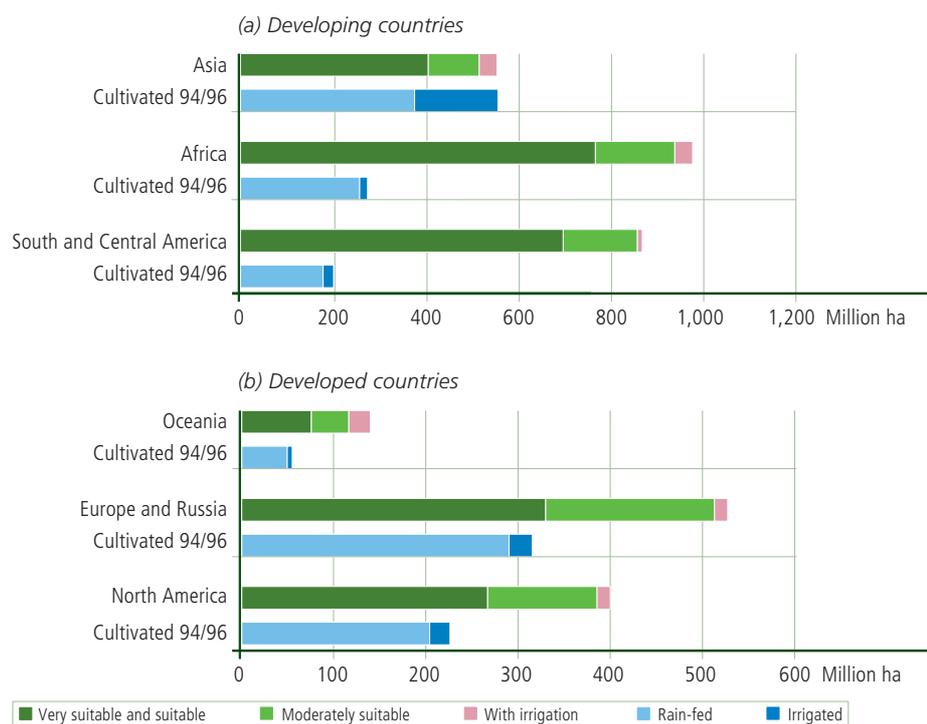


Figure 6. Comparison of land with crop production potential and land used for cultivation in 1994–1996 .

Cultivation potential in forest ecosystems

The FAO Global Forest Resource Assessment 2000 estimates land area currently in forest ecosystems to be 3.9 billion ha, occupying some 29% of the world's land area. Closed, open, and plantation forests amount to 3.4 billion ha, 445 million ha, and 65 million ha, respectively.

Russia and Brazil, which account for 19% of the total land area and 5.2% of the world population, have 36% of the global forest areas. The USA and Canada have some 470 million ha of forest, equivalent to 12% of the global forest areas. China, Australia, the Democratic Republic of Congo, and Indonesia account for a further 15% of forestland. These eight countries account for more than 60% of the total forest area in the world.

During the past decade, 127 million ha of the world's forest areas were cleared, while some 36 million ha of forest were replanted. China reported replanting about

50% of this gain. Europe, Russia, and the USA accounted for 24% of it. But Africa lost about 53 million ha of forest during this period.

The loss of forestland in most countries is primarily due to the expansion of crop cultivation. In some areas this is the result of population pressure for more arable land. In other places, like Brazil, commercial agriculture and livestock production are encroaching on forestland. Commercial logging of timber has also contributed to loss of forestland.



*Although forestland in some regions
has significant potential for crop cultivation,
environmental consequences of forest clearance would be serious:
loss of biodiversity and disruption of carbon sinks,
hydrological cycles, and fragile ecosystems.*

In the AEZ assessment, the cereal cultivation potential in forest areas reveals that some 470 million ha of land with cultivation potential for wheat, rice, or maize coincide with land classified as predominantly forest ecosystems, and this accounts for some 19% of land suitable for at least one of the three cereals (see Table 3 and Figure 7).

Rather wide variations occur between regions. In Russia, for example, less than 9% of the land predominantly in forest ecosystems was assessed to have cultivation potential for cereal crops. Yet, this equates to about a quarter of Russia's land with rain-fed cultivation potential. In South America, these figures are 27% and 35%, respectively, and in North America they are 20% and 39%, respectively.

Table 3. Land with rain-fed cultivation potential for wheat, rice, or maize in forest ecosystems (million ha).

Region	Total land	Total land in forest ecosystems	Land with rain-fed cultivation potential			
			VS+S		VS+S+MS	
			Total	In forest ecosystems	Total	In forest ecosystems
Oceania	850	72	44	7	73	11
Asia	3,113	388	263	14	384	25
Africa	2,990	246	404	25	592	43
Europe & Russia	2,259	761	282	41	463	76
South & Central America	2,049	751	283	128	474	200
North America	2,138	562	235	82	342	115
<i>Developing countries</i>	8,171	1,405	1,076	166	1,574	266
<i>Developed countries</i>	5,228	1,381	565	132	884	204
<i>World</i>	13,400	2,786	1,612	298	2,429	470

Note: VS=very suitable; S=suitable; MS=moderately suitable.

Considering only the most suitable land in forest ecosystems, about 298 million ha are classified as very suitable or suitable for cultivation of wheat, rice, or maize with mixed levels of inputs. About 44% of this land is located in South and Central America, and altogether some 56% is located in the developing countries.

The spatially quantified information on the productive value of forest areas in terms of (1) potential values of crop and wood production, (2) the conservation role of forests in watershed management and flood control, and (3) their importance as carbon sinks and as habitats of rich biodiversity is relevant in national considerations concerning the use and conservation of forest areas. These issues need to be central in international negotiations on preservation of regional forest ecosystems in the world.

