ISSN 1684-8241

11

Mapping biophysical factors that influence agricultural production and rural vulnerability

ENVIRONMENT AND NATURAL RESOURCES SERIES

[GEO-SPATIAL DATA AND INFORMATION] ENVIRONMENTAL MANAGEMENT ASSESSMENT AND MONITORING GLOBAL ENVIRONMENTAL CHANGE

POVERTY MAPPING
GEOGRAPHY OF POVERTY
GEOGRAFÍA DE LA POBREZA
GÉOGRAPHIE DE LA PAUVRETÉ

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Food and Agriculture Organization of the United Nations and
International Institute for Applied Systems Analysis, Rome 2007

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Ideas contained in this document are solely those of the authors and do not necessarily represent the views of FAO or IIASA. The conclusions given in this report are considered appropriate at the time of its preparation. They may be modified in the light of further knowledge gained at subsequent stages of the project.

ISBN 978-92-5-105689-9

FOREWORD

GIS technology provides the tools for integration of environmental and socio-economic geospatial data through space and time, allowing possibilities for assessment, monitoring, and change detection in both human and natural systems.

This publication, jointly prepared by FAO and IIASA, explains the GIS-based methodologies used for constructing a set of databases relating to biophysical factors that influence agricultural production and rural vulnerability and shows the distribution of rural populations in various agro-ecological environments. The databases themselves have been released by FAO as part of a larger collection – the *Food Insecurity, Poverty and Environment Global GIS Database (FGGD)* – which is available as a digital atlas on two DVDs, with an accompanying hardcopy version.

We are confident that continued application of such GIS-based analysis techniques will not only deepen our understanding of the links between poverty and the environment, but will also prove to be of immediate use to those concerned with improving living conditions in vulnerable environments in a sustainable manner.

FAO is grateful to the Government of Norway for the encouragement and funding it has provided for this work.

Jeffrey B. Tschirley
Chief, Climate Change and Bioenergy Division, FAO

ABSTRACT

This monograph is part of a series of reports that explain how techniques of spatial analysis can be used to investigate poverty and environment links worldwide. It combines rural population distribution data contained in the global rural population database for the year 2000 (FAO, 2005) with methods and results of the *Global agro-ecological assessment for agriculture in the 21st Century* (Fischer *et al.*, 2002), in order to estimate the distribution of the world's rural population by agricultural suitability class, land use category and type of farming system. Refinements in GIS databases and analysis techniques have been developed collaboratively by FAO and IIASA in the project *Improving Methods for Poverty and Food Insecurity Mapping and its Use at Country Level*, which was jointly implemented by FAO, UNEP/GRID-Arendal and CGIAR centers and funded by the Government of Norway. The report considers the constraints imposed by environmental conditions at different levels of human input, evaluates agricultural production potential of the world's land area at a resolution of 5 arc-minutes (about 85 square kilometre at the equator), and reports on rural habitation in relation to agricultural production potential, land use patterns and farming systems. Other related reports are: *A geospatial framework for the analysis of poverty and environment links, Mapping global urban and rural population distributions and Food Insecurity, Poverty and Environment Global GIS Database (FGGD) and Digital Atlas for the Year 2000*.

Mapping biophysical factors that influence agricultural production and rural vulnerability
by Harrij van Velthuizen, Barbara Huddleston, Günther Fischer, Mirella Salvatore, Ergin Ataman, Freddy O. Nachtergaele, Marina Zanetti and Mario Bloise

96 pages, 5 boxes, 3 figures, 28 tables, 57 maps.

Environment and Natural Resources Series No. 11, FAO, Rome 2007

Keywords:
Global agro-ecological zones, GAEZ, AEZ, productivity potential, suitability, rural population, GIS, land cover, farming system, environmental constraint, poverty mapping

This series replaces the following:
Environment and Energy Series
Remote Sensing Centre Series
Agrometeorology Working Paper

A list of documents published in the above series and other information can be found at the Web site: **www.fao.org/sd/enpub1_en.htm**

ACKNOWLEDGEMENTS

The authors have benefited from the continuous technical advice and counsel of many colleagues in FAO, IIASA, IFPRI and other organizations. Special thanks go to the following individuals for their technical advice, assistance for improving the document and/or providing maps and data: Jelle Bruinsma, FAO/ESDG; John Dixon, CIMMYT; Jippe Hoogeveen, FAO/AGLW; Tim Robinson, FAO/AGAL; Kate Sebastian, IFPRI; Jan Slingenbergh, FAO/AGAH.

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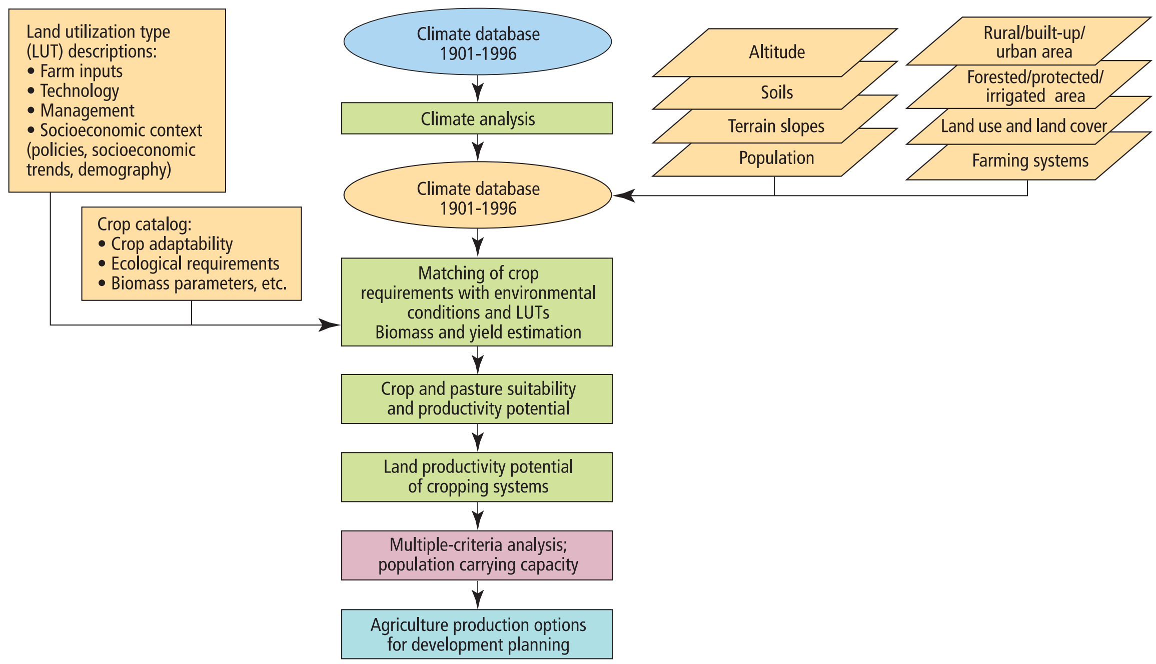
ACRONYMS

AEZ	Agro-Ecological Zones
AGAH	Animal Health Service
AGAL	Livestock, Information, Sector Analysis and Policy Branch
AGLW	Water Resources, Development and Management Service
AGPC	Crop and Grassland Service
CGIAR	Consultive Group on International Agricultural Research
CRU	Climate Research Unit of the University of East Anglia
CSI	Crop suitability index
CV	Coefficient of variation
ESDG	Global Perspective Studies Unit
FAO	Food and Agriculture Organization
FS	Farming systems
GAEZ	Global Agro-Ecological Zones
GIS	Geographic Information System
GLCC	Global Land Cover Classification
GRID-Arendal	Global Resource Information Database (Arendal, Norway)
GTOPO30	Global 30 arc-second Digital Elevation Model
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis
IUCN	International Union for the Conservation of Nature and Natural Resources
LGP	Length of growing period
LUTs	Land Utilization Types
MS	moderately suitable
mS	marginally suitable
NOAA	National Oceanic and Atmospheric Administration
NPP	Net Primary Productivity
ORNL	Oak Ridge National Laboratory
PSI	Pasture suitability index
S	suitable
SD	Standard deviation
SDRN	Environmental and Natural Resource
UN	United Nations
UNEP	United Nation Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
VS	very suitable
WCMC	World Conservation Monitoring Centre

CHAPTER 1 INTRODUCTION

A GIS-based analysis of geophysical factors that influence agricultural production involves assessment of the suitability of land for agricultural activity at a very high degree of spatial resolution. The assessments of land suitability that are described in this report rely mainly on the FAO/IIASA global agro-ecological zoning (GAEZ) method for evaluating productivity potential of the world's land area for rainfed agriculture, which was updated and published in 2002, as the *Global Agro-ecological Assessment for Agriculture* (see Figure 1.1 and Annex 1 for details).

FIGURE 1.1
The AEZ framework



In this report, focus is placed on refining and applying the method as a basis for eventual evaluation of agricultural production performance in relation to potential in low-income developing countries. Georeferenced data at a resolution of 5 arc-minutes have been used to compile the maps.

While GIS maps and databases for global environmental conditions and agricultural productivity potential have been available for quite some time, it is only in the past few years that it has become possible to overlay these maps with georeferenced population data. An urban area mask has been developed specifically for use in this report (FAO, 2005). This mask differentiates urban and rural areas; based on population distribution data generated by the LandScan Global Population Database (ORNL Online) and Nighttime Lights of the World (NOAA Online). It has been used to create a gridded rural area and population database at a resolution of 5 arc-minutes. All rural population numbers reported here have been derived from this database. The method employed is summarised in Chapter two.

Current suitability of land for agricultural activity depends on three factors: (i) environmental conditions, (ii) biophysical requirements of plants and animals to survive and thrive, and (iii) level and nature of human inputs. Climate, i.e., temperature and rainfall, determines whether or not growing conditions needed for specific crops are present. It is thus the first variable considered in the evaluation of biological yield potential of an area for individual crops.

Other environmental variables that may modify biological yield potential of an area include availability of water for cultivation, soil attributes and terrain slope. Discussion of these environmental variables, and the extent to which environmental conditions constrain prospects for crop agriculture and pasture around the globe, is the subject of Chapter three of this report.

Crop models specify the biophysical requirements of individual crops and their yield potentials under different sets of environmental conditions and management/input levels. Chapter four of this report presents a classification of the suitability of the world's land area for rainfed agriculture.

The suitability of land for each crop is assessed by comparing likely attainable yields with the maximum biological yield for that crop in ideal environmental conditions. Land where attainable yields are very close to the maximum potential yield is classified as very suitable for that crop, whereas land where attainable yields are far below the potential maximum is classified as only marginally suitable or not suitable.

Land production potential is the result of the interplay of crop suitability with human factors (settlement, land use patterns, technological advance, agricultural inputs, cropping systems and farm management practices). For this report, production potentials for nine crop groups have been evaluated at three levels of inputs and management practices under rainfed conditions. Zones suitable for multiple cropping have been identified and mapped; the overall suitability of land for crop production is evaluated and the suitability of land for pasture is assessed.

The AEZ method provides a suitability classification for all land, regardless of how it is currently being used. Chapter four also presents information about non-agricultural uses of land and the distribution of irrigated area, and explains how this information has been used to compile suitability maps for this report that exclude area not currently available for rainfed agriculture. Chapter five reports the results of an evaluation of the distribution of rural population in the seven major farming system classes in developing and transition countries with respect to exposure to severe environmental constraints, agricultural suitability class and dominant land cover type.

CHAPTER 2

POPULATION AND HUMAN SETTLEMENTS

2.1 DISTINGUISHING URBAN AND RURAL AREA

To determine the size and distribution of the world's rural population reported in this study, it was first necessary to create a georeferenced map that differentiated urban and rural areas. In this report, population density thresholds are used to differentiate urban from rural area, as they provide a solid basis for estimating distribution of rural population across rural land area. The method is described in detail in *Mapping global urban and rural population distributions* (FAO, 2005).

The procedure involved the creation of an urban area mask based on two sources: (i) a GIS map showing the location of nighttime lights and (ii) the LandScan 2002 ambient population map, adjusted to UN population data for 2000. The LandScan map shows the distribution of the world's population at a resolution of 30 arc-seconds (one square kilometre at the equator). The urban mask has been generated by capturing the densely-populated gridcells, up to a threshold corresponding approximately to UN urban population figures by country for the year 2000. Gridcells not captured by the urban area mask are considered rural, even though a few of them may contain rural settlements and other built-up area. To distinguish non-settled from settled rural area, FAO created another grid which classifies rural pixels with population density greater than 2 000 persons per square kilometre as rural settlements. This threshold was selected based on an IIASA analysis that showed that almost negligible land area would be left for agriculture in areas with population density greater than this number. Due to unreliability of data for states with an area of less than 3 000 square kilometres or population of less than 500 000 and non-availability of data for Antarctica and states and territories for which the UN does not publish urban and rural population data, pixels for these areas were coded as "not assessed".

Three 30 arc-second databases contain the urban area, rural area and rural settlement grids that were compiled using the method summarized above. The databases are available on the DVDs that contain the FGGD Digital Atlas for the year 2000 (FAO, 2006).

2.2 ESTIMATING THE DISTRIBUTION OF RURAL POPULATION

By overlaying the area grids on the LandScan population distribution grid, FAO has generated three population distribution grids – for urban, rural and rural settlement populations respectively. Applications using these three databases can estimate urban, total rural, settled rural and non-settled rural populations for any area of interest.

Maps compiled for this report are at the lower resolution of 5 arc-minutes, aggregated from the 30 arc-second rural area and population grids with minor adjustments to bring results into conformity with country totals from the higher resolution grids. The 5 arc-minute grids are also available on the FGGD Digital Atlas DVDs. The values from the 5 arc-minute grid for total rural population are those used in this report.

2.3 SIZE OF EXCLUDED AREA AND POPULATION

As the reference map and GIS software used for the GAEZ study and its refinements differ from those used by FAO/SDRN to generate its rural and urban area and population grids (FAO, 2005), there are differences in the estimation of global area and built-up area between the two sources. Hence global area as defined for this report, is less than that published in the GAEZ study.

Throughout most of this report, another distinction has been made within total rural area, between that which is currently available for rainfed agriculture, irrespective of its suitability, and that which is not (see table 2.1). More detail on the method used for estimating distribution of global land cover types and the amount of land currently available for rainfed agriculture is given in Annex 2, together with a summary table showing the distribution of total rural population, by dominant land cover type. The size of the rural population excluded from consideration in this report as a result of these various area exclusions is shown in Table 2.2.

TABLE 2.1

Comparison of global area estimates, under different assumptions for urban and rural area

	GAEZ	FAO/SDRN		
	Total area	Total area	Study area	Area currently available for rainfed agriculture, irrespective of suitability
	km^2 (1 000)	km^2 (1 000)	km^2 (1 000)	km^2 (1 000)
Global land area, incl. inland water bodies	–	134,369	131,144	–
Inland water bodies	–	1,779	1,779	–
Global land area, excl. inland water bodies	133,995	132,590	129,365	–
Built-up area and artificial surfaces	1,161	–	2,991	–
Non built-up area	132,834	–	126,374	101,030

TABLE 2.2

Comparison of global population estimates, under different assumptions for urban and rural area

	UN 2000	FAO/SDRN	
	Total population	Population in study area	Rural population on currently available land for rainfed agriculture
	persons (1 000)	persons (1 000)	persons (1 000)
World	6,081,258	6,043,273	–
Urban	2,878,689	2,836,720	–
Rural	3,202,569	3,206,553	2,541,590

CHAPTER 3

ENVIRONMENTAL CONDITIONS AND CONSTRAINTS

A major factor determining the vulnerability of rural populations to hunger is the quality and availability of land and water resources for agricultural production. Information about this factor has been derived from the FAO/IIASA global agro-ecological zones (GAEZ) assessment, referred to in Chapter one.

The worldwide land resources database compiled for the GAEZ study enables an evaluation of biophysical limitations and production potentials for major food, feed, fodder and fibre crops in different environments and under various levels of inputs and management conditions.