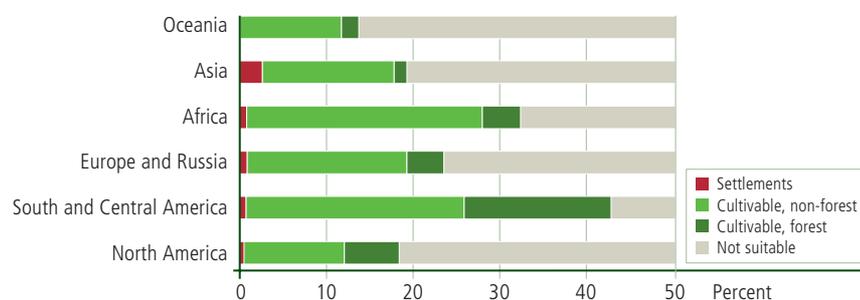


Figure 7. Share of total land suitable for crops, by forest and non-forest area.

Yield and production potentials

The maximum attainable yields in the AEZ assessment (see Table 4) represent average values from simulated year-by-year agro-climatic yields during the period from 1960 to 1996. These yields were calculated for rain-fed and irrigated cultivation in the tropics, subtropics, and temperate/boreal zones.

Table 4. Maximum attainable yields under rain-fed and irrigated conditions (tons/ha).

Input level		Crop		
		Wheat	Rice	Maize
<i>Rain-fed</i>				
Low	Tropics	2.7	5.0	5.1
	Subtropics	4.3	4.7	5.8
	Temperate	4.9	4.9	5.3
Intermediate	Tropics	5.7	7.7	8.5
	Subtropics	8.4	7.3	8.9
	Temperate	8.7	6.9	8.7
High	Tropics	8.5	9.9	12.5
	Subtropics	11.8	9.2	12.3
	Temperate	12.1	8.6	12.1
<i>Irrigated</i>				
Intermediate	Tropics	7.4	9.5	10.5
	Subtropics	10.2	9.9	12.2
	Temperate	9.7	8.7	11.3
High	Tropics	11.1	12.2	15.6
	Subtropics	14.2	12.7	17.1
	Temperate	13.5	10.9	15.7

Long-term yields, also estimated using AEZ procedures, assume that proper cycles of cropping and fallow are respected. At high levels of inputs with balanced fertilizer applications and proper pest and disease management, only limited fallow periods will be required. At low levels of inputs, assuming virtually no application of chemical fertilizer and only limited organic fertilizer, and very limited or no application of biocides, considerable fallow periods are needed in the crop rotations to restore soil nutrient status and to break pest and disease cycles.

The yields attained in the long term, when accounting for fallow period requirements, are well below the estimated short-term maximum attainable yields. Required fallow periods vary with soil and climate conditions. On average, long-term yields are 10%, 20%, and 55% lower than maximum attainable yields at high, intermediate, and low levels of inputs, respectively (see Table 5). It should also be noted that there is a more than threefold increase in short-term attainable yield and a

Table 5. Maximum short-term attainable and long-term sustainable yields for rain-fed wheat, rice, or grain maize averaged over all VS+S+MS land, by region and level of inputs (tons/ha).

Region	Low inputs		Intermediate inputs		High inputs	
	Short-term attainable	Long-term sustainable	Short-term attainable	Long-term sustainable	Short-term attainable	Long-term sustainable
Oceania	0.7	0.4	3.2	2.6	5.3	4.8
Asia	1.1	0.5	3.7	3.0	6.2	5.6
Africa	1.1	0.4	3.8	3.1	6.7	6.0
Europe & Russia	0.9	0.4	3.6	2.9	5.5	5.0
South & Central America	1.2	0.6	3.6	3.0	5.6	5.1
North America	0.8	0.4	3.6	2.8	5.8	5.2
<i>Developing countries</i>	1.1	0.5	3.7	3.0	6.2	5.6
<i>Developed countries</i>	0.9	0.4	3.5	2.8	5.6	5.1
<i>World</i>	1.0	0.5	3.7	3.0	6.0	5.4

Note: VS=very suitable; S=suitable; MS=moderately suitable.

sevenfold increase in long-term attainable yield in all regions as farming technology and management increases from low to intermediate levels of inputs. At the high level of inputs, the yield level increases further—by 60% to 80%. These estimates for low, intermediate, and high levels of inputs reflect present knowledge and technology.

Intensification of agriculture will be the main means to increase production. In many developing countries, provided adequate inputs and improved management are applied, there is considerable scope for increased yields. For example, in the developing countries the 1995–1997 actual yields per ha for wheat averaged about 1.8 tons for rain-fed conditions and 3.1 tons with irrigation, with an overall average of 2.4 tons per ha, compared with 3.1 tons per ha for major developed country exporters.



***Intensification of agriculture
will be the main means to increase food production.
There is considerable scope for increasing crop yields
in developing countries.***

Currently there is a wide variation in the level of inputs (e.g., fertilizer application) across regions. In sub-Saharan Africa, an average of 8 kg of nutrients are applied per ha, whereas in other developing countries the rate is about 80 kg of nutrients per hectare, and in the developed countries over 200 kg of nutrients are applied per hectare. These figures are overall averages and include both rain-fed and irrigated crop

production. There is considerable scope for improved management and use of inputs—particularly of nutrients—in many developing countries, especially in Africa and South America, where the levels of application are low.