The land resources database, organized 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;
- Quantification of potential rainfed crop yield and production under the assumptions of three levels of farming technology and management;
- Estimation of the extent of land area suitable for rainfed and irrigated cultivation and pasture;
- Estimation of the potential for production increase, either through bringing additional land under cultivation or through increasing input levels.

The global distribution and severity of climate, soil, and terrain slope constraints derived from the GAEZ land resources database are described briefly below, and the distribution of the world's rural population, as affected by each type of constraint, is presented.

3.1 CLIMATE

For the GAEZ study, historical climate database layers relevant to crop and pasture production potential were created from two datasets compiled by the Climate Research Unit (CRU) at the University of East Anglia (New *et al.*, 1998; CRU, 2002): one consisting of average climate data for the period from 1961 to 1990 and the other consisting of similar data for individual years for the period from 1901 to 1996. These data have then been used to determine the thermal climate, length of growing period and degree of climate variability for each grid cell (FAO & IIASA, 2002; IIASA, 2002).

3.1.1 Thermal climates

The classification system for thermal climate zones used in the GAEZ study includes the following latitudinal belts: tropics, subtropics with summer rainfall, subtropics with winter rainfall, and temperate, boreal and polar/arctic belts. The temperate and boreal belts have been further subdivided according to continentality into three classes, namely: oceanic, sub-continental and continental.

The thermal climate classification system is shown in Box 3.1 while Table 3.1 gives the land area and rural population of the thermal climate zones of the world and Map 3.1 presents their geographic distribution.

BOX 3.1

CLASSIFICATION OF THERMAL CLIMATES

Tropics: *All months with monthly mean temperatures, corrected to sea level, above 18 °C*	
Subtropics: *One or more months with monthly mean temperatures, corrected to sea level, below 18°C but above 5 °C*	Subtropics summer rainfall: *Northern hemisphere: rainfall in April-September ≥ rainfall in October-March* *Southern hemisphere: rainfall in October-March ≥ rainfall in April-September*
	Subtropics winter rainfall: *Northern hemisphere: rainfall in October-March ≥ rainfall in April-September* *Southern hemisphere: rainfall in April-September ≥ rainfall in October-March*
Temperate belt: *At least one month with monthly mean temperatures, corrected to sea level, below 5 °C and four or more months above 10 °C*	Oceanic temperate: *Seasonality less than 20 °C*
	Sub-continental temperate: *Seasonality 20-35 °C*
	Continental temperate: *Seasonality more than 35 °C*
Boreal belt: *At least one month with monthly mean temperatures, corrected to sea level, below 5 °C and more than one but less than four months above 10 °C*	Oceanic boreal: *Seasonality less than 20 °C*
	Sub-continental boreal: *Seasonality 20-35 °C*
	Continental boreal: *Seasonality more than 35 °C*
Polar/arctic belt: *All months with monthly mean temperatures, corrected to sea level, below 10 °C*	

Note: seasonality refers to the difference in mean temperature of the warmest and coldest month, respectively.

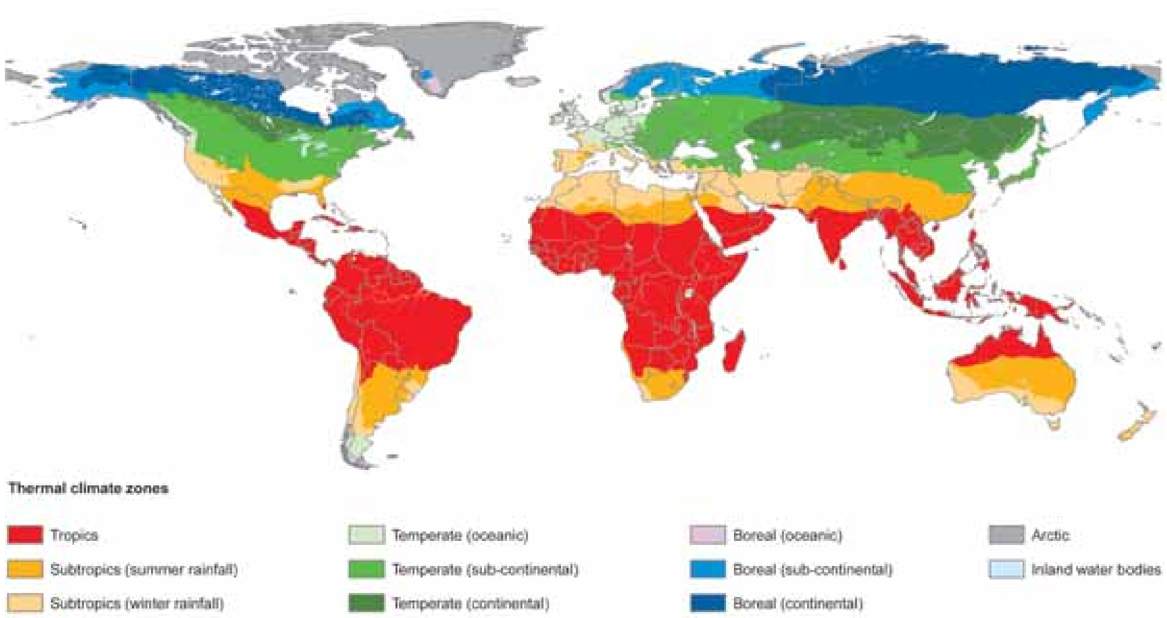
TABLE 3.1

Rural area and rural population of the world, by thermal climate zone

Thermal climate zone	Rural area		Rural population		Rural population density
	km² (1 000)	share of total rural area %	persons (1 000)	share of total rural population %	persons/km²
Tropics	48,613	38.5	1,397,910	43.6	29
Subtropics (summer rainfall)	17,668	14.0	899,920	28.0	51
Subtropics (winter rainfall)	12,583	10.0	185,638	5.8	15
Temperate (oceanic)	2,119	1.7	49,713	1.6	23
Temperate (sub-continental)	17,798	14.0	594,445	18.5	33
Temperate (continental)	9,152	7.2	72,365	2.3	8
Boreal (oceanic)	224	0.2	393	0.0	2
Boreal (sub-continental)	3,768	3.0	3,623	0.1	1
Boreal (continental)	11,887	9.4	2,467	0.1	0
Arctic	2,562	2.0	79	0.0	0
Total	126,374	100.0	3,206,553	100.0	25

MAP 3.1

Thermal climate zones of the world



3.1.2 Length of growing period zones

A general characterization of moisture conditions is achieved in AEZ through the concept of length of growing period (LGP), i.e. the period during the year when both moisture availability and temperature are conducive to crop growth. To capture the temperature component alone, the expression $LGP_{t=5}$ (temperature growing period) is used to indicate the number of days with mean daily temperature above 5 °C, i.e. conducive for crop growth. The expression LGP is then used to refer to the number of days within $LGP_{t=5}$ when moisture conditions are considered adequate.

The growing period for most crops continues beyond the rainy season and, to a greater or lesser extent, crops mature on moisture stored in the soil profile. However, the amount of soil moisture stored in the soil profile, and available to a crop, varies, e.g., with depth of the soil profile, the soil physical characteristics, and the rooting pattern of the crop. The relevant values for individual soil units in a gridcell were used to set limits to available soil moisture (see Section 3.2), enabling calculation of possible extension of the growing period beyond the end of the rainy season for individual soils. Table 3.2 presents the global area and rural population of the various LGP zones and Map 3.2 shows the global distribution of LGP zones.

TABLE 3.2

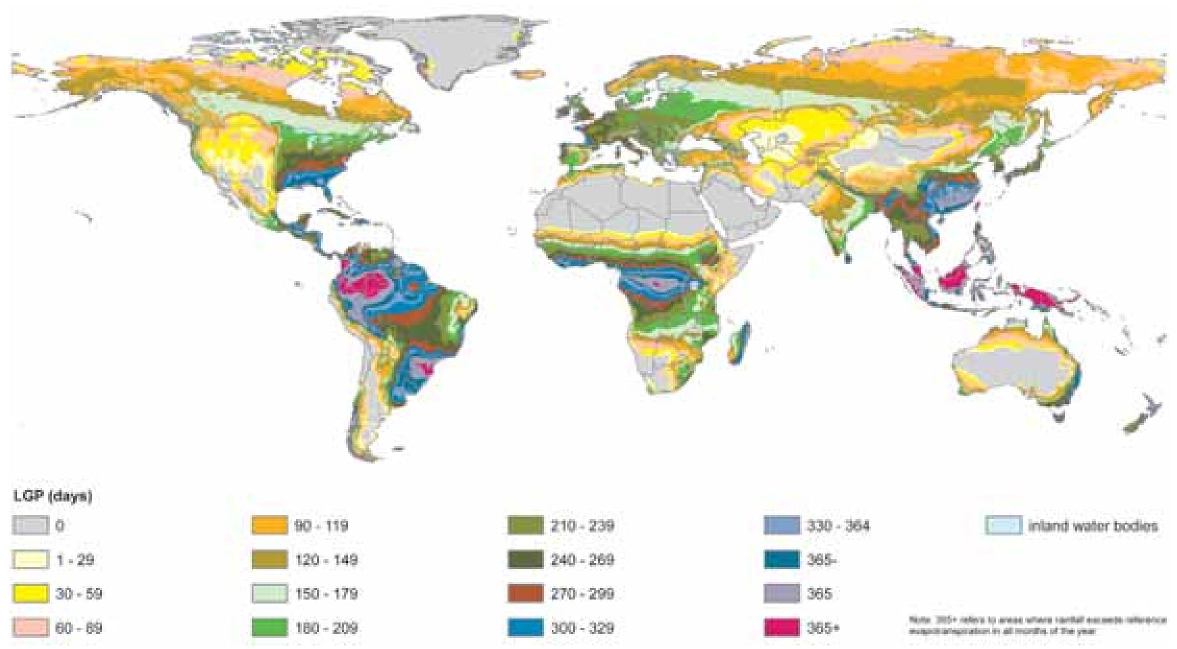
Rural area and rural population of the world, by length of growing period (LGP) zone

LGP zone		Rural area		Rural population		Rural population density
Description	Days of moisture availability where LGP $_{t=5}$ equals 365 days	km² (1 000)	share of total rural area %	persons %	share of total rural population (1 000)	persons/km²
Hyper-arid	0 days	23,5257	18.6	119,998	3.7	5
Arid	1-29 days	5,001	4.0	28,183	0.9	6
Arid	30-59 days	9,275	7.3	61,122	1.9	7
Dry semi-arid	60-89 days	9,998	7.9	96,641	3.0	10
Dry semi-arid	90-119 days	12,577	10.0	158,741	5.0	13
Moist semi-arid	120-149 days	12,595	10.0	352,059	11.0	28
Moist semi-arid	150-179 days	10,688	8.5	340,540	10.6	32
Sub-humid	180-209 days	7,672	6.0	356,983	11.1	47
Sub-humid	210-239 days	6,639	5.3	322,011	10.0	49
Sub-humid	240-269 days	6,359	5.0	286,561	9.0	45
Humid	270-299 days	5,506	4.4	361,134	11.3	66
Humid	300-329 days	4,272	3.4	218,847	6.8	51
Humid	330-364 days	2,192	1.7	110,267	3.4	50
Humid	365- days	3,389	2.7	148,135	4.6	44
Humid	365 days	4,100	3.2	214,360	6.7	52
Per-humid*	365+ days	2,584	2.0	30,971	1.0	12
Total		126,374	100.0	3,206,553	100.0	25

* Per-humid (LGP 365+) refers to areas where rainfall exceeds reference evapotranspiration in all months of the year.

MAP 3.2

Length of growing period (LGP) zones of the world



3.1.3 Climate variability

On the basis of annual climate data for the period 1901-96, the actual length of growing period (LGP) in each gridcell was calculated for each individual year, and standard deviation of LGP (SD in days) and coefficients of variation (CV in percent) were determined. Table 3.3 and Map 3.3 show estimated coefficients of variation of LGP for the period 1901–96, highlighting areas with unreliable growing periods. Areas with particularly high annual variability in growing conditions are found in the mid-west of the USA, northeast Brazil, northeast Argentina and Uruguay, southern Africa and the southeast of Australia. In all these areas, the SD of LGP exceeds 40 days and the CV is larger than 45 percent.

TABLE 3.3

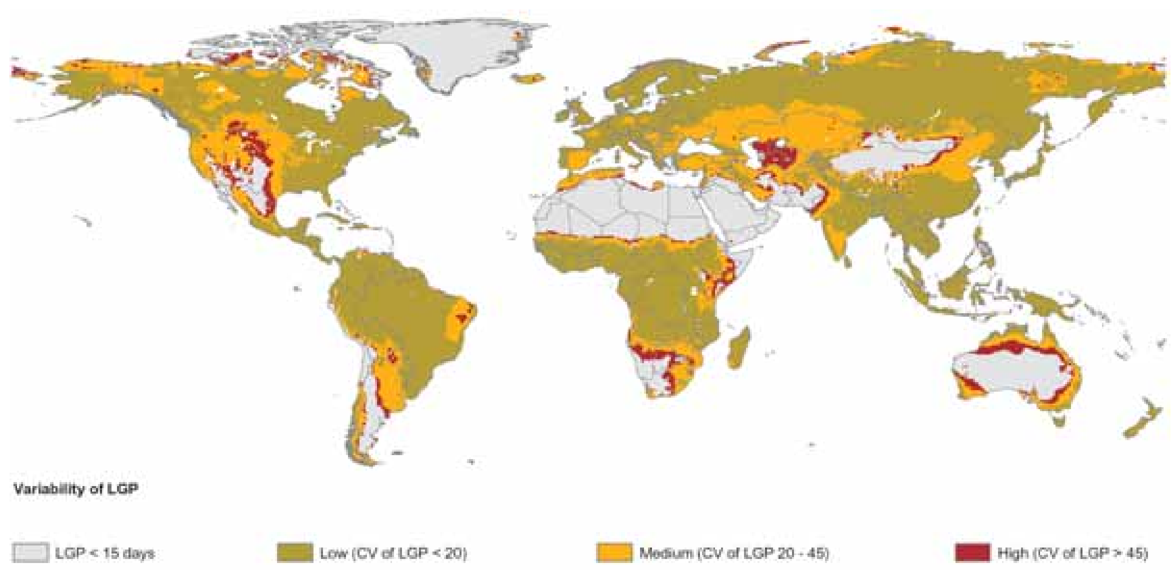
Rural area and rural population of the world, by variability of LGP

Variability of LGP	Rural area		Rural population		Rural population density
	km² (1 000)	share of total rural area %	persons (1 000)	share of total rural population %	persons/km²
LGP < 15 days	25,751	20.6	134,335	4.3	5
High	7,026	5.6	57,563	1.8	8
Medium	26,428	21.1	700,743	22.3	27
Low	66,074	52.7	2,253,025	71.6	34
Total	125,279	100.0	3,145,666	100.0	25.0

Notes: where LGP is less than 15 days, rainfed agriculture is not possible and the CV of LGP is irrelevant.
High: CV of LGP > 45 percent; Medium: CV of LGP 20–45 percent; Low: CV of LGP < 20 percent.
Totals differ slightly from the figures shown in other tables, as the resolution for the base map was different.

MAP 3.3

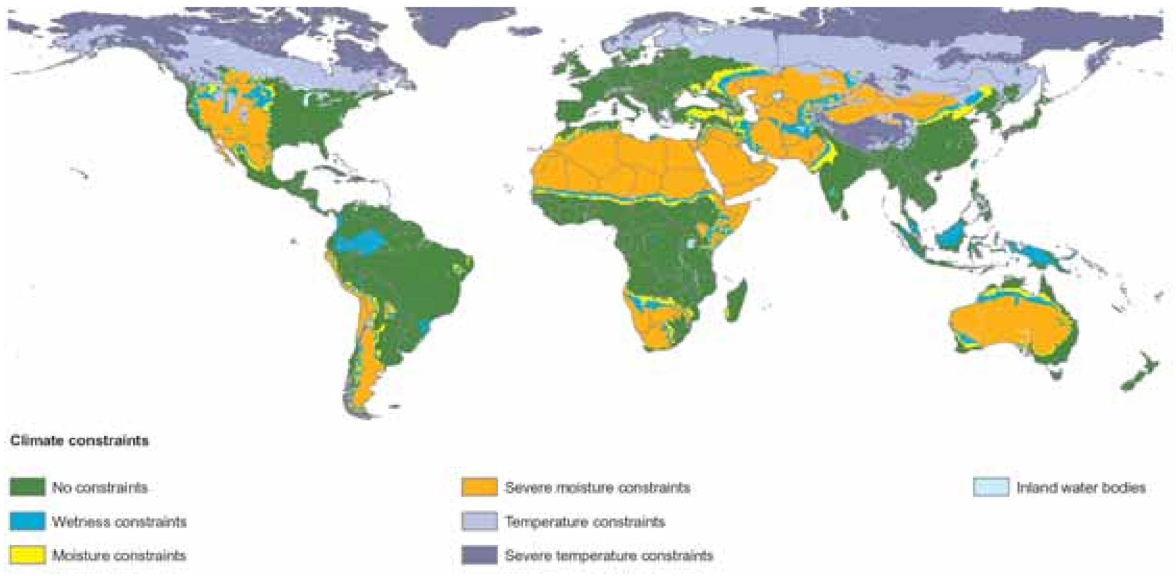
Coefficient of variation (CV) of length of growing period (LGP), 1901-1996



3.1.4 Climate constraints

Climate constraints are classified according to length of periods with cold temperatures and moisture limitations. Temperature constraints are related to the length of the temperature growing period ($LGP_{t=5}$). An $LGP_{t=5}$ of less than 120 days is considered a severe constraint, while an $LGP_{t=5}$ of less than 180 days is considered as posing moderate constraints to crop production. Within areas where $LGP_{t=5}$ does not pose a severe constraint, hyper-arid and arid moisture regimes (LGP<60 days) are considered to be severe constraints, while dry semi-arid moisture regimes (LGP 60–119 days) and per-humid regimes (LGP>365 days) are considered to be moderate constraints. The extent of global land area affected by climate constraints is depicted in Map 3.4.

MAP 3.4
Global land area with climate constraints



Both of these constraints can be removed by use of appropriate technologies. In arid areas where there are underground water reserves or where rainwater can be harvested, irrigation is possible; irrigation technologies can also be used to manage excess moisture. Also, greenhouses and heated barns permit the growing of crops and raising of livestock where temperatures would otherwise be prohibitive. The constraints depicted on the map therefore pertain only to open-air rainfed agriculture.

3.2 SOILS

3.2.1 Soil types and qualities

The FAO/UNESCO Digital Soil Map of the World (FAO & UNESCO, 1991) provides a classification of soils into 106 soil units. These units are defined in terms of measurable and observable properties of the soil itself, many of which are directly relevant to agricultural production potential. The gridded database includes information about the percentage occurrence of soil units in each pixel; other information about the properties of each soil unit is kept in a linked soil association composition database.

In order to represent them in map form, the soil units have been collapsed into 26 major soil groups. In Table 3.4 the major soil groups are shown together with the distribution of global rural area and rural population by soil group. Map 3.5 depicts the distribution of these major soil groups on the world's land surface.

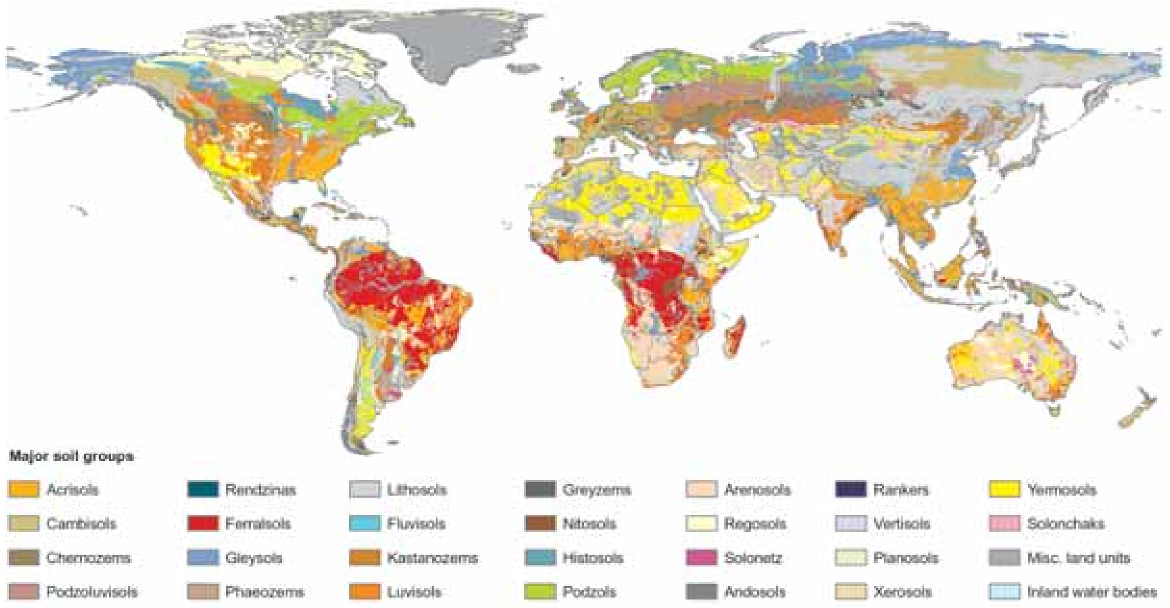
TABLE 3.4

Rural area and rural population of the world, by major soil group

Major soil group			Suited for agricultural use	Rural area	Rural population	Rural population density
Symbol	**Name**	**Description**		**km² (1 000)**	**persons (1 000)**	**persons/km²**
A	Acrisols	Soils with subsurface accumulation of low activity clays and low base saturation	marginally to moderately	8,003	417,575	52
B	Cambisols	Weakly to well developed soils	well	8,942	460,535	52
C	Chernozems	Soils with a thick, dark topsoil rich in organic matter with a calcareous subsoil	well	2,096	30,821	15
D	Podzoluvisols	Soils with accumulation of clay in subsoil with some subsurface accumulation of iron-aluminium-organic compounds	moderately to well	2,382	15,323	6
E	Rendzinas	Shallow soils overlaying calcareous hard rock	marginally to moderately	422	8,991	21
F	Ferralsols	Deep strongly weathered soils with a chemically poor but physical stable subsoil	marginally to moderately	10,366	107,191	10
G	Gleysols	Soils with permanent or temporary wetness near the surface	not to moderately	5,509	438,681	80
H	Phaeozems	Soil with a thick, dark topsoil rich in organic matter and evidence of removal of carbonates	well	1,438	36,638	25
I	Lithosols	Very shallow soils over hard rock in unconsolidated very gravely material	not	21,624	289,350	13
J	Fluvisols	Young soils in alluvial deposits	moderately to very well	2,979	212,822	71
K	Kastanozems	Soils with a thick dark brown topsoil, rich in organic matter and a calcareous or gypsum rich subsoil	well	4,548	31,757	7
L	Luvisols	Soil with a accumulation of high activity clays and high base saturation	very well	8,698	405,738	47
M	Greyzems	Grey soils rich in organic matter	well	293	2,040	7
N	Nitosols	Deep, dark red, brown or yellow clayey soils having a pronounced shiny structure	very well	1,990	144,288	73
O	Histosols	Soils which are composed of organic materials	not to moderately	2,419	11,446	5
P	Podzols	Acid soils with subsurface accumulation of iron-aluminium-organic compounds	marginally to moderately	4,463	22,909	5
Q	Arenosols	Sandy soils featuring very weak or no soil development	marginally to moderately	6,778	74,688	11
R	Regosols	Soils with very limited soil development	moderately to well	6,189	60,882	10
S	Solonetz	Soils with subsurface clay accumulation rich in sodium	not to marginally	1,108	3,139	3
T	Andosols	Young soils in volcanic deposits	well to very well	929	38,486	41
U	Rankers	Shallow mountain slope soils with weak soil development	marginally	55	618	11
V	Vertisols	Often dark coloured soils in cracking and swelling clays	moderately to well	3,030	192,148	63
W	Planosols	Soils with a bleached temporary water saturated topsoil and slowly permeable subsoil	marginally to moderately	1,177	11,066	9
X	Xerosols	Desert soils with some organic matter in the topsoil, takyric features or gypsic or calcic subsoils	marginally to well	4,486	75,506	17
Y	Yermosols	Desert soils with virtually no organic matter in the topsoil, takyric features or gypsic or calcic subsoils	not to marginally	11,318	88,712	8
Z	Solonchaks	Strongly saline soils	not	1,278	18,706	15
MU	Misc. Units	Dunes, shifting sands, salt flats, rock debris, desert detritus and glaciers and snowcaps	not	3,855	6,497	2
Total				126,374	3,206,553	25

MAP 3.5

Major soil groups of the world



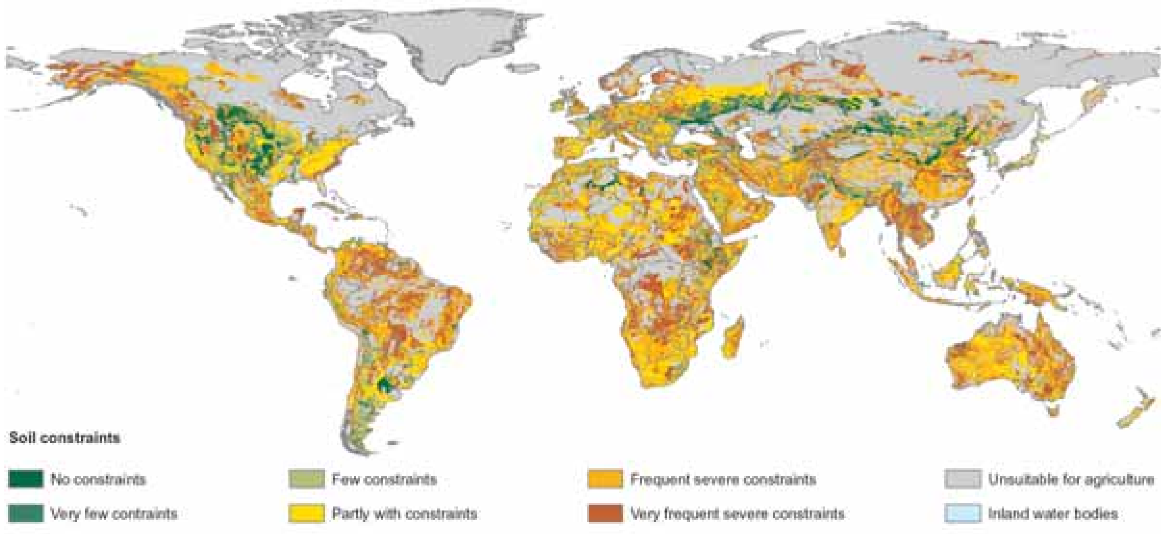
3.2.2 Soil constraints

Soil depth and soil quality, as defined below, are the attributes that are relevant for evaluation of the suitability of land for agriculture. The shallower the soil, and the poorer its quality, the more severe are the constraints to crop agriculture and grazing. Criteria used in the GAEZ study for establishing the severity of soil constraints are described below and the global distribution of these constraints is shown in Map 3.6.

- **Depth:** soils with a depth of less than 50 cm are severely constrained; those with a depth of 50–100 cm are moderately constrained. Deeper soils are not constrained.
- **Soil chemical status and natural fertility:** soils with high salinity, sodicity or gypsum contents are severely constrained, as are soils with low natural fertility; those with moderate natural fertility are moderately constrained; those with high natural fertility are not constrained.
- **Drainage:** soils that are poorly or imperfectly drained (gleysols, planosols, soils with antraquic phases) are severely constrained; soils with gleyic and stagnogleyic subgroups are moderately constrained; excessively and well-drained soils are not constrained.
- **Texture:** coarse textured soils and soils with stones, boulders or rock outcrops in the surface layer or at the surface are severely constrained; soils with heavy cracking clays are moderately constrained; other soils with medium and fine textures are not constrained.
- **Miscellaneus land:** this land is not fit for agriculture and includes: dunes, shifting sands, salt flats, rock debris, desert detritus, and glaciers and snow caps. Miscellaneous land units are classified as severely constrained.

MAP 3.6

Global land area with soil constraints



3.3 TERRAIN SLOPE

3.3.1 Terrain slope classes

Sloping terrain is more difficult to cultivate than flatland, and is subject to higher rates of water runoff and soil erosion. Generally speaking, the steeper the slope, the greater the constraint to productivity potential, although this constraint can be relieved to some extent through use of terraces.

In the context of suitability of a land area for agriculture, the unit of measurement used to define terrain slope classes is the percent slope. This refers to the rise in elevation in meters over a range of 100 meters. The Digital Soil Map of the World distinguishes three broad slope classes, namely, level to undulating (dominant slopes ranging between 0 and 8 percent), rolling to hilly (dominant slopes ranging between 8 and 30 percent), and steeply dissected to mountainous (dominant slopes more than 30 percent). As with soil types, terrain slopes also exhibit a high degree of variation within small areas.

For the GAEZ study seven slope classes were defined, and the distribution of slope classes was determined for each 30 arc-second gridcell of the Global Digital Elevation Model (GTOPO30). The results were aggregated into 5 minute gridcells and, based on known relationships between soil types and slope, into individual soil association units. From this a derived slope distribution was developed. The results are shown in Map 3.7.

3.3.2 Terrain slope constraints

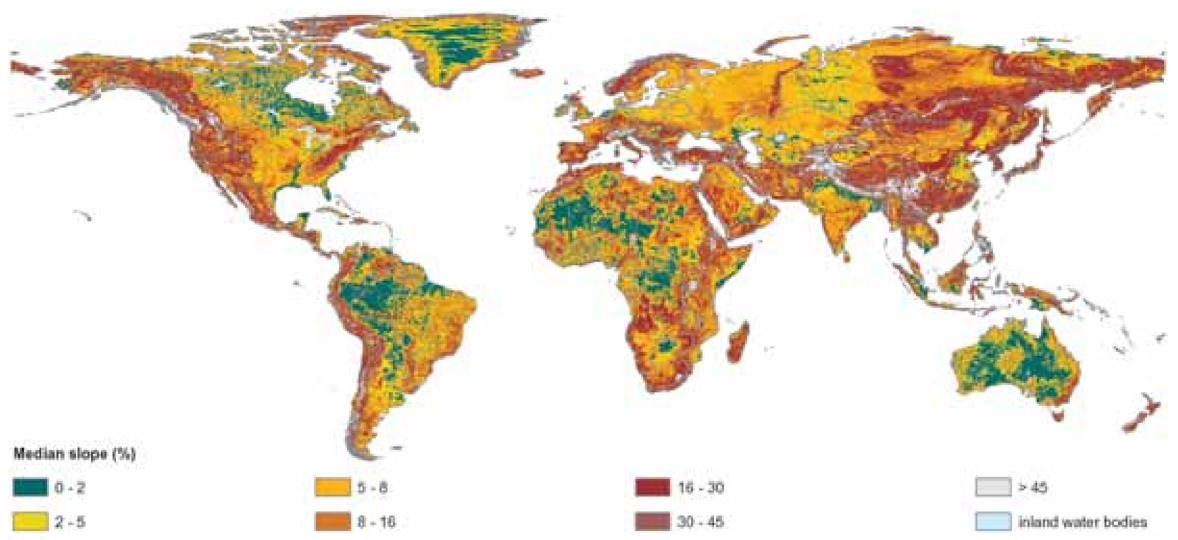
The slope thresholds applied in the GAEZ study to define the degree of constraint to productivity of different categories of agricultural land are as shown below. Map 3.8 depicts the extent of terrain slope constraints on the world's land surface, while Table 3.5 shows the distribution of global rural area and rural population by degree of terrain slope constraint.

- **For rainfed land:** land with slopes greater than 30 percent is severely constrained; land with slopes from 16–30 percent is moderately constrained; land with slopes 8–16 percent is slightly constrained; land with slopes 0–8 percent is not constrained.