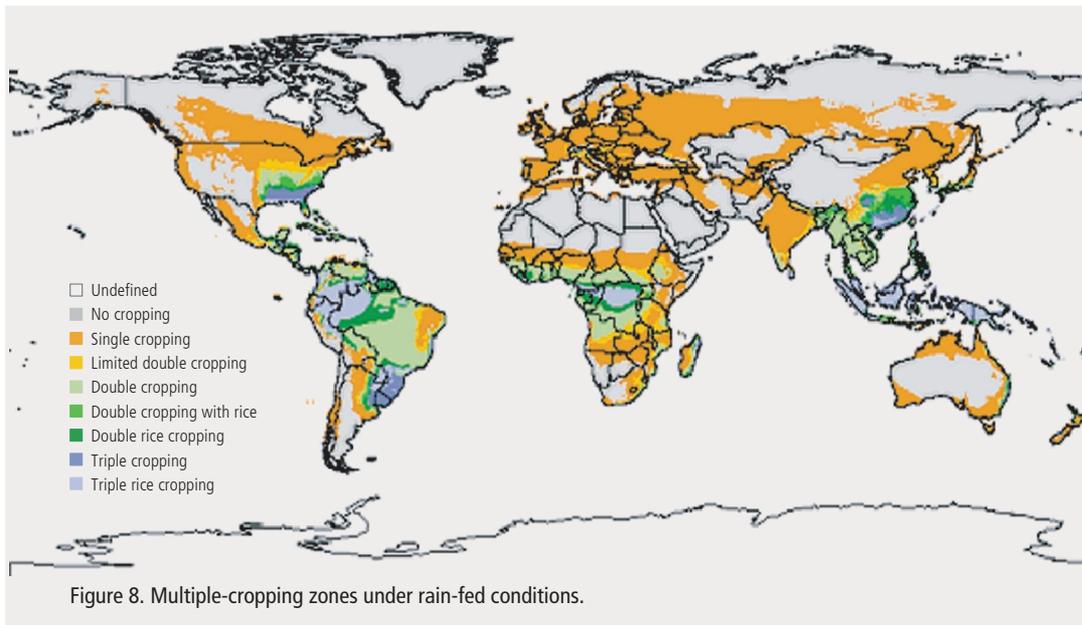
The environmental implications of increasing fertilizer and chemical inputs in the future will have to be taken into account, along with the lessons and experiences from the green revolution. Also, any strategy for increasing food production through intensification must consider the socioeconomic issues of small and resource-poor farmers—in particular, their access to and ability to purchase inputs.

In areas where growing periods are sufficiently long, the AEZ methodology takes into account viable sequential cropping. To perform this estimation, a multiple-cropping zone classification is used to determine feasible crop combinations. The algorithms



used for constructing cropping patterns have been designed to ensure that typical crop sequences in cultivation cycles are used. For instance, in the typical double-cropping areas around Shanghai, rice or maize was selected as the most productive summer crop, and wheat or barley was chosen as the winter crop. Figure 8 shows the occurrence of multiple-cropping zones worldwide.

The potential area allowing double or triple cropping of rain-fed cereals is limited in the developed world. In Europe and Russia, it is virtually nonexistent. In the



developing world as a whole, about 55% of the land with the potential for rain-fed cultivation of cereals is suitable for double or triple cropping. In South and Central America it exceeds 80%: 65% for double and 17% for triple cropping (see Table 6).

Table 6. Share of cultivable land suitable for multiple cropping of rain-fed cereals at intermediate levels of inputs.

Region	Total suitable (million ha)	Single cropping (%)	Double cropping (%)	Triple cropping (%)
Oceania	87	83	13	4
Asia	366	63	32	5
Africa	678	59	39	2
Europe & Russia	422	100	<1	0
South & Central America	606	19	65	17
North America	297	57	30	13
<i>Developing countries</i>	1,645	45	47	8
<i>Developed countries</i>	811	82	13	5
<i>World</i>	2,455	57	36	7

Irrigation impact on crop production

Currently about 200 million ha of arable land is irrigated in developing countries and some 54% of this is accounted for by China and India. In the developed countries, irrigated land amounts to about 66 million ha. Irrigation is an important component of agricultural production in developing countries, as it accounts for some 40% of production on 22% of the total cultivated land area. The contribution of irrigation for cereals is even higher, accounting for 58% of total production in the developing world.

The Global AEZ model was used to estimate irrigated land productivity under the assumption that water resources of good quality are available and irrigation infrastructure is in place (Figure 9). When limiting the analysis to soil conditions indicating the presence of water (such as Gleysols and Fluvisols), some 65 million ha (i.e., only about 1.8% of arid and hyper-arid zones) were assessed as prime land for irrigated cereals, which in turn equates to less than 3% of total prime land for cereals.

The results clearly suggest that irrigation is more important for providing a stable water supply in areas of rainfall variability rather than for bringing land in hyper-arid and arid regions into cultivation.



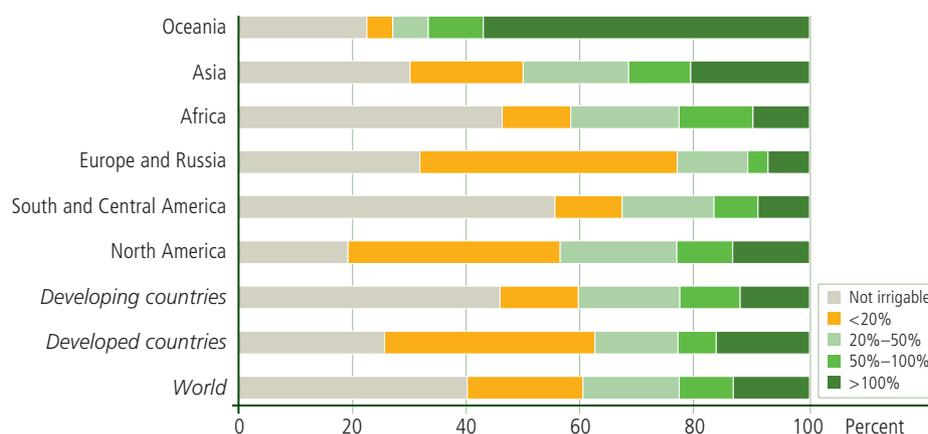


Figure 9. Distribution of land with cultivation potential by irrigation impact classes, showing increase in potential output with full exploitation of irrigation.

With irrigation, the area potentially suitable for staple food and oil crops on the best land (very suitable and suitable) at a high level of inputs increases in the range of 13% to 30%. For sugar crops and cotton, the increase is substantially higher. Table 7 compares rain-fed cultivation potential with rain-fed and/or irrigated cultivation potential for six crops at high and intermediate levels of inputs.



Irrigation expansion is more effective in areas of uncertain rainfall than in hyper-arid and arid areas.

Results were obtained for production of cereal crops on currently cultivated land and on all potentially cultivable land for (1) rain-fed production of one crop per year, (2) rain-fed multiple cropping, and (3) rain-fed *and* irrigated multiple cropping. The results show the following:

- ◆ Comparing rain-fed multiple cropping with one rain-fed crop per year on currently cultivated land, about 25% and 10% more production is achieved in the developing and developed countries, respectively.
- ◆ Comparing rain-fed and/or irrigated multiple cropping with one rain-fed crop per year on currently cultivated land, about 75% and 50% more production is achieved in the developing and developed countries, respectively.
- ◆ If all potentially cultivable land is cultivated, cereal production in developing countries more than doubles, whereas for the developed countries, the increase is over 50%.