- **<u>For non-terraced land with gravity irrigation:</u>** land with slopes greater than 8 percent is severely constrained; land with slopes 5–8 percent is moderately constrained; land with slopes 2–5 percent is slightly constrained; land with slopes 0–2 percent is not constrained.
- **<u>For land with sprinkler irrigation:</u>** land with slopes greater than 16 percent is severely constrained; land with slopes 8–16 percent is moderately constrained; land with slopes 5–8 percent is slightly constrained; land with slopes 0–5 percent is not constrained.

MAP 3.7

Terrain slope classes of the world



MAP 3.8

Global land area with terrain slope constraints

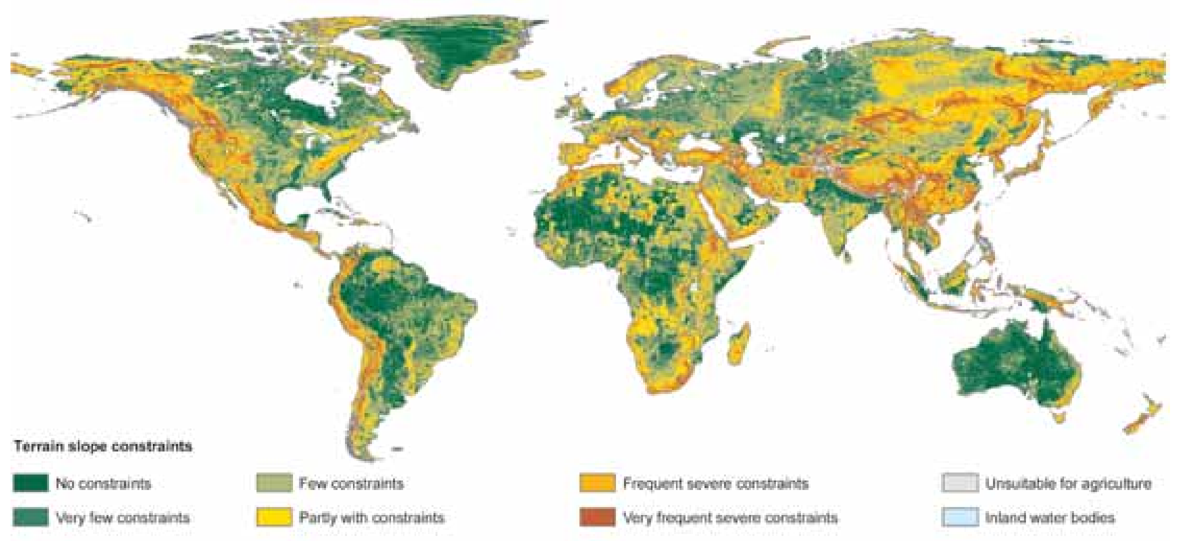


TABLE 3.5

Rural area and rural population of the world, by degree of terrain slope constraint

Terrain slope constraints	Rural area		Rural population		Rural population density
	km² (1 000)	share of total rural area %	persons (1 000)	share of total rural population %	persons/km²
No constraints	16,945	13.4	444,422	13.9	26
Very few constraints	26,246	20.8	804,980	25.1	31
Some constraints	36,333	28.7	884,514	27.6	24
Some severe constraints	22,704	18.0	561,862	17.5	25
Frequent severe constraints	14,303	11.3	342,953	10.7	24
Very frequent severe constraints	8,557	6.8	152,130	4.7	18
Unsuitable for agriculture	1,286	1.0	15,692	0.5	12
Total	126,374	100.0	3,206,553	100.0	25

3.4 ENVIRONMENTAL CONSTRAINTS TO RAINFED AGRICULTURE

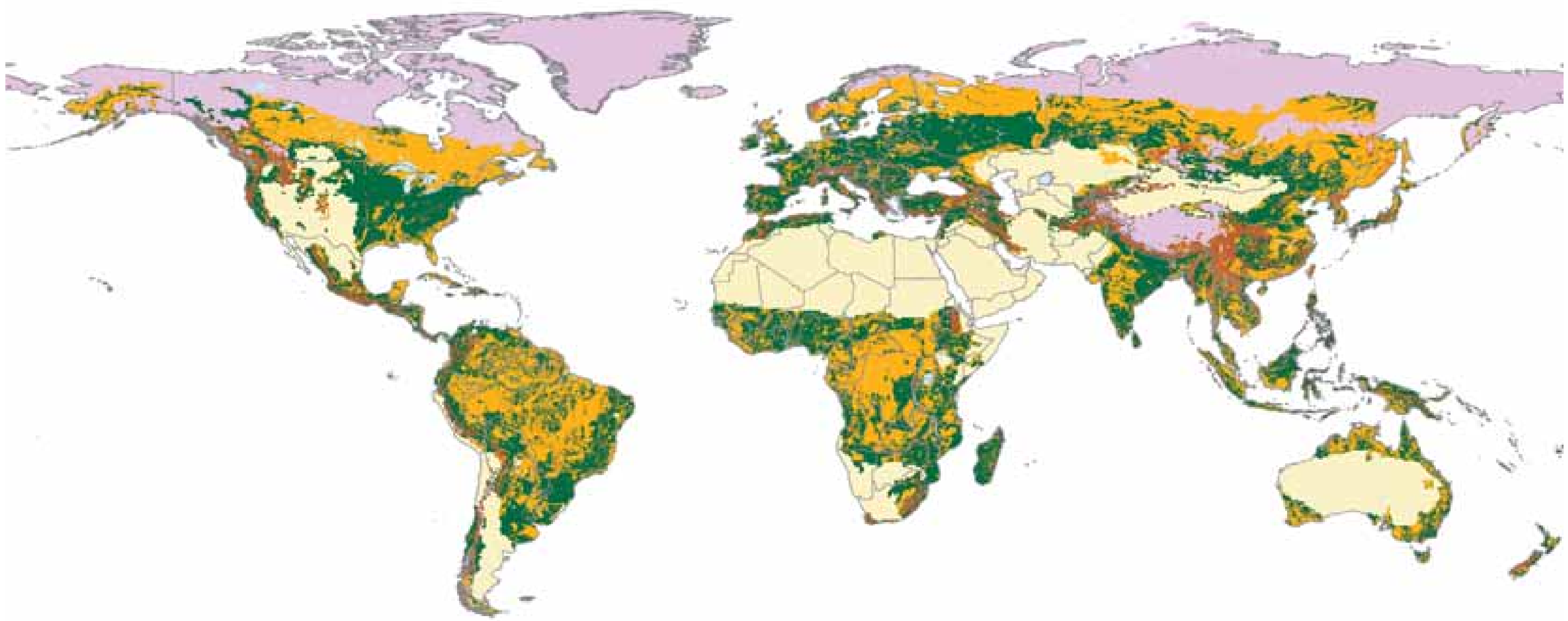
3.4.1 Global occurrence of combined constraints

The GAEZ land resources database allows characterization of various regions according to the prevailing climate, soil and terrain constraints. Based on this, a constraint classification has been formulated and has been applied to each gridcell of the database.

On the basis of currently available soil, terrain and climatic data, the GAEZ study estimated that some 10.5 billion hectares of land, i.e., almost four-fifths of the global land surface (excluding Antarctica) suffer rather severe constraints for rainfed crop cultivation. Map 3.9 shows the occurrence of different types of severe constraints in hierarchical order, while Table 3.6 presents their regional distribution and Table 3.7 shows the rural land area that is affected by all of the various kinds of constraints for rainfed crop production considered in the analysis. An estimated 12 percent of rural area considered in this report is too cold, 26 percent is too dry, eight percent is too steep, and some 50 percent is constrained by poor soil conditions. The analysis concludes that only 3.5 percent of the land surface can be regarded to be entirely free of constraining factors. Only for Melanesia, Southern Europe and Western Europe does the share of essentially constraint-free conditions exceed 50 percent.

MAP 3.9

Hierarchical distribution of severe environmental constraints



Environmental constraint class

- Too cold
- Too dry
- Too steep
- Poor soils
- Not severely constrained
- Inland water bodies

TABLE 3.6

Extent of the world's rural land area with severe environmental constraints for rainfed crop production, by region

Major area and region	Rural area	Rural area with severe constraints		Land area with severe constraints for rainfed cultivation of crops*			
				too cold ($LGP_{t=5}$ <120)	too dry ($LGP_{t=5}$ <60)	too steep (slope >30%)	poor soils**
	km²	km²	share of rural area in the region	share of rural area in the region	share of rural area in the region	share of rural area in the region	share of rural area in the region
	(1 000)	(1 000)	%	%	%	%	%
AFRICA							
Eastern Africa	6,161	3,146	51.1	-	19.0	5.3	37.3
Middle Africa	6,486	4,498	69.3	-	12.9	0.9	61.4
Northern Africa	7,918	7,117	89.9	-	77.6	2.5	50.0
Southern Africa	2,635	1,947	73.9	-	57.6	9.1	16.2
Western Africa	5,971	3,922	65.7	-	49.1	0.1	37.0
AMERICAS							
Caribbean	179	95	53.1	-	-	11.2	48.0
Central America	2,371	1,593	67.2	-	32.1	18.1	35.9
Northern America	18,078	13,502	74.7	28.9	14.5	7.3	53.6
South America	16,921	10,119	59.8	0.6	10.1	5.1	50.2
ASIA							
Eastern Asia	10,750	7,716	71.8	17.0	20.5	20.0	46.1
Japan	329	174	52.9	-	-	25.8	46.2
South-central Asia	10,099	7,344	72.7	1.6	47.3	12.9	49.5
South-eastern Asia	4,290	2,187	51.0	-	-	14.3	45.9
Western Asia	4,410	3,703	84.0	-	72.0	12.3	27.2
EUROPA							
Eastern Europe	18,020	13,695	76.0	40.8	1.3	6.1	74.3
Northern Europe	1,440	958	66.5	15.1	-	4.4	64.9
Southern Europe	1,232	430	34.9	0.6	0.2	21.6	22.6
Western Europe	858	315	36.7	0.7	-	13.6	31.5
OCEANIA							
Australia and New Zealand	7,781	6,373	81.9	-	61.9	0.9	40.6
Melanesia	445	172	38.7	-	-	17.1	25.2
Developed	**47,738**	**35,447**	**74.3**	**26.8**	**16.1**	**6.3**	**58.4**
Developing	**78,636**	**53,559**	**68.1**	**2.7**	**32.1**	**8.7**	**45.2**
World	**126,374**	**89,006**	**70.4**	**11.8**	**26.0**	**7.8**	**50.2**

* percentages may sum to more than total share of severely constrained rural area in the region, because several constraints coincide in some locations.
** shallow, low fertility, poor drainage, stony or sandy, saline, sodic gypsic.

TABLE 3.7

Extent of the world's total land area affected by climate, soil and terrain constraints for rainfed crop production, by type of constraint

Factor	Value/ Class	Degree*	Hyper-arid LGP 0 days CC	Arid LGP 1-60 CC	Dry semi-arid LGP 60-119 C	Moist semi-arid LGP 120-179	Sub-humid LGP 180-269	Humid LGP 270-365	Per-humid*** LGP 365+ C	Total km² (1 000)	Total share of total %
			km² (1 000)								
Temperature	$LGP_{t=5} > 180$		23,660	9,878	10,113	9,843	22,020	21,096	2,680	99,290	74.1
	$LGP_{t=5} < 180$	C	667	1,243	1,811	13,312	0	0	0	17,033	12.7
	$LGP_{t=5} < 120$	CC	3,199	2,570	11,903	0	0	0	0	17,672	13.2
Terrain	0–8%		17,238	7,598	10,725	11,658	11,274	12,352	1,608	72,453	54.1
slopes	8–16%	C	4,890	2,452	4,290	4,543	4,094	3,172	330	23,771	17.7
	16–30%	C	3,546	1,960	4,804	4,195	3,956	3,136	420	22,017	16.4
	> 30%	CC	1,852	1,682	4,007	2,760	2,696	2,436	322	15,755	11.8
Soil depth	Deep		15,972	9,525	15,848	17,760	18,337	18,575	2,422	98,439	73.5
	Medium	C	1,208	280	302	275	208	94	36	2,403	1.8
	Shallow	CC	4,210	2,253	6,543	4,494	2,942	2,062	205	22,707	16.9
Soil fertility	High		12,646	6,320	7,420	6,010	5,989	3,105	203	41,692	31.1
	Medium	C	1,829	1,337	3,143	6,114	8,098	8,277	1,254	30,053	22.4
	Low	CC	6,914	4,401	12,130	10,405	7,400	9,348	1,206	51,805	38.7
Soil drainage	Good		21,047	11,307	19,672	19,710	18,637	17,871	2,328	110,572	82.5
	Poor	CC	342	751	3,021	2,819	2,850	2,859	335	12,977	9.7
Soil texture	Medium/fine		11,117	7,957	15,967	16,206	15,970	17,537	2,478	87,232	65.1
	Sandy/stony	CC	3,076	1,350	2,447	1,795	1,246	735	59	10,708	8.0
	Cracking clay	C	7,196	2,751	4,279	4,527	4,272	2,459	126	25,610	19.1
Soil chemical	None		19,062	9,579	21,023	21,604	20,926	20,399	2,639	115,233	86.0
constraints	S/S/G**	CC	2,327	2,479	1,670	924	561	332	24	8,317	6.2
Miscellaneous land units		CC	6,136	1,634	1,134	627	533	365	17	10,445	7.8
Total *without* constraints			0	0	0	1,346	2,264	1,084	0	4,694	3.5
Total with *moderate* constraints		C	0	0	5,279	5,418	6,721	6,178	1,032	24,628	18.4
Total with *severe* constraints		CC	27,526	13,692	18,547	16,392	13,035	13,834	1,647	104,673	78.1
Total	km² (1 000)		27,526	13,692	23,827	23,156	22,020	21,096	2,680	133,995	
	share of total (%)		20.5	10.2	17.8	17.3	16.4	15.7	2.0	100.0	

* C = moderate or slight constraint; CC = severe constraint.
** Salinity/Sodicity/Gypsum.
*** Per-humid (LGP 365+) refers to areas where rainfall exceeds reference evapotranspiration in all months of the year.
Notes: individual constraints are non-additive, i.e., they may overlap. Total area is defined as moderately constrained if there are no severe constraints, but at least one moderate constraint is present; area is defined as severely constrained if at least one severe constraint is present.

3.4.2 Distribution of rural population by constraint class

The presence of constraints reduces the productivity potential of the land below the maximum yield potential of the crop or crops being grown. However, unless the constraints are severe, production and sustainable agriculture is possible in the presence of constraints, and in fact, this is the condition in which most agriculture is practiced around the world. Except in locations that are absolutely too cold or too dry for rainfed agriculture, even those with severe terrain and soil constraints can sustain some agriculture, at least for a few years until the soils are exhausted or eroded. Table 3.8 shows the rural population living in areas with severe constraints, by region. This shows that, for the world as a whole, 38.2 percent of the total rural population is living in areas with poor soils. Regarding other constraints, as compared to other regions, Northern Africa has the largest share of its total rural population living in areas that are too dry, whereas Southern Africa, Western Asia and Central America have the largest shares living in areas that are too steep.

Overall, the share of the rural population living with some kind of severe constraint comes to 46 percent for developing countries, but only 28.6 percent for developed countries.