Table 7. Percentage of total land suitable for crop production.

	Rain-fed cultivation potential		Rain-fed and/or irrigated cultivation potential	
	High inputs (% VS+S)	Intermediate inputs (% VS+S+MS)	High inputs (% VS+S)	Intermediate inputs (% VS+S+MS)
Cereals	14.9	18.7	16.8	19.8
Roots and tubers	8.5	11.3	10.9	12.6
Pulses	7.8	11.2	10.1	12.2
Oil crops	11.2	15.2	14.6	16.5
Sugar crops	4.0	6.7	7.7	9.1
Cotton	3.3	4.3	4.8	5.2

Note: VS=very suitable; S=suitable; MS=moderately suitable.

Figure 10 highlights the impact of multiple cropping and irrigation on cereal production potential in developing and developed countries.

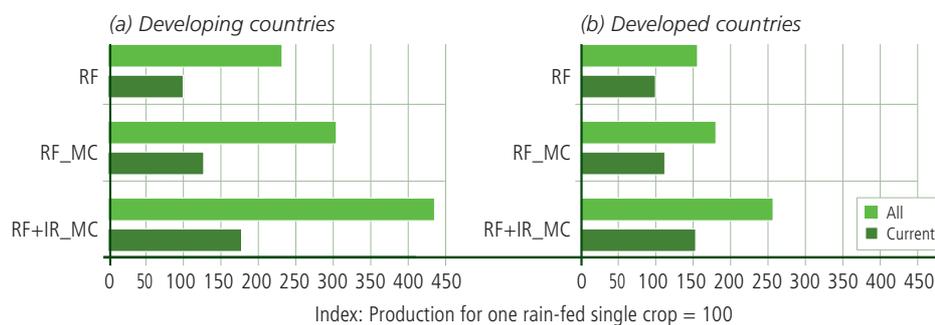


Figure 10. Comparisons of cereal production for current cultivated land and all cultivable land for one rain-fed crop per year (RF), rain-fed multiple cropping (RF_MC), and rain-fed and irrigated multiple cropping (RF+IR_MC). Changes are relative to crop production potential for rain-fed single cropping.

Climate change and food production



Human activities are changing the Earth's climate, and this is having an impact on all ecosystems. The expected changes in climate will alter regional agricultural systems with substantial consequences for food production. The specifics of the impact will depend on how the effects of climate change translate into factors that determine viability and utility of ecosystems.

Article 2 of the Framework Convention on Climate Change states that impacts on world food supply should be a key area in considering

at which point climate change might imply dangerous anthropogenic interference with the climate system. The AEZ methodology and the spatial database with global coverage provide a comprehensive basis for ecological assessments and quantification of regional and national crop production impacts of climate variability and climate change.

During the past few years, case studies on the potential impacts of climate change have been compiled for a number of countries, including Australia, Egypt, Finland, Indonesia, Malaysia, the Netherlands, Norway, Thailand, the UK, the USA, and Vietnam. These initiatives differ markedly in their baseline data, methods of analysis, and scenarios of climate change. The majority of these studies have been based on climate change experiments with general circulation models (GCMs), but often do not apply the same scenarios.

In the context of the present debate over international agreements such as the Kyoto Protocol and the outcome of the Third Assessment of the Intergovernmental Panel on Climate Change (IPCC), it is important that uniform assessments be carried out to compare and evaluate national, regional, and global impacts of climate change on food and agriculture production. Such quantified and spatial information provides important inputs that can underpin national and regional adaptive policies to mitigate the consequences of climate change and also facilitate international negotiations on climate change, taking into account the contribution of various countries to global warming as well as their specific development needs and priorities.



Climate change puts agriculture at great risk.

*Many developing countries could lose over a fifth of crop production,
with serious food security consequences,
while developed countries could see significant agricultural production gains.*

The effects of global warming and atmospheric carbon concentrations will result in improved growing conditions in some areas, and thus crop production may be raised. At the same time, however, higher temperatures may intensify pest and disease problems, which in turn would lead to crop losses. Crop yields in some countries may also be affected by drier conditions and increased water stress. At the same time, elevated atmospheric carbon dioxide levels are expected to augment crop productivity because of increased photosynthetic growth and improved water-use efficiency.

Temperature and rainfall sensitivity

Global warming will lead to higher temperatures and changes in rainfall, and this in turn will modify the extent and productivity of land suitable for agriculture. The application of a set of temperature and rainfall sensitivity scenarios revealed a modest increase of cultivable rain-fed land for temperature increases up to 2°C on a global

Table 8. Climate sensitivity of land suitable for cereal production (% change).

Region	Temperature increase and rainfall change						
	Temperature increase			Temperature increase and rainfall change			
	+1°C	+2°C	+3°C	+1°C, +5%	+2°C, +5%	+2°C, +10%	+3°C, +10%
Oceania	-4	-5	-9	1	0	4	0
Asia	4	3	-2	5	2	4	0
Africa	-4	-8	-12	-4	-8	-8	-13
Europe & Russia	13	17	20	16	21	24	28
Central America	-1	-4	-9	-4	-6	-9	-13
South America	-4	-11	-20	-7	-13	-14	-23
North America	12	16	20	16	21	24	28
<i>Developing countries</i>	-1	-6	-11	-2	-6	-6	-11
<i>Developed countries</i>	11	15	18	15	19	22	25
<i>World</i>	4	3	1	5	5	6	4

scale. With a still higher temperature increase alone—that is, with current precipitation patterns and amounts—the extent of cultivable rain-fed land starts to decrease. When both temperature and rainfall amounts increase, the extent of cultivable rain-fed land increases steadily. For example, a temperature increase of 3°C paired with a rainfall increase of 10% would lead globally to about 4% more cultivable rain-fed land. These figures are presented in Table 8.

In the developed countries this increase is markedly higher, exceeding 25%. In contrast, developing countries would experience a decrease of 11%, which could have serious consequences for food security in a number of poor developing countries in Africa, Central and South America, and Asia.

Impacts of climate change on cereal production

The AEZ climate impact assessment is based on the projections of several GCMs, including the ECHAM4 model of the Max Planck Institute, the HadCM2 model of the Hadley Centre for Climate Prediction and Research, and the CGCM1 model of the Canadian Centre for Climate Modelling. A detailed report of the simulation results, including assessment of the IPCC 2001 emission scenarios (SRES), and a comparative AEZ analysis of climate change consequences for food production are in preparation.

This section illustrates the results of changes in rain-fed cereal production based on the climate change projections of the ECHAM4 model. For this analysis we have assumed a high level of inputs and management for areas classified as being in cultivation in 1992–1993 and for all land with production potential for rain-fed cereals. Thus the study assesses impacts on current agricultural land and also estimates where shifts in land productivity are likely to occur. Note that the calculations fully account for optimal adaptations of crop calendars as well as switching of crop types. Also, yield increases resulting from higher carbon dioxide concentrations in the atmosphere are incorporated.

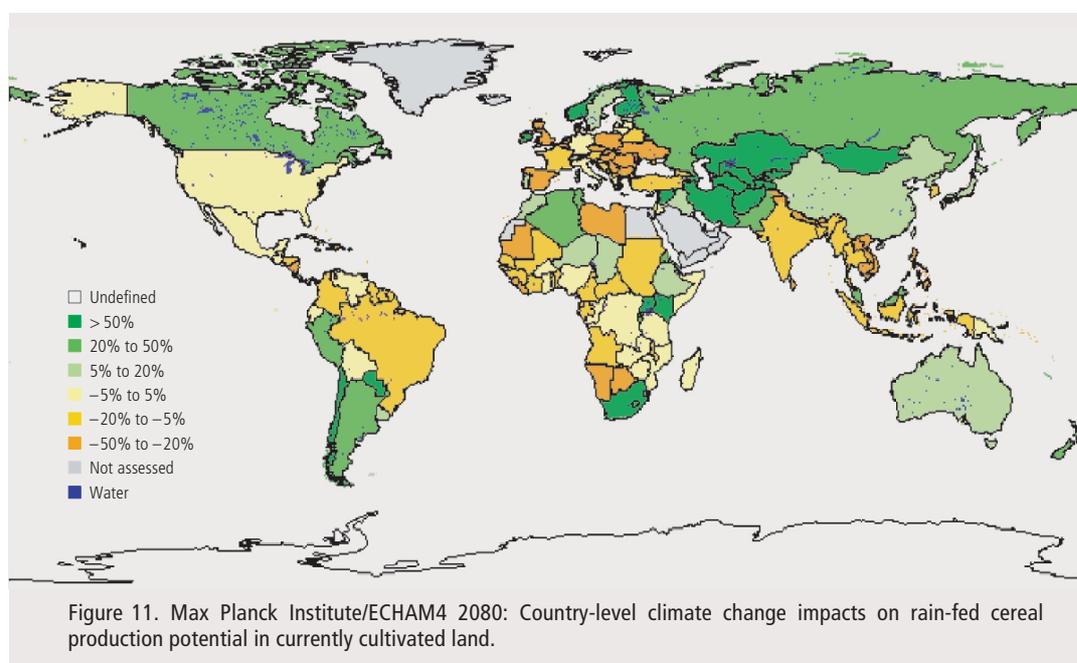
The rain-fed potential cereal production, assuming one crop per year with a high level of inputs on land currently under cultivation, shows a net decrease of some 100 million tons at the global level. The results in terms of percentage losses and gains for individual countries are shown in Figure 11 and summarized in Box 2.

The results discussed in Box 2 assume one cereal crop per year on currently cultivated land. When multiple cropping and irrigation are also taken into account, agricultural systems are better able to adapt, as indicated in Figure 12, which shows the changes in production potential and the number of countries gaining and losing.

Multiple cropping provides an additional potential production increase of about 235 million tons in developed countries and some 135 million tons in developing countries compared with growing one rain-fed cereal crop per year. When irrigation is considered as well, further net increases of 225 and 50 million tons, respectively, are attained. Also, the number of countries gaining production potential with climate change increases, in particular among the developed countries.

The results highlight that climate change will benefit the developed countries more than the developing countries when considering one rain-fed cereal crop per year or multiple rain-fed cropping and irrigated production.

Figure 13 presents, by grid cell, the impact of climate change on multiple-cropping cereal production considering all land with cultivation potential for rain-fed cereals.