TABLE 3.8

Rural population living in areas with severe environmental constraints for rainfed crop production, by region

Major area and region	Rural population	Rural population living in areas with severe constraints		Rural population living in areas with severe constraints, by type of constraint			
				too cold ($LGP_{t=5}$ <120)	too dry ($LGPP_{t=5}$ <60)	too steep (slope >30%)	poor soils*
	persons (1 000)	persons (1 000)	share of rural population in the region %	share of rural population in the region %	share of rural population in the region %	share of rural population in the regionin %	share of rural population in the region %
AFRICA							
Eastern Africa	192,660	81,847	42.5	-	5.5	8.5	33.0
Middle Africa	63,814	37,407	58.6	-	1.5	0.9	56.9
Northern Africa	87,120	63,387	72.8	-	53.0	6.3	57.8
Southern Africa	23,744	10,535	44.4	-	14.3	17.9	15.3
Western Africa	137,301	43,960	32.0	-	4.6	0.1	28.7
AMERICAS							
Caribbean	12,782	5,380	42.1	-	-	9.9	38.4
Central America	43,558	19,874	45.6	-	6.9	18.7	28.1
Northern America	68,742	22,023	32.0	0.3	6.4	1.3	25.4
South America	93,805	39,025	41.6	0.4	5.1	6.7	33.1
ASIA							
Eastern Asia	830,605	453,297	54.6	0.3	2.2	7.3	49.1
Japan	27,559	6,265	22.7	-	-	3.8	21.0
South-central Asia	1,040,585	386,445	37.1	0.1	8.7	3.1	31.1
South-eastern Asia	320,510	163,547	51.0	-	-	2.9	49.6
Western Asia	64,148	33,783	52.7	-	32.5	20.5	26.7
EUROPA							
Eastern Europe	94,972	25,309	26.6	1.2	1.3	0.8	25.8
Northern Europe	116,163	6,050	37.4	1.9	-	1.1	36.9
Southern Europe	49,254	12,474	25.3	0.5	0.1	10.5	19.3
Western Europe	30,487	8,867	29.1	0.2	-	4.4	27.3
OCEANIA							
Australia and New Zealand	4,168	2,212	53.1	-	12.0	0.3	46.8
Melanesia	4,576	1,443	31.5	-	-	10.2	23.1
Developed	**291,345**	**83,200**	**28.6**	**0.7**	**2.1**	**3.2**	**25.2**
Developing	**2,915,208**	**1,339,930**	**46.0**	**0.1**	**7.0**	**5.4**	**39.4**
World Total	**3,206,553**	**1,423,130**	**44.4**	**0.2**	**6.6**	**5.2**	**38.2**

* shallow, low fertility, poor drainage, stony or sandy, saline, sodic gypsic.

CHAPTER 4

LAND PRODUCTIVITY POTENTIALS

4.1 PROCEDURE FOR ESTIMATING PRODUCTIVITY POTENTIAL OF LAND FOR RAINFED CROPS AND PASTURE

The characterization of climate, soil and terrain conditions relevant to agricultural production provides a first indication of the degree of suitability of land areas for rainfed agriculture, based on geophysical factors. However, this covers only one face of the total picture. The techniques of suitability analysis have been developed to permit consideration of the more complex interplay of geophysical, biological and socioeconomic factors that actually determine productivity potentials in real life conditions.

4.1.1 Definition of land utilization types (LUTs)

The GAEZ method (see Chapter one) uses crop models and environmental matching procedures to identify the degree of crop-specific environmental limitations across the world's land area, under three different assumptions about the input levels and management conditions. The crop models use the environmental requirements and adaptability characteristics of each crop species assessed and calculate the expected yields under different sets of environmental conditions and input/management scenarios, while the input/management scenarios reflect different investment options that may be implemented by humans. These are combined by specifying a number of crop production systems, termed land utilization types, or LUTs. A LUT consists of a set of technical specifications within a socioeconomic setting. As a minimum requirement, both the nature of the produce and the setting must be specified. Attributes specific to particular land utilization types include crop information such as cultivation practices, input requirements, crop calendars, and utilization of main produce, crop residues, and by-products.

For the GEAZ studies completed thus far (FAO & IIASA, 2002 and FAO & IIASA, 2003), 171 crop LUTs have been defined, each with defined environmental requirements and adaptability characteristics for a specific crop type. Table 4.1 shows the crops and crop types included in the nine crop groups considered in this report. Based on this information, global productivity potential is assessed for each crop type, at three different levels of inputs and management under rainfed conditions, and two different levels of inputs and management under irrigated conditions (see Box 4.1).

TABLE 4.1

Crop groups, crops and crop types considered in this report

CROP GROUPS AND CROPS	CROP TYPES	THERMAL CLIMATE ZONES
Cereals	**(83)**	
Wheat (hibernating)	4	Boreal, Temperate and Subtropics
Wheat (non-hibernating)	12	Boreal, Temperate, Subtropics and Tropics
Rice, japonica (wetland)	4	Tropics, Subtropics and Temperate
Rice, indica (wetland)	4	Tropics and Subtropics
Rice (dryland)	3	Tropics
Maize (grain)	13	Tropics, Subtropics and Temperate
Maize (silage)	6	Subtropics and Temperate
Barley (hibernating)	4	Boreal, Temperate and Subtropics
Barley (non-hibernating)	12	Boreal, Temperate, Subtropics and Tropics
Sorghum	7	Tropics, Subtropics and Temperate
Pearl millet	2	Tropics
Foxtail millet (setaria)	4	Subtropics and Temperate
Rye (hibernating)	4	Temperate and Subtropics
Rye (non-hibernating)	4	Boreal, Temperate and Subtropics
Fibre crops	**(7)**	
Cotton	7	Tropics, Subtropics and Temperate
Oil Crops	**(25)**	
Soybean	6	Tropics, Subtropics and Temperate
Rape (hibernating)	2	Temperate and Subtropics
Rape (non-hibernating)	6	Temperate, Subtropics and Tropics
Groundnut	3	Tropics, Subtropics and Temperate
Sunflower	6	Temperate, Subtropics and Tropics
Oil palm	1	Tropics and Subtropics
Olive	1	Subtropics and Temperate
Pulses	**(17)**	
Phaseolus bean	9	Tropics, Subtropics and Temperate
Chickpea	5	Subtropics and Tropics
Cowpea	3	Tropics
Roots and Tubers	**(14)**	
White potato	4	Boreal, Temperate, Subtropics and Tropics
Cassava	1	Tropics
Sweet potato	3	Subtropics and Tropics
White yam	2	Tropics
Greater yam	2	Tropics
Yellow yam	1	Tropics
Cocoyam (taro)	1	Tropics
Stimulants	**(7)**	
Cocoa	1	Tropics
Arabica coffee	1	Tropics
Robusta coffee	1	Tropics
Tobacco	4	Tropics, Subtropics and Temperate
Sugar Crops	**(6)**	
Sugarcane	1	Tropics and Subtropics
Sugar beet	5	Temperate and Subtropics
Fruit Crops	**(1)**	
Banana/Plantain	1	Tropics and Subtropics
Citrus	1	Tropics and Subtropics
Vegetables	**(10)**	
Cabbage	2	Tropics, Subtropics and Temperate
Onion	4	Tropics, Subtropics and Temperate
Tomato	4	Tropics, Subtropics and Temperate
Total	**171**	

BOX 4.1

ASSUMED LEVELS OF INPUTS AND MANAGEMENT IN FARMING SYSTEMS UNDER THREE INPUT SCENARIOS

Low level of inputs/traditional management (rainfed)

Under the low level of input, traditional management assumption, the farming system is largely subsistence based and not necessarily market oriented. Production is based on the use of traditional cultivars (if improved cultivars are used, they are treated in the same way as local cultivars), labour intensive techniques, and no application of nutrients, no use of chemicals for pest and disease control and minimum conservation measures.

Intermediate level of inputs/improved management (rainfed or irrigated)

Under the intermediate level of input, improved management assumption, the farming system is partly market oriented Production for subsistence plus commercial sale is a management objective. Production is based on improved varieties, on manual labour with hand tools and/or animal traction and some mechanization, is medium labour intensive, uses some fertilizer application and chemical pest disease and weed control, adequate fallows and some conservation measures.

High level of inputs/advanced management (rainfed or irrigated)

Under the high level of input, advanced management assumption, the farming system is mainly market oriented. Commercial production is a management objective. Production is based on improved high yielding varieties, is fully mechanized with low labour intensity and uses optimum applications of nutrients and chemical pest, disease and weed control.

4.1.2 Estimation of maximum attainable and long-term achievable crop yields

Ranges for maximum attainable yields ranges were calculated for each crop present in tropical, sub-tropical and temperate/boreal zones. The maximum attainable yields for each crop under rainfed conditions represent averages of simulated year-by-year yields attainable during the period 1960 to 1996.

With balanced fertilizer applications and proper pest and disease management (which is best possible at high level of inputs), only limited fallow will be required to maintain soil fertility and to keep pest and disease outbreaks in check. At low level of inputs, assuming no application of chemical fertilizer and only limited used of organic material, and very limited or no application of biocides, there is need for considerable fallow periods in the crop rotations to restore soil nutrient status and to break pest and disease cycles. In the GAEZ study, long-term achievable yields are calculated by applying a fallow-period requirement factor dependent on climatic conditions, soil type, crop, and level of inputs/management. The yields attained in the long-term are well below the estimated maximum attainable yields when accounting for fallow period requirements.

4.1.3 Estimation of land productivity potential for rainfed cereals

Table 4.2 compares maximum (short-term) attainable yields and long-term achievable yields on suitable land (see Section 4.1.5) for staple cereals (rainfed wheat, rice, grain maize). On average, long-term achievable yields are 10, 20, and 55 percent lower than maximum attainable yields, respectively at high, intermediate and low levels of inputs. These represent the best estimate of the productivity potential of land for this crop group.

TABLE 4.2

Maximum (short-term) attainable and long-term achievable yields for staple cereals (rainfed wheat, rice, grain maize) averaged over all VS+S+MS land, by region and level of inputs

Major area	Low inputs		Intermediate inputs		High inputs	
	Short-term attainable t/ha	Long-term achievable t/ha	Short-term attainable t/ha	Long-term achievable t/ha	Short-term attainable t/ha	Long-term achievable t/ha
Africa	1.0	0.4	3.7	3.0	6.4	5.8
America						
Latin America and Caribbean	1.2	0.6	3.7	3.1	5.8	5.3
North America	0.8	0.4	3.6	2.8	5.8	5.2
Asia (*including Japan*)	1.0	0.5	3.5	2.8	5.3	4.8
Europe						
Europe (excluding Russian Federation)	1.0	0.4	4.0	3.1	6.4	5.8
Russian Federation	0.7	0.3	2.9	2.5	4.4	4
Oceania (*including Australia and New Zealand*)	0.7	0.4	3.2	2.6	5.3	4.8
Developed	**0.9**	**0.4**	**3.5**	**2.8**	**5.6**	**5.1**
Developing	**1.1**	**0.5**	**3.7**	**3.0**	**6.2**	**5.6**
World	**1.0**	**0.4**	**3.7**	**3.0**	**5.9**	**5.4**

Note: the short-term attainable yields represent yields attained during the cultivation phase of cultivation-fallow cycles. These are referred to as maximum or short-term attainable yields. In low and intermediate input agriculture, fallow and/or crop rotations are needed to maintain the soil nutrient balance and to break pest and disease cycles. The required intensity of fallow depends on crop rotations implemented, on soil characteristics such as soil nutrient availability and nutrient retention capacity, on climatic conditions and on management and agricultural inputs applied. Long-term achievable yields are calculated by applying a fallow period requirement factor. As a rule of thumb for low level input/management conditions, fallow period requirements may vary between 30–90% of the cultivation-fallow cycle. For intermediate level input/management conditions, fallow requirements may vary between 10–30%.

4.1.4 Variability of rainfed cereal production

The historical climate data for individual years (see Section 3.1) have been used to calculate a time series of production potentials for cereals. Of a total of 83 cereal types, consisting of cultivars of wheat, rice, barley, rye, sorghum, millet, and setaria, AEZ tests and selects for each of the 2.2 million gridcells of the land resources database for each year the cereal type that results in the highest production, given the climatic conditions for that year.

During the 20th century, the global average of potential cereal production, based on year-by-year simulations for currently cultivated land with fixed inputs, increased by over five percent between the period 1901-30 and the period 1961-90. On the other hand, simulations based on average climate data for the whole period from 1961 to 1990 produced a figure for average potential cereal production for the globe that was almost 10 percent higher than the average obtained using historical climate data for individual years. This comparison provides a rough estimate of the losses being incurred due to climate variability. Results by region are shown in Table 4.3.

The table highlights the fact that the coefficient of variation for production potential for rainfed cereals actually appears to be significantly higher in developed nations than in developing nations. However, Map 4.1, which presents the variability of cereal production potential for the period 1961-1990 on a country-by-country basis, shows that the most vulnerable individual countries occur mainly in Central Asia and Africa.

TABLE 4.3

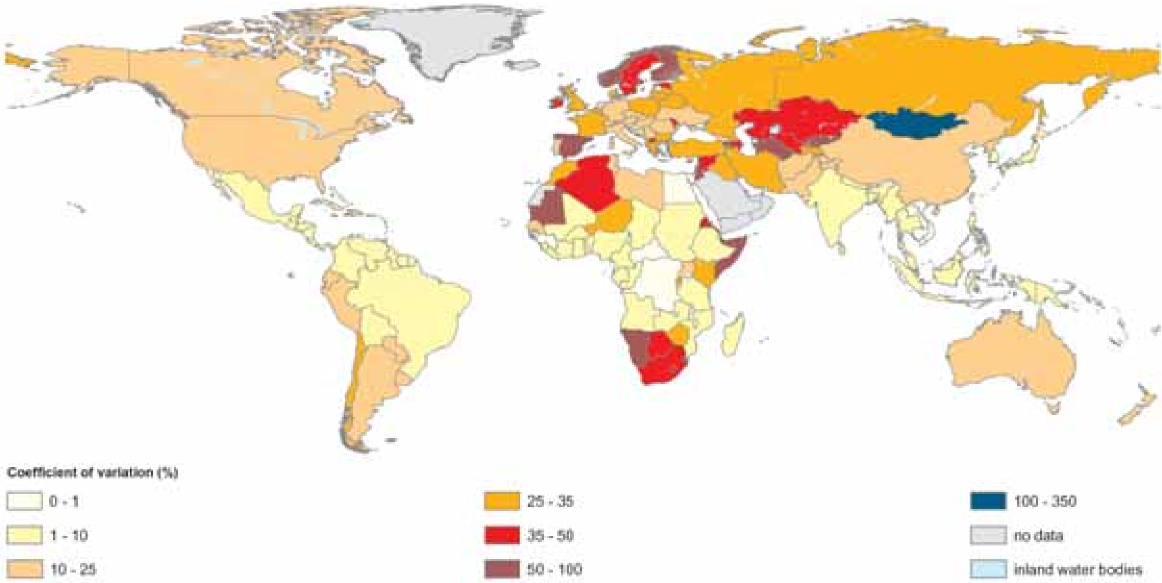
Variability of cereal production potential, based on observed climate variability for the periods 1901-30, 1931-60, 1961-90 compared to reference climatic conditions of 1961-90, on current cultivated land, by region

Major area and region	Time period average, based on historical climate data for individual years						Simulated average for period
	1901-30		1931-60		1961-90		1961-90
	average potential production	coefficient of variation	average potential production	coefficient of variation	average potential production	coefficient of variation	average potential production
	mill. tons	%	mill. tons	%	mill. tons	%	mill. tons
AFRICA							
Eastern Africa	326	3.5	324	3.0	327	5.6	344
Middle Africa	81	2.6	79	3.1	80	2.0	82
Northern Africa	22	18.0	22	20.4	23	22.4	25
Southern Africa	43	33.2	42	29.8	41	36.7	38
Western Africa	134	5.5	135	5.7	133	7.6	139
AMERICA							
Central America & Caribbean	96	3.2	97	6.1	98	5.9	101
North America	993	16.6	1,006	18.0	1,060	14.4	1,189
South America	469	7.8	464	6.0	487	7.1	543
ASIA							
East Asia & Japan	391	9.4	410	10.7	420	10.1	448
South Asia	711	9.7	736	6.0	739	6.5	783
Central Asia	28	19.7	30	21.8	31	23.0	26
Southeast Asia	220	2.6	221	1.9	219	2.4	220
Western Asia	73	22.2	60	33.7	66	23.3	79
EUROPE							
Eastern Europe	473	17.0	460	20.5	499	17.0	613
Russian Federation	408	27.0	402	23.3	495	26.5	629
Northern Europe	111	25.7	125	22.0	122	17.2	154
Southern Europe	149	14.4	148	14.2	150	10.0	170
Western Europe	272	19.9	274	16.3	278	19.8	345
OCEANIA							
Oceania & Polynesia	49	32.3	50	29.0	54	26.3	55
Developed	**2,477**	**10.1**	**2,489**	**10.8**	**2,681**	**8.1**	**3,178**
Developing	**2,579**	**3.4**	**2,606**	**3.3**	**2,650**	**3.8**	**2,815**
World	**5,055**	**5.3**	**5,095**	**5.3**	**5,330**	**4.7**	**5,993**

Note: the climate datasets used to create this table are explained in Section 3.1.