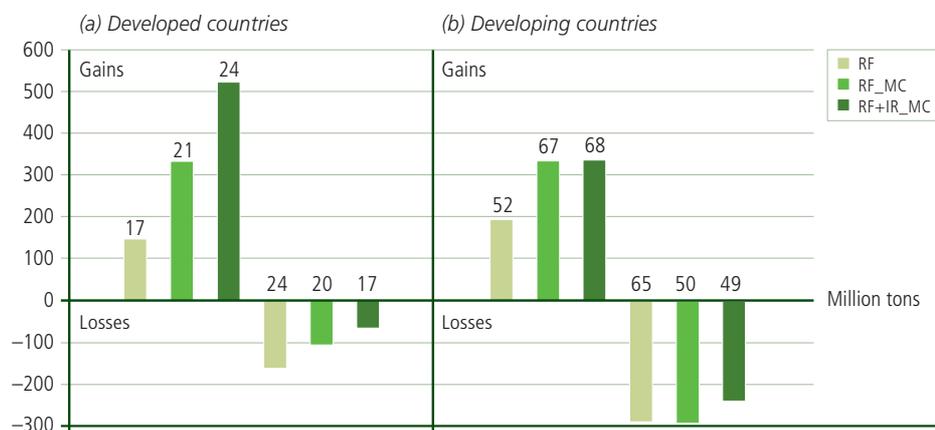
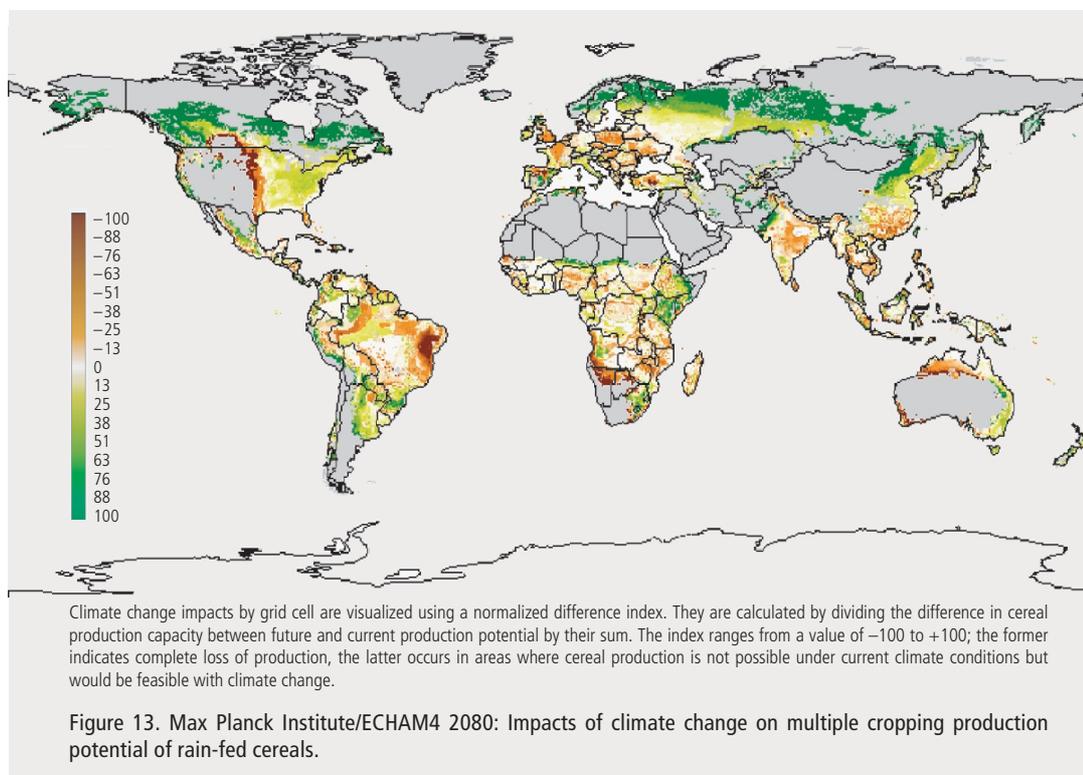


Figure 12. Impact of climate change on rain-fed (RF), rain-fed multiple cropping (RF_MC), and rain-fed and/or irrigated multiple cropping (RF+IR_MC) cereal production potential. Number of countries affected is also shown.



Box 2. Percentage losses and gains in cereal production for various countries as a result of climate change.

In the developed countries, rain-fed cereal production with a high level of inputs under reference climate conditions is estimated to total 1.9 billion tons on currently cultivated rain-fed land. This decreases by some 15 million tons in the 2080s as a result of ECHAM4-projected climate change. Seventeen developed countries together gain 145 million tons, and over 90% of this gain in production occurs in just two countries, Russia and Canada.

Twenty-four countries, representing over 60% of the population in the developed countries in 1995, lose 160 million tons. Among the countries substantially losing are Romania, Hungary, Belgium, the Netherlands, the UK, the Czech Republic, and Ukraine. Among the major cereal producers, the losses in the USA, France, and Ukraine exceed 20 million tons each. By contrast, Finland, Norway, Canada, New Zealand, and Russia are among the countries benefiting most.

In the developing world as a whole, the potential cereal production on currently cultivated land at an assumed high level of inputs totals some 3.0 billion tons. By the 2080s, production decreases by 90 million tons with the ECHAM4-predicted climate change. At the aggregate level, assuming an average consumption of 300 kg per capita, this production is sufficient to meet future cereal food needs. However, there are wide variations in the impact of climate change for individual countries.

Sixty-five developing countries, representing more than half the developing world's total population in 1995, lose about 280 million tons of potential cereal production as a result of climate change. This loss, valued at an average US\$200 per ton for cereals, totals US\$56 billion—equivalent to some 16% of the agricultural gross domestic product of these countries in 1995. The other 52 developing countries gain some 190 million tons.

In Central America and the Caribbean, all countries lose production. The rain-fed cereal production potential on currently cultivated land in this region declines by about 9%.

South America gains about 30 million tons. Of the 12 countries in this region, six countries lose over 60 million tons, and the others gain 90 million tons. Brazil, representing half the region's population, loses 14%.

In Africa, the food security situation is poor and there have been only limited production gains over the past three decades. One-third of the region's current population of some 640 million is undernourished. Twenty-nine countries face an aggregate loss of some 35 million tons in their potential cereal production. Over 40% of this loss occurs in just four countries—Tanzania, Sudan, Cote d'Ivoire, and Angola. Some 17 African countries gain a total of 30 million tons, with over 60% of this gain accounted for by Kenya and South Africa.

In East and South Asia, where at present two-thirds of the world's 800 million undernourished live, the impact of climate change is mixed. India loses a massive 125 million tons, equivalent to some 18% of its rain-fed cereal production potential. In contrast, China's rain-fed potential cereal production of about 360 million tons increases by 15%.

In Central Asia, all countries except Georgia gain, with Turkmenistan, Kazakhstan, and Azerbaijan accounting for over 85% of the increase.

Climate change and food security

The FAO has estimated the total number of undernourished people in 94 developing countries at 792 million. Sixteen of these countries, mainly in the Middle East, North Africa, and South America, have relatively high levels of gross domestic product (GDP) per capita of more than US\$3000. These countries, accounting for about 1% of the total undernourished, are not discussed here.

The impact of climate change on cereal production is estimated for the remaining 78 developing countries. These countries are considered in terms of three groups according to the proportion of undernourished in each country's total population. The groups are 5%–20% undernourished (Group 1), 20%–35% undernourished (Group 2), and more than 35% undernourished (Group 3). To estimate the climate impact on cereal production, for each country the percentage changes in potential production on currently cultivated land were determined, taking into account multiple cropping and irrigated production. These changes were applied to the country's cereal production in 1994–1996. In other words, to demonstrate the food implications of climate change, impacts were scaled with the actual production in the mid-1990s.