MAP 4.1

Variability of rainfed cereal production potential, by country, 1961-1990



4.1.5 Estimation of crop and pasture suitability indices

For each of the approximately 2.2 million gridcells of the database suitability results were estimated for each crop type, at each of the three input levels considered under rainfed conditions and for gridcells classified as irrigated area for each of the two input levels considered under irrigated conditions. The outcomes were then mapped by means of a suitability index (SI). This index reflects the suitability make-up of a particular gridcell. In this index VS represents the portion of the gridcell with attainable yields that are 80 percent or more of the maximum potential yield for the specified input scenario. Similarly, S, MS and mS represent portions of the gridcell with attainable yields 60–80 percent, 40–60 percent, and 20–40 percent of the maximum potential yield, respectively. SI is calculated using the following equation:

$$SI = VS*0.9 + S*0.7 + MS*0.5 + mS*0.3$$

where: *VS = very suitable; S = suitable; MS = moderately suitable; mS = marginally suitable*

The resulting database permits generation of a suitability map based on the crop suitability index (CSI) for each gridcell for any combination of crop types that the analyst specifies. In this report, CSI are presented for nine crop groups at low, intermediate and high input levels under rainfed conditions.

To estimate production potential of the global land surface for pasture, estimates of maximum potential and attainable pasture yields were generated and a pasture suitability index (PSI) at low input level under rainfed conditions was obtained for each gridcell in the land resources database, using the same AEZ matching procedures that were employed for estimating rainfed crop production potential. For the GAEZ study, a reassessment of global pasture production potential was made by combining the AEZ matching procedure results and the zonal features of grassland composition. First, the original AEZ biomass and yield calculation procedures were revised to better cope with, in particular, arid and hyper-arid environments. This modification entailed the incorporation of monthly rainfall events, available from CRU climate database (see Section 3.1). This enabled more realistic assessments of moisture regimes in space and time. Another modification involved the replacement of the LGP-based biomass and yield estimation in arid zones by an enhanced Net Primary Productivity (NPP) calculation procedure, which was applied in the arid environments prevailing in zones with LGP of less than 30 days (Zhang and Zhou, 1995). These two modifications have significantly improved correspondence with satellite-derived data for arid pasture and shrub areas.

4.2 SUITABILITY OF CURRENTLY AVAILABLE LAND FOR RAINFED CROPS AND PASTURE

4.2.1 Estimation of land area currently available for rainfed agriculture

The fact that an area of land has been determined to be suitable for rainfed crop agriculture or pasture does not necessarily mean it is available for such use. A sizeable part of the more suitable area is covered by forests, and is likely to remain so for the foreseeable future. Some suitable land, much of it forested, has been set aside as protected area, for environmental or other reasons. Also, although the extents involved are small, in some locations human settlements have been built on land that would otherwise be suitable or very suitable for agriculture. Finally irrigated area, although representing highly productive agricultural land which may also be used for rainfed crops as well, has been kept separate from land currently available for rainfed agriculture. Although suitability analysis has also been done for irrigated area, in this report we are considering only suitability under rainfed conditions, as these are the conditions where agriculture is likely to be more vulnerable and poor and hungry people are likely to be found. Hence, land area currently available for rainfed agriculture excludes area belonging to the above-mentioned land cover categories. The method used to create the land cover database from which area currently available for rainfed agriculture has been derived is explained in more detail in Annex 2. The Annex also contains the individual maps generated for each land cover category.

4.2.2 Suitability results

Crop and pasture suitability indices have been calculated for all of the world's land area, using the procedures described in Section 4.1.5. Rainfed suitability has been calculated for nine crop groups that are important to most farming systems in developing countries, namely, cereals, fibre crops, oil crops, pulses, roots and tubers, stimulants, sugar crops, tree fruits and vegetables. The algorithm examines in each gridcell all the crop types belonging to a particular crop group. Among these it determines the crop type that maximizes agronomic suitability. In the suitability maps for the crop groups and for pasture, CSI and PSI have been classified according to the Box 4.2.

BOX 4.2

CROP AND PASTURE SUITABILITY CLASSES

CROP AND PASTURE SUITABILITY CLASSES	CSI AND PSI VALUE
not suitable	0
very low	1-10
low	10-20
medium low	20-35
medium	35-50
medium high	50-65
high	65-80
very high	80-100

Figure 4.1 shows the share of global land area with medium high to very high suitability for each of these crop groups under rainfed conditions at high, intermediate and low inputs ok level, and for pasture and low levels of input; Figure 4.2 shows the same information for land area currently available for rainfed agriculture. Annex 3 contains maps showing present rainfed suitability on currently available land for each of the nine crop groups that have been assessed, at all three level of inputs .

FIGURE 4.1

Rural land area with medium high to very high suitability for rainfed crops, by crop group, with low, intermediate and high level of inputs, and pasture at low level of inputs

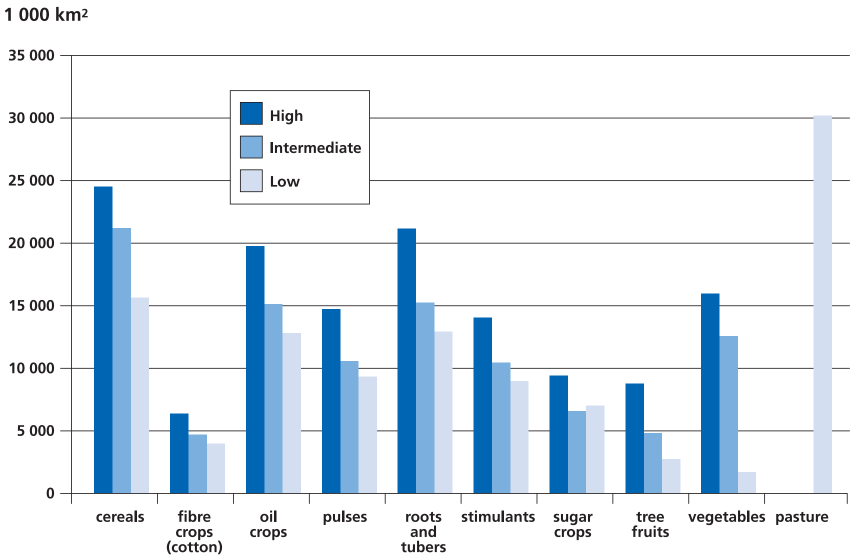
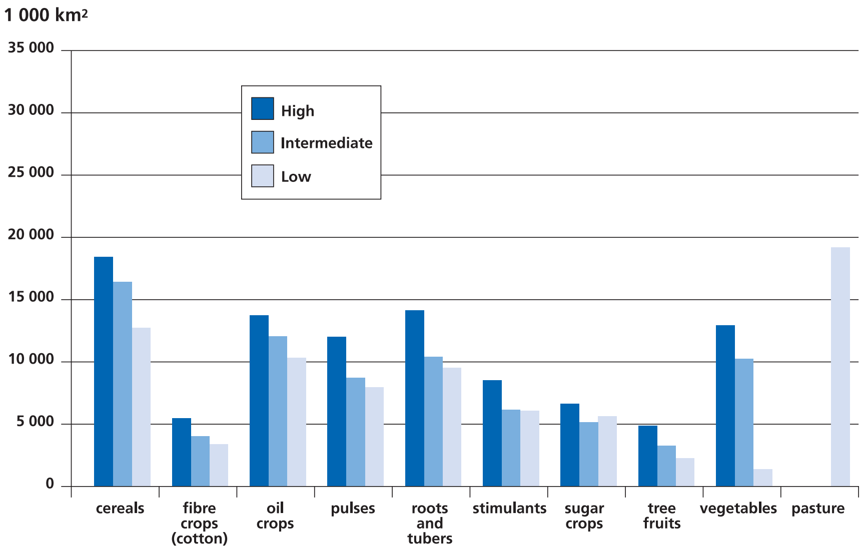


FIGURE 4.2

Rural land area currently available for rainfed agriculture with medium high to very high suitability for rainfed crops, by crop group, with low, intermediate and high level of inputs, and pasture at low level of inputs



4.2.3 Multiple cropping zones

In the AEZ crop suitability analysis, the LUTs considered refer to single cropping of individual crop types, i.e., each crop type is presumed to occupy the land only once a year and in pure stand. In areas where the growing periods are sufficiently long to allow more than one crop to be grown in the same year or season, single crop yields do not reflect the full potential of total time and space available per unit area of land for rainfed production.

To assess multiple cropping potential, a number of multiple cropping zones have been defined through matching both growth cycle and temperature requirements of individual suitable crop types with time available for crop growth. For rainfed conditions this period is approximated by the LGP, i.e., the number of days during which both temperature and moisture conditions permit crop growth. Eight zones were defined and are depicted for currently available land in Map 4.2. Table 4.4 presents the occurrence of these multiple cropping zones on currently available land in major world regions.

MAP 4.2

Multiple cropping zones under rainfed conditions, currently available land

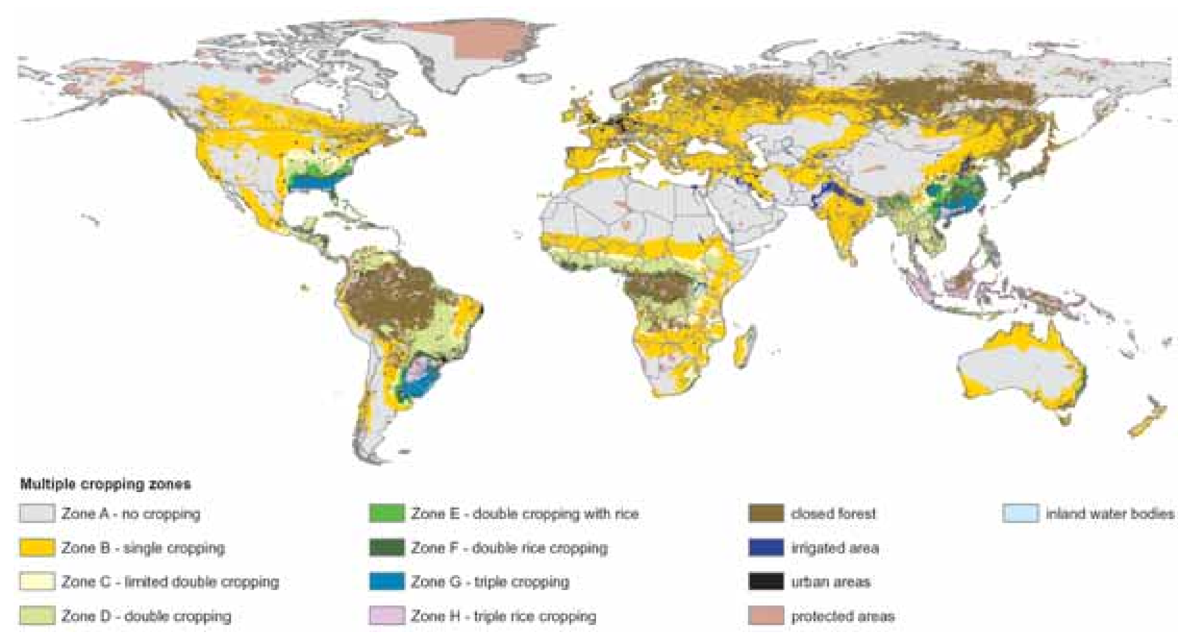


TABLE 4.4

Occurrence of multiple cropping zones under rainfed conditions, currently available land

Major area and region	Currently available land	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F	Zone G	Zone H
	km² (1 000)	share of currently available land %							
AFRICA									
Eastern Africa	5,595	16.6	50.1	15.8	14.0	-	1.6	-	1.9
Middle Africa	4,060	18.2	23.0	7.2	42.5	-	7.3	-	1.8
Northern Africa	7,704	76.2	18.2	3.3	2.3	-	-	-	-
Southern Africa	2,360	50.6	41.2	5.5	1.4	0.7	0.3	0.3	-
Western Africa	5,685	46.4	28.4	6.9	14.7	-	3.3	-	0.3
AMERICAS									
Caribbean	156	-	-	3.2	62.2	-	21.8	-	12.8
Central America	2,230	27.9	34.7	7.4	18.4	-	7.8	-	3.8
Northern America	16,196	51.7	34.9	3.7	3.3	2.0	1.2	2.8	0.4
South America	9,992	21.5	20.8	5.4	32.6	1.5	5.2	5.2	7.8
ASIA									
Eastern Asia	9,402	52.8	24.5	3.6	3.3	5.2	4.9	4.5	1.2
Japan	88	-	47.8	12.5	19.3	17.0	1.1	2.3	-
South-central Asia	8,812	45.7	46.4	3.2	2.9	1.0	0.4	0.2	0.2
South-eastern Asia	3,158	0.1	0.6	1.4	48.1	2.3	6.7	0.2	40.6
Western Asia	4,152	73.6	26.1	0.2	0.1	-	-	-	-
EUROPA									
Eastern Europe	11,173	58.5	40.9	0.6	-	-	-	-	-
Northern Europe	1,005	42.7	57.3	-	-	-	-	-	-
Southern Europe	1,002	1.9	87.6	9.5	1.0	-	-	-	-
Western Europe	655	7.0	91.0	1.8	0.2	-	-	-	-
OCEANIA									
Australia and New Zealand	7,332	63.1	34.3	1.1	0.8	0.5	0.1	0.1	-
Melanesia	273	-	-	-	8.1	-	7.3	-	84.6
Developed	**37,451**	**53.5**	**39.6**	**2.3**	**1.7**	**1.0**	**0.5**	**1.2**	**0.2**
Developing	**63,579**	**41.2**	**28.4**	**5.3**	**14.8**	**1.3**	**3.2**	**1.5**	**4.3**
World	**101,030**	**45.7**	**32.6**	**4.2**	**9.9**	**1.2**	**2.2**	**1.4**	**2.8**

Note: Zone A – no cropping; Zone B – single cropping; Zone C – limited double cropping (relay cropping, one wetland rice crop may be possible); Zone D – double cropping (sequential cropping, wetland rice crop not possible); Zone E – double cropping (sequential cropping; one wetland rice crop possible); Zone F – limited triple cropping (partly relay cropping, if two wetland rice crops, no third crop possible); Zone G – triple cropping (sequential cropping of three short-cycle crops; two wetland rice crops possible); Zone H – triple rice cropping (sequential cropping of three wetland rice crops possible).

4.3 PRODUCTIVITY POTENTIAL OF CURRENTLY AVAILABLE LAND FOR RAINFED CROPS AND PASTURE

4.3.1 Productivity potential for rainfed crops with maximizing technology mix

Map 4.3 presents the spatial distribution of currently available land with cultivation potential for rainfed crops, under a maximizing technology mix. The estimates on which this map are based depend on a variety of assumptions: the range of crop types considered, the definition of what minimum level of output qualifies as acceptable, the social acceptance of land-cover conversions (in particular forests), and the assumptions on what land constraints may be alleviated with different levels of inputs and investment. To estimate the overall productivity potential of the global land surface for rainfed crops, a procedure has been applied that creates a set of assumptions for each of the above factors for each gridcell in the database, and then mixes crops and inputs so as to maximise extents of land suitable for cultivation.

When considering all crop types modelled in AEZ and applying a maximizing technology mix, results show that a little less than one-quarter of the Earth's land surface can be regarded as suitable for rainfed crop cultivation. When suitable land that is not currently available is deducted, Table 4.5 shows that only 22.7 percent of the Earth's land surface is both suitable and available, 36 percent of it in developed regions and 64 percent in developing regions. The share of currently available land that has medium high to very high potential for rainfed crop cultivation is by far the highest in Western Europe and Caribbean where the figure is respectively 66 and 51 percent. The lowest shares occur in Western Asia, Australia and New Zealand and Southern Africa where the figures fall below 10 percent. These differences only become significant, however, if scarcity of good agricultural land forces people onto less suitable and therefore less productive land, where obtaining a sustainable livelihood from agriculture may be more difficult, if not impossible.

MAP 4.3

Suitability of currently available land for rainfed crops, using maximising crop and technology mix

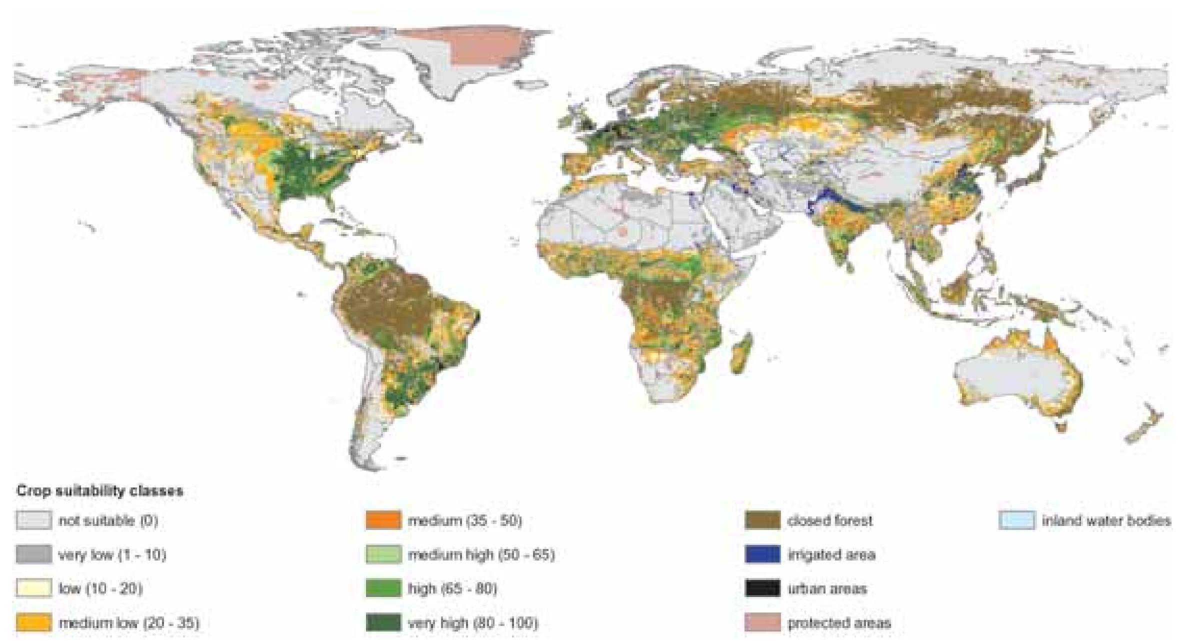


TABLE 4.5

Extents of currently available land with potential for rainfed cultivation under maximizing technology mix, by region

Major area and region	Currently available land	Available land with medium high to very high suitability for rainfed cultivation		Available land with very low to medium suitability for rainfed cultivation	
	km² (1 000)	km² (1 000)	share of currently available land in the region %	km² (1 000)	share of currently available land in the region %
AFRICA					
Eastern Africa	5,595	2,227	39.8	2,803	50.1
Middle Africa	4,060	1,866	46.0	1,438	35.4
Northern Africa	7,704	808	10.5	2,044	26.5
Southern Africa	2,360	164	6.9	1,054	44.7
Western Africa	5,685	1,328	23.4	1,612	28.4
AMERICAS					
Caribbean	156	80	51.3	75	48.1
Central America	2,230	337	15.1	1,351	60.6
Northern America	16,196	3,855	23.8	5,237	32.3
South America	9,992	4,104	41.1	3,684	36.9
ASIA					
Eastern Asia	9,402	1,134	12.1	3,086	32.8
Japan	88	32	36.4	56	63.6
South-central Asia	8,812	1,206	13.7	4,537	51.5
South-eastern Asia	3,158	1,064	33.7	2,071	65.6
Western Asia	4,152	239	5.8	1,297	31.2
EUROPA					
Eastern Europe	11,173	2,824	25.3	1,655	14.8
Northern Europe	1,005	286	28.5	274	27.3
Southern Europe	1,002	369	36.8	596	59.5
Western Europe	655	433	66.1	175	26.7
OCEANIA					
Australia and New Zealand	7,332	493	6.7	2,671	36.4
Melanesia	273	85	31.1	181	66.3
Developed	**37,451**	**8,292**	**22.1**	**10,664**	**28.5**
Developing	**63,579**	**14,642**	**23.0**	**25,233**	**39.7**
World	**101,030**	**22,934**	**22.7**	**35,897**	**35.5**

4.3.2 Productivity potential of currently available land for rainfed pasture

Recent estimates of pasture and grazing areas available globally suggest that almost a quarter of the earth's land surface is covered by pasture or shrub vegetation that could, and often does, provide feed resources for ruminants. Results of the pasture suitability assessments for currently available land are given in Table 4.6. Worldwide, about 19 percent of available land has medium high to very high potential for pasture – slightly less than the aggregate amount with medium high to very high potential for rainfed crops. However, the share of available land area that has at least marginal suitability for pasture is double the share for rainfed crops – around 70 percent for pasture compared to 35 percent for crops. Map 4.4 shows the suitability of currently available land for pasture.

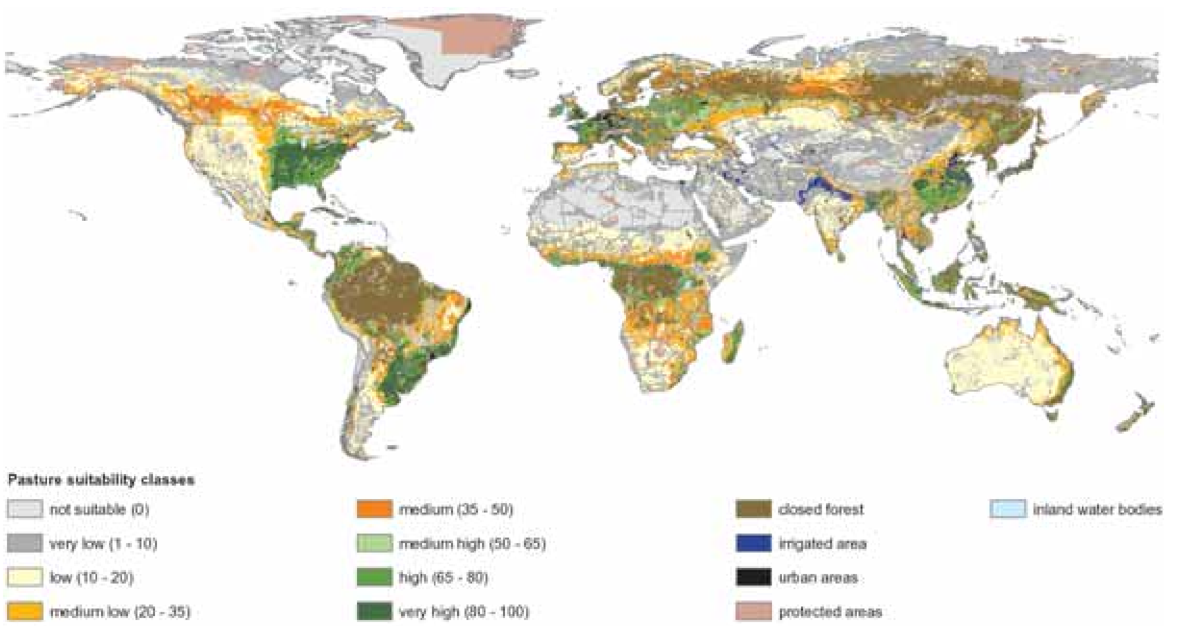
TABLE 4.6

Extents of currently available land with potential for pasture, by region

Major area and region	Currently available land	Available land with medium high to very high suitability for pasture		Available land with very low to medium suitability for pasture	
	km² (1 000)	km² (1 000)	share of currently available land in the region %	km² (1 000)	share of currently available land in the region %
AFRICA					
Eastern Africa	5,595	1,493	26.7	4,071	72.8
Middle Africa	4,060	1,205	29.7	2,470	60.8
Northern Africa	7,704	89	1.2	3,855	50.0
Southern Africa	2,360	142	6.0	2,206	93.5
Western Africa	5,685	492	8.7	3,582	63.0
AMERICAS					
Caribbean	156	144	92.3	12	7.7
Central America	2,230	496	22.2	1,733	77.7
Northern America	16,196	3,339	20.6	11,477	70.8
South America	9,992	3,865	38.7	5,793	58.0
ASIA					
Eastern Asia	9,402	1,895	20.2	6,418	67.4
Japan	88	76	86.4	11	12.5
South-central Asia	8,812	374	4.2	7,305	85.3
South-eastern Asia	3,158	1,910	60.5	1,242	39.5
Western Asia	4,152	47	1.1	3,534	85.1
EUROPA					
Eastern Europe	11,173	1,915	17.1	8,906	79.7
Northern Europe	1,005	312	31.0	693	69.0
Southern Europe	1,002	262	26.1	735	73.3
Western Europe	655	485	74.0	166	25.3
OCEANIA					
Australia and New Zealand	7,332	413	5.6	6,852	93.5
Melanesia	273	198	72.5	75	27.5
Developed	**37,451**	**6,802**	**18.2**	**28,840**	**77.0**
Developing	**63,579**	**12,350**	**19.4**	**42,296**	**66.7**
World	**101,030**	**19,152**	**19.0**	**71,136**	**70.5**

MAP 4.4

Suitability of currently available land for pasture



4.4 DISTRIBUTION OF RURAL POPULATION ON CURRENTLY AVAILABLE AGRICULTURAL LAND

The previous sections have examined the suitability of currently available land for rainfed production of crops and pasture, considered separately. In this Section, the combined productivity potential of available land is examined and the distribution of rural population on this land, by combined agricultural suitability class, is presented.

Map 4.5 shows the combined suitability of currently available land for pasture and for rainfed crops at intermediate level of inputs. Area and population data for currently available land, by region and combined agricultural suitability class are given in Table 4.7. For this purpose, four suitability classes have been defined as shown in Box 4.3.

BOX 4.3

COMBINED AGRICULTURAL SUITABILITY CLASSES

A. Not suited for rainfed agriculture	Land not suited for pasture or rainfed crops (PSI = 0 and CSI < 20)
B. Marginal agricultural land	Land very poorly suited for pasture and at best poorly suited for rainfed crops (PSI: 1-10 and CSI < 20) Land poorly suited for pasture and at best poorly suited for rainfed crops (PSI: 10-20 and CSI < 20) Land suited for pasture and at best poorly suited for rainfed crops (PSI > 20 and CSI < 20)
C. Good agricultural land	Land suited for rainfed crops and pasture possible (CSI: 20-50 and PSI > 0) Land well suited for rainfed crops and pasture possible (CSI: 50-80 and PSI > 0)
D. Prime agricultural land	Prime land for rainfed crops and pasture possible (CSI > 80 and PSI > 0)

The difference in the distribution of good to prime land across regions reflects mainly the distribution of cold barren land, desert and tropical rainforest among the continents. What is more important is the pattern of human settlement. In developed countries, 26.4 percent of the rural population live in areas with prime agricultural land, and only 11.3 percent live in marginal areas. In developing countries, by contrast, only 10.5 percent live in areas with prime agricultural land, whereas 23.3 percent live on land that is only marginally suitable for rainfed agriculture, even with an intermediate level of inputs and management. This result suggests that, even with substantial investment to raise inputs and management from their current low level to an intermediate level, the prospects for alleviating poverty through sustainable agricultural growth in these marginal areas is slim. And if investment in a high level of inputs and management are made, this will almost certainly mean introducing large-scale commercial agriculture, with current small–scale farmers becoming paid farm workers or leaving agriculture.

MAP 4.5

Combined suitability of currently available land for pasture and rainfed crops (intermediate level of inputs)

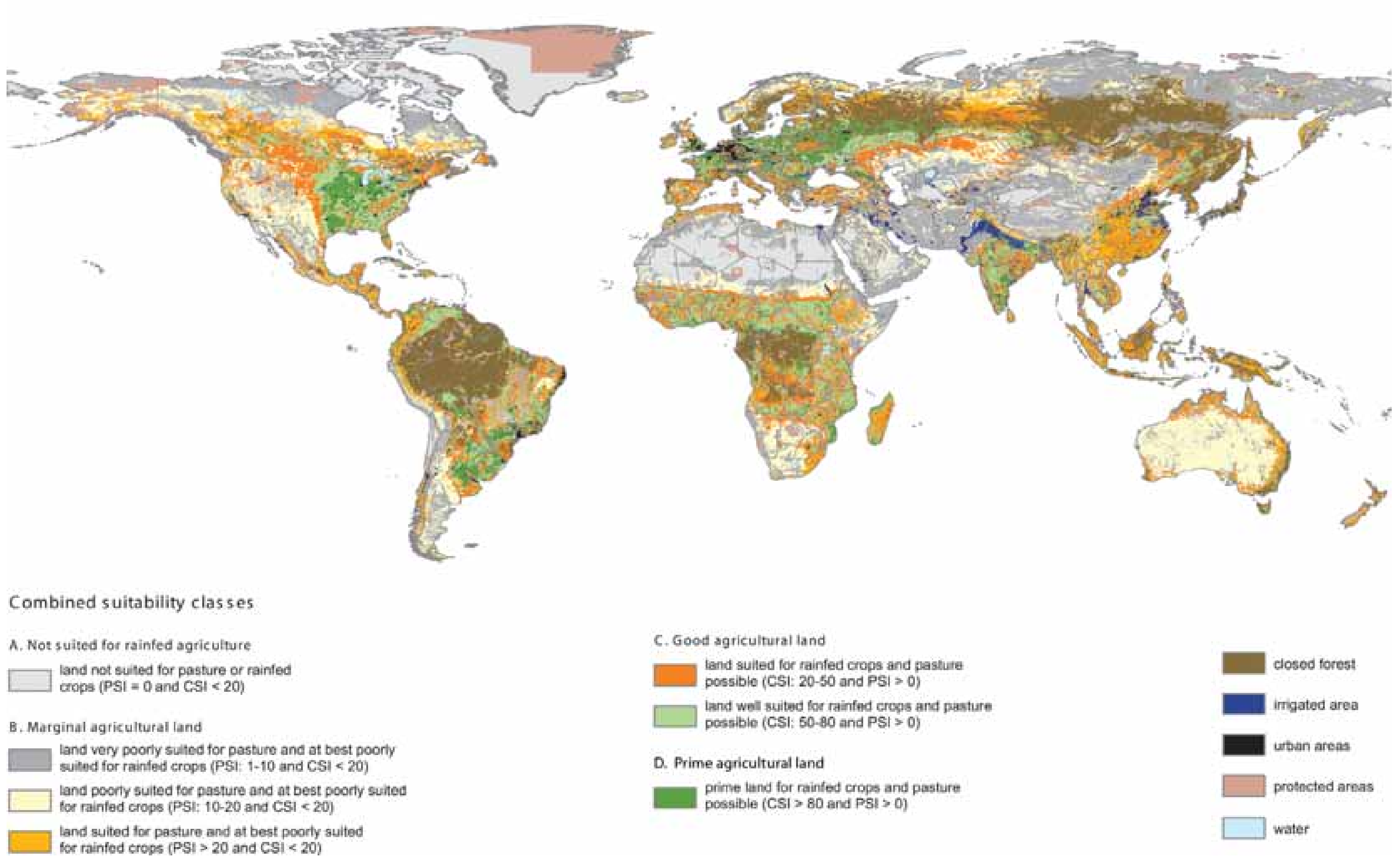


TABLE 4.7

Currently available land area and rural population, by region and combined agricultural suitability class at intermediate level of inputs