Some 12% of 2.1 billion people in the 28 countries of Group 1 are undernourished, and their average per capita food deficit is estimated to be about 250 calories per day. The impact of climate change is negative in 11 countries, where the food gap is further exacerbated by a loss of 12 million tons as a result of climate change, equivalent to a 10% decrease of their cereal production. Thirteen of the remaining 17 countries in Group 1 gain enough cereal production to close the undernourished food gap. China, with some 140 million undernourished and an estimated deficit of 4 million tons, gains as much as 100 million tons in cereal production.

In Group 2, comprising 27 countries and a population of some 1.5 billion, about a quarter of the population is undernourished, with an average daily food deficit of some 300 calories per capita. The results indicate that in 19 countries with over 80% of the undernourished in Group 2, cereal production will decrease by 19 million tons in addition to the present food gap of 9 million tons. India, accounting for 60% of the undernourished in Group 2, faces a decline of 9 million tons in cereal production as a result of climate change in addition to the present food gap of 6 million tons. Only three countries in Group 2 gain sufficient production to close the gap.

Most of the 23 countries in Group 3 are in sub-Saharan Africa. Almost half the total population of 440 million is undernourished, with an average daily deficit of some 390 calories per capita. For 10 of these countries the results show a decrease of potential cereal production as a result of climate change. Six of the remaining 13 countries benefit substantially from climate change—enough to overcome the estimated food gap. Results for all groups are shown in Table 9.



The impact of climate change on cereal production is cause for serious concern in some 40 “losing” countries. These countries have a total combined population of about 2 billion, of which 450 million are undernourished. Comparing the decrease of 33 million tons in total production in these countries with the food gap of 15 million tons, the loss implies that the number of undernourished may drastically increase with climate change. Many of these countries are food insecure and poor. They lack the resources to produce enough food and often do not have the foreign exchange to finance food imports. Production losses resulting from climate change could further worsen the prevalence and depth of hunger. This burden will undoubtedly fall disproportionately on the poorest and the most vulnerable.



Fairness and Equity

Greenhouse gas emissions since 1950:

75% from developed countries

25% from developing countries

Climate change impacts will result in additional pressure to intensify and expand agricultural land, both of which will contribute to greenhouse gas emissions. In addition, agricultural land expansion will unavoidably lead to losses of biodiversity, especially through clearance of forests. Such considerations must be central in mitigating the impacts of climate change on food and agricultural production.

Global warming raises the issue of fairness, as illustrated in Figure 14, which shows the magnitude of climate change impacts on cereal production potential in

Table 9. Impact of climate change on food security.

	Number of countries	GDP, 1995 (US\$/capita)	Population, 1995 (millions)	Under-nourished population (millions)	Cereal production, 1994–1996 (million tons)	Cereal gap (million tons)	Climate impact on cereals (million tons)
<i>Losing</i>							
Group 1	11	2,113	464	41	129	1	–12
Group 2	19	486	1,264	291	307	9	–19
Group 3	10	264	256	122	39	5	–2
<i>Gaining</i>							
Group 1	17	873	1,658	182	513	5	111
Group 2	8	490	198	48	29	1	11
Group 3	13	190	184	98	26	4	6

relation to per capita carbon dioxide emissions from 1994 to 1996. Developing countries have thus far contributed relatively little to the causes of global warming. Yet, many of these countries will suffer the consequences of reduced food production caused by climate change.

The world community of nations must responsibly meet the challenge of addressing climate change mitigation policies. This must take into account differences between nations in natural, technological, and financial resources.

The timely implementation of international agreements on climate change will be critical in the context of achieving societal goals of equity and sustainable development.

The AEZ methodology and spatial results for the world's agro-ecosystems provide a comprehensive knowledge-based approach to sustainable agricultural development.

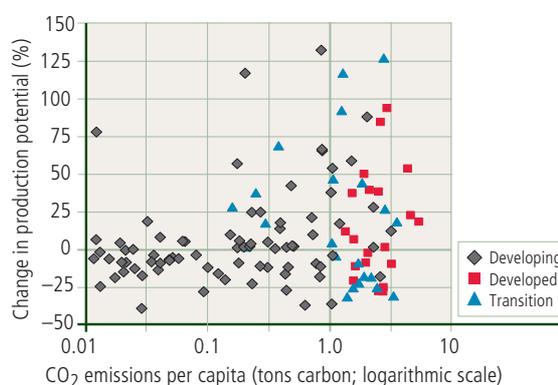


Figure 14. Climate change impacts and carbon dioxide emissions.

Population change and arable land

The world population is projected to increase by some 3.3 billion during the next 50 years, and almost all of this increase will be in the developing world. In 1995, the global average use of arable land per person was 0.26 ha for a world population of 5.7 billion people. The total cultivated land in the world was just over 1.5 billion ha, including 260 million ha of irrigated land.



*Population increase in Asia,
with 60% of the world's population,
will reduce per capita availability of cultivated land
below the critical level of 0.1 ha per person.*

Although the AEZ results indicate considerable scope for expansion of agricultural land in some regions, such expansion is neither likely nor desirable in light of environmental consequences and infrastructure development costs. Much of the potential agricultural land is concentrated in Africa and South and Central America, where the

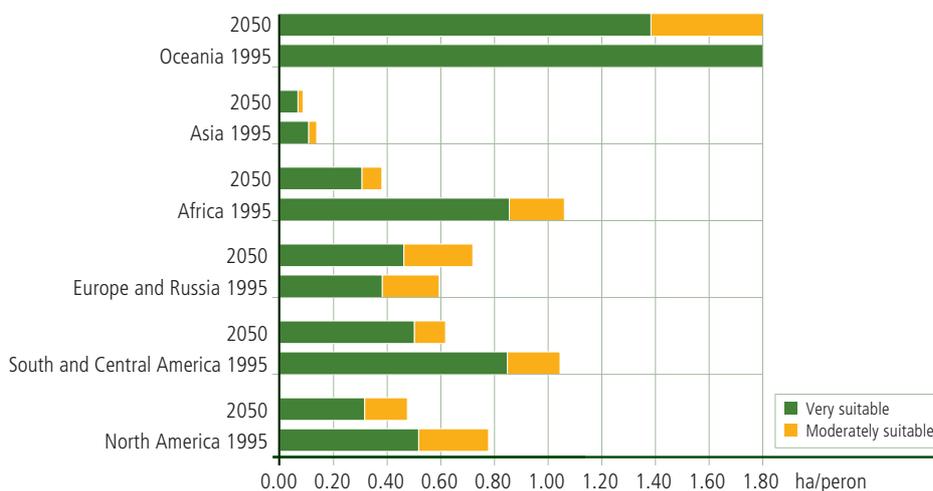


Figure 15. Per capita availability of land with crop cultivation potential.

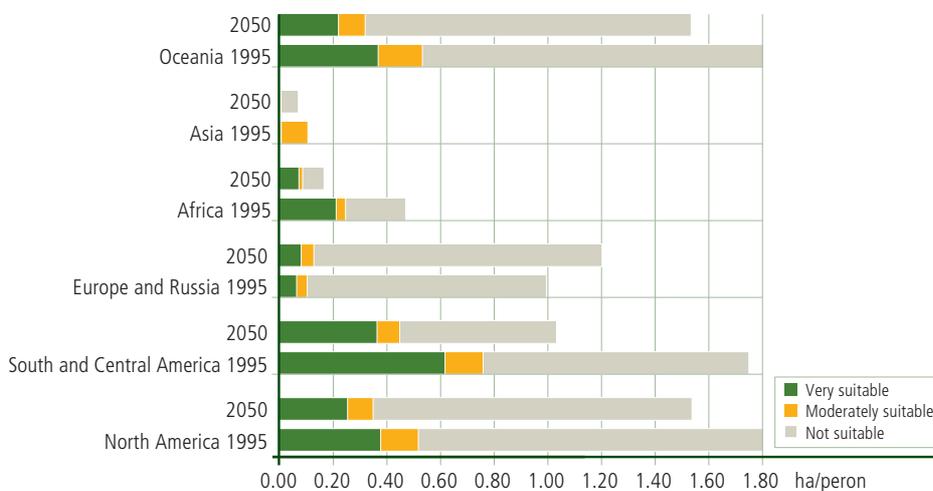


Figure 16. Per capita availability of land with crop cultivation potential in forest ecosystems.

population is projected to increase by 1.2 billion and 0.3 billion, respectively, over the next 50 years. In contrast, many countries in Asia have little potential for additional agricultural land; yet this region's population is projected to increase by 1.7 billion by 2050. In the developed countries, the population is not expected to increase much and it is unlikely that additional land, though available, will be brought into cultivation.

During the past four decades, cultivated land in developing countries increased from 680 to 960 million ha, an increase of 40%, while in the developed countries it changed little. The AEZ results identify a further 900 million ha of potential agricultural land and an additional 800 million ha in forest areas. Figure 15 shows per capita current (1995) and future (2050) availability of land with crop cultivation potential. There is some additional potential in areas currently in forest ecosystems, as indicated in Figure 16.

Any cultivation of these forest ecosystems, however, would result in harmful environmental consequences, such as loss of biodiversity, impacts on the carbon cycle and global warming, and increased risk of flooding.

The environmental concerns regarding agricultural expansion and intensification call for sustainable and responsible use of potential agricultural land resources and farming technology to meet the food needs of future populations.



Concluding Remarks

Limitations of the Study

Important caveats concerning the Global AEZ results must be considered. While the study is based on the most recent global data compilations, the quality and reliability of these data sets are known to be uneven across regions, including, for example, soil data based on the FAO/UNESCO Soil Map of the World. Substantial improvements are being made to the soil information, and several regional updates have recently become available.

The current status of land degradation cannot be inferred from the Soil Map of the World. The only study with global coverage, the Global Assessment of Soil Degradation (GLASOD), indicates that the status of land degradation may very well affect potential productivity of land. However, this degradation study offers insufficient detail and quantification for application within the Global AEZ model.

Socioeconomic needs of rapidly increasing and wealthier populations are the main driving forces in allocating land resources to various uses. Such considerations are critical for rational planning of sustainable agricultural development. As an extension of basic land productivity assessments, IIASA and the FAO have introduced interactive multiple-criteria model analysis for use in national and subnational resource planning. It is at this level of analysis that socioeconomic considerations can be effectively taken into account.

Though various modes have been pursued for “ground-truthing” and verifying results of the Global AEZ suitability analysis, there is a need for further validation of the results and underlying databases.

Next Steps

The present study has outlined various applications where biophysical assessments based on AEZ can substantially contribute to effective resource use for sustainable agricultural development. While improvement of the basic methodology and data is a general aim, the planned work is concerned with regional applications and case studies. Several activities related to AEZ are currently under way or under consideration:

- ◆ A CD-ROM covering the former Soviet Union, Mongolia, and China at a 5-km resolution grid. This CD-ROM deals with various data sets, including results of AEZ applications generated by IIASA's Land-Use Change (LUC) Project. It also includes an AEZ application for biomass plantation forestry, traditional forestry, and conservation forestry.

- ◆ Analysis of impacts of climate variability and climate change on agricultural production. This application ranges from global to subnational assessments. We intend to include water resources data and modeling to enhance the assessment of irrigation production potentials at the watershed level.
- ◆ Specific AEZ studies for “hot spots,” with special reference to the effect of climatic variability on food security. Proposed study areas include countries in eastern and southern Africa, and China.
- ◆ Development of a geographically explicit environmental and socioeconomic database and application of AEZ multiple-criteria analysis to assess alternative European rural development policies, including impacts of the impending accession of Central and East European countries to the European Union.
- ◆ An AEZ study of China, embedding a multifaceted environmental characterization of agricultural land use within an economic model, provides a biophysical basis for the estimation of spatially explicit agricultural production relations and allows consistent linkage to the modeling of the demand for irrigation water.

The AEZ approach combined with socioeconomic modeling provides an integrated tool for sustainable land-use planning and resource development at the subnational and national levels. To date, several regional and more than 20 country studies have been undertaken (see Figure 17). It is envisaged that the methodology and the results in this first Global AEZ assessment will catalyze many more detailed studies, particularly at the regional and national levels.