Major area and region	Data	Unit	A. Not suited for rainfed agriculture	B. Marginal agricultural land	C. Good agricultural land	D. Prime agricultural land	Total
AFRICA							
Eastern Africa	area	km² (1 000)	12	2,082	3,139	362	5,595
		share of total %	0.21	37.21	56.11	6.47	100
	population	persons (1 000)	64	44,305	121,199	15,894	181,462
		share of total %	0.04	24.42	66.78	8.76	100
	density	persons/km²	5	21	39	44	32
Middle Africa	area	km² (1 000)	351	757	2,672	280	4,060
		share of total %	8.64	18.65	65.81	6.90	100
	population	persons (1 000)	63	5,266	34,649	4,957	44,935
		share of total %	0.14	11.72	77.11	11.03	100
	density	persons/km²	less than 1	7	13	18	11
Northern Africa	area	km² (1 000)	3,404	2,925	1,273	102	7,704
		share of total %	44.19	37.98	16.52	1.31	100
	population	persons (1 000)	1,818	18,731	27,468	1,611	49,628
		share of total %	3.66	37.74	55.35	3.25	100
	density	persons/km²	1	6	22	16	6
Southern Africa	area	km² (1 000)	10	1,877	466	7	2,360
		share of total %	0.42	79.53	19.75	0.30	100
	population	persons (1 000)	4	11,800	10,393	154	22,351
		share of total %	0.02	52.79	46.50	0.69	100
	density	persons/km²	less than 1	6	22	22	9
Western Africa	area	km² (1 000)	1,473	1,717	2,325	170	5,685
		share of total %	25.91	30.20	40.90	2.99	100
	population	persons (1 000)	415	16,096	102,343	10,982	129,836
		share of total %	0.32	12.40	78.82	8.46	100
	density	persons/km²	less than 1	9	44	65	23
AMERICAS							
Caribbean	area	km² (1 000)	1	35	113	7	156
		share of total %	0.64	22.44	72.43	4.49	100
	population	persons (1 000)	1	3,147	8,010	387	11,545
		share of total %	0.01	27.26	69.38	3.35	100
	density	persons/km²	1	90	71	55	74
Central America	area	km² (1 000)	2	1,474	722	32	2,230
		share of total %	0.09	66.10	32.38	1.43	100
	population	persons (1 000)	2	22,146	16,245	1,148	39,541
		share of total %	0.01	56.01	41.08	2.90	100
	density	persons/km²	1	15	23	36	18
Northern America	area	km² (1 000)	1,380	8,789	4,883	1,144	16,196
		share of total %	8.52	54.27	30.15	7.06	100
	population	persons (1 000)	25	6,448	39,184	15,644	61,301
		share of total %	0.04	10.52	63.92	25.52	100
	density	persons/km²	less than 1	1	8	14	4
South America	area	km² (1 000)	280	3,880	4,850	982	9,992
		share of total %	2.80	38.83	48.54	9.83	100
	population	persons (1 000)	1,206	22,947	42,902	10,204	77,259
		share of total %	1.56	29.70	55.53	13.21	100
	density	persons/km²	4	6	9	10	8
ASIA							
Eastern Asia	area	km² (1 000)	1,021	6,270	1,986	125	9,402
		share of total %	10.86	66.69	21.12	1.33	100
	population	persons (1 000)	3,877	183,241	428,873	54,166	670,157
		share of total %	0.58	27.34	64.00	8.08	100
	density	persons/km²	4	29	216	433	71

see next page

Major area and region	Data	Unit	A. Not suited for rainfed agriculture	B. Marginal agricultural land	C. Good agricultural land	D. Prime agricultural land	Total
Japan	area	km² (1 000)	1	30	50	7	88
		share of total %	1.14	34.09	56.82	7.95	100
	population	persons (1 000)	136	2,948	9,823	1,576	14,483
		share of total %	0.95	20.35	67.82	10.88	100
	density	persons/km²	136	98	196	225	165
South-central Asia	area	km² (1 000)	821	5,301	2,314	376	8,812
		share of total %	9.32	60.15	26.26	4.27	100
	population	persons (1 000)	3,644	116,715	489,706	134,161	744,226
		share of total %	0.49	15.68	65.80	18.03	100
	density	persons/km²	4	22	212	357	84
South-eastern Asia	area	km² (1 000)	1	1,442	1,678	37	3,158
		share of total %	0.03	45.66	53.14	1.17	100
	population	persons (1 000)	1	63,271	210,790	7,062	281,124
		share of total %	-	22.51	74.98	2.51	100
	density	persons/km²	1	44	126	191	89
Western Asia	area	km² (1 000)	518	3,083	525	26	4,152
		share of total %	12.48	74.25	12.64	0.63	100
	population	persons (1 000)	369	28,685	22,289	1,907	53,250
		share of total %	0.69	53.87	41.86	3.58	100
	density	persons/km²	1	9	42	73	13
EUROPA							
Eastern Europe	area	km² (1 000)	351	6,964	2,807	1,051	11,173
		share of total %	3.14	62.33	25.12	9.41	100
	population	persons (1 000)	308	5,215	44,078	28,768	78,369
		share of total %	0.39	6.65	56.24	36.72	100
	density	persons/km²	1	1	16	27	7
Northern Europe	area	km² (1 000)	1	582	332	90	1,005
		share of total %	0.10	57.91	33.03	8.96	100
	population	persons (1 000)	-	2,388	7,792	2,589	12,769
		share of total %	-	18.70	61.02	20.28	100
	density	persons/km²	-	4	23	29	13
Southern Europe	area	Km² (1 000)	5	291	632	74	1,002
		share of total %	0.50	29.04	63.07	7.39	100
	population	persons (1 000)	116	6,110	26,651	5,688	38,565
		share of total %	0.30	15.84	69.11	14.75	100
	density	persons/Km²	23	21	42	77	38
Western Europe	area	km² (1 000)	4	104	380	167	655
		share of total %	0.61	15.88	58.02	25.49	100
	population	persons (1 000)	24	1,811	14,582	7,213	23,630
		share of total %	0.10	7.66	61.71	30.53	100
	density	persons/km²	6	17	38	43	36
OCEANIA							
Australia and New Zealand	area	km² (1 000)	31	5,670	1,560	71	7,332
		share of total %	0.42	77.33	21.28	0.97	100
	population	persons (1 000)	2	1,318	2,044	160	3,524
		share of total %	0.06	37.40	58.00	4.54	100
	density	persons/km²	less than 1	less than 1	1	2	less than 1
Melanesia	area	km² (1 000)	-	154	118	1	273
		share of total %	-	56.41	43.22	0.37	100
	population	persons (1 000)	-	2,488	1,144	3	3,635
		share of total %	-	68.45	31.47	0.08	100
	density	persons/km²	-	16	10	3	13

see next page

Major area and region	Data	Unit	A. Not suited for rainfed agriculture	B. Marginal agricultural land	C. Good agricultural land	D. Prime agricultural land	Total
Developed	area	km² (1 000)	1,773	22,430	10,644	2,604	37,451
		share of total %	4.73	59.90	28.42	9.95	100
	population	persons (1 000)	611	26,238	144,154	61,638	232,641
		share of total %	0.26	11.28	61.97	26.49	100
	density	persons/km²	less than 1	1	14	24	6
Developing	area	km² (1 000)	7,894	30,997	22,181	2,507	63,579
		share of total %	12.42	48.75	34.89	3.94	100
	population	persons (1 000)	11,464	538,838	1,516,011	242,636	2,308,949
		share of total %	0.50	23.34	65.66	10.50	100
	density	persons/km²	1	17	68	97	36
World	area	km² (1 000)	9,667	53,427	32,825	5,111	101,030
		share of total %	9.57	52.88	32.49	5.06	100
	population	persons (1 000)	12,075	565,076	1,660,165	304,274	2,541,590
		share of total %	0.48	22.23	65.32	11.97	100
	density	persons/km²	1	11	51	60	25

CHAPTER 5

PRODUCTIVITY POTENTIALS IN MAJOR FARMING SYSTEMS OF DEVELOPING AND TRANSITION COUNTRIES

5.1 FARMING SYSTEM ZONES OF DEVELOPING AND TRANSITION COUNTRIES

A pioneering study published jointly by FAO and the World Bank in 2001 on farming systems and poverty, identified and characterized 44 farming systems (FS) practiced to greater or lesser extent in developing and transition countries. The classification method bases the definition of each farming system on the dominant type of resource base and the dominant livelihood pattern of farm households. In most cases, there is a gradual transition from one system to another, so the boundaries between them are not actually as sharply defined as they appear in maps. Detail regarding the characteristics of each farming system, by region, is given in Annex 4.

In this report, seven major farming system classes have been used as the basis for assessing the distribution of rural area and rural population in each farming system class with respect to severity of environmental constraints, suitability for rainfed agriculture and dominant land cover type. Map 5.1 depicts the spatial distribution of the seven farming system classes on the entire area of developing and transition countries; Table 5.1 shows the farming system classes and the farming systems belonging to each.

MAP 5.1

Farming system classes in developing and transition countries, 2000

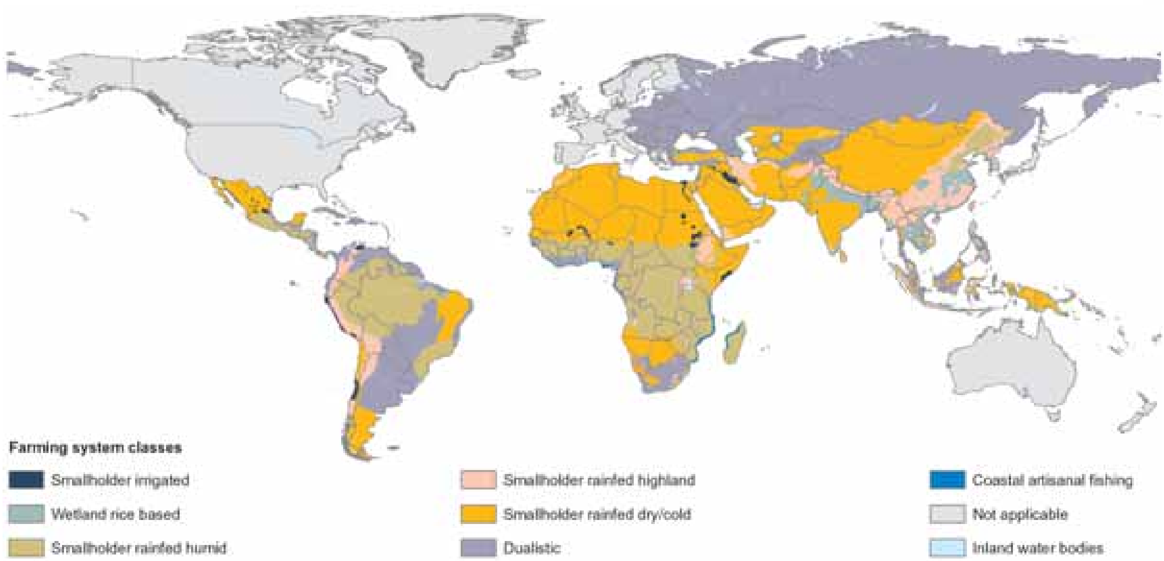


TABLE 5.1

Farming system classes and farming systems of developing and transition countries

Farming system class	Farming systems	Where found
Smallholder irrigated*	Smallholders in large-scale irrigation schemes	Africa, Western Asia, Latin America and Caribbean
Wetland rice-based	Rice, rice-wheat, lowland rice Lowland rice	South Asia East Asia and Pacific
Smallholder rainfed humid	Forest based, rice-tree crop, root crop, cereal-root crop mixed, maize mixed Tree crop, root-tuber, temperate mixed Forest based, intensive mixed, maize-beans	Africa South Asia, East Asia Latin America and Caribbean
Smallholder rainfed highland	Highland perennial, highland temperate mixed Highland mixed, sparse mountain Upland intensive mixed, highland extensive mixed Intensive highland mixed, high altitude mixed, moist temperate mixed forest-livestock	Africa Western Asia, South Asia East Asia, and Pacific Latin America and Caribbean
Smallholder rainfed dry/cold	Agropastoral millet/sorghum Pastoral, sparse arid, small scale cereal-livestock Rainfed mixed, dryland mixed Rainfed mixed, dry rainfed, pastoral, sparse arid Pastoral, sparse arid, sparse forest Dryland mixed, pastoral, sparse forest	Africa Africa, Western Asia Western Asia South Asia East Asia and Pacific Latin America and Caribbean
Dualistic	Tree crop, large commercial and smallholder Irrigated, mixed, forest based livestock, horticulture mixed, large scale cereal-vegetable, extensive cereal-livestock, pastoral, sparse cold Tree crop mixed Coastal plantation and mixed, extensive mixed, cereal-livestock, temperate mixed, extensive dryland-mixed	Africa European and Central Asian countries in transition East Asia and Pacific Latin America and Caribbean
Coastal artisanal fishing	Coastal artisanal fishing	Africa, Western Asia, South Asia, East Asia and Pacific

* In this farming system category, which represents a small but important class of agriculture, smallholders in large-scale irrigation schemes grow most or all of their crops under irrigation. However, various forms of small-scale irrigation and moisture management techniques are found in most farming systems dominated by rainfed cropping.

5.2 DISTRIBUTION OF SUITABLE AREA, CURRENT LAND COVER AND RURAL POPULATION BY MAJOR FARMING SYSTEM CLASS IN DEVELOPING AND TRANSITION COUNTRIES

Area and rural population data have been generated for each of the seven major farming system classes represented in Map 5.1; the results are given in Table 5.2. Two classes are so small in area that meaningful analysis of the suitability of cropland currently in use was not possible. These are the smallholder irrigated and coastal artisanal fishing systems. Together, they contain less than three percent of the total rural population in the countries covered by the farming systems analysis. They are shown as “other” in the table.

TABLE 5.2

Area and population of the developing and transition countries, total and rural, by major farming system class

Farming system (FS) class	Total area	Rural area		Total population	Rural population		
	FS area	FS area	FS area as share of rural area	FS population	FS population	FS population as share of rural population	Density of rural population
	km² (1 000)	km² (1 000)	%	persons (1 000)	persons (1 000)	%	persons/km²
Wetland rice based	3,260	3,030	3.1	1,647,484	1,102,317	36.6	364
Smallholder rainfed humid	19,725	19,398	14.6	766,570	409,633	13.6	21
Smallholder rainfed highland	7,938	7,749	8.5	851,816	564,317	18.7	73
Smallholder rainfed dry/cold	34,890	34,608	43	880,763	545,489	18.1	16
Dualistic	31,261	30,675	29.7	785,527	304,111	10.1	10
Other*	1,342	1,260	1.4	200,928	85,538	2.8	68
Total	98,416	96,720	100	5,133,088	3,011,405	100	31

* Includes smallholder irrigated and coastal artisanal fishing, which together cover less than 1.5 percent of total rural area and contain less than three percent of total rural population.

Not surprisingly, the wetland rice-based system, found entirely in Asia, accounts for more than a third of the total rural population in developing and transition countries; it also has by far the smallest area (only three percent of total rural area in developing and transition countries) and by far the highest population density count (364 persons per square kilometre). Other systems with relatively high population densities are the smallholder rainfed highland (73 persons per square kilometre) and the irrigated other (68 persons per square kilometre).

Table 5.3 shows that the share of the rural population living in areas with severe constraints remains fairly constant across most farming systems. At around 45 percent of the total, this is about the same as the share for the rural population of developing countries as a whole (see Section 3.4.2). Exceptions are the dualistic system, where the share drops to 36.8 percent, and the "other" category, where the share comes to 72.9 percent, reflecting population living in irrigated areas that are otherwise too dry for rainfed agriculture.

TABLE 5.3

Rural area and rural population of the developing and transition countries, by major farming system class, with proportion subject to severe environmental constraints

Farming system class	Rural population	Too cold		Too dry		Too steep		Poor soils		All severe constraints		
		Area	Pop.	Area	Pop.	Area	Pop.	Area	Pop.	Area	Pop.	Share of pop. in FS class
	persons (1 000)	km² (1 000)	persons (1 000)	km² (1 000)	persons (1 000)	km² (1 000)	persons (1 000)	km² (1 000)	persons (1 000)	km² (1 000)	persons (1 000)	%
Wetland rice based	1,102,317	-	-	186	53,197	36	1,883	1,359	455,137	1,454	480,419	43.6
Smallholder rainfed humid	409,633	10	6	42	229	439	10,322	10,275	178,042	10,600	185,278	45.2
Smallholder rainfed highland	564,317	136	805	564	15,010	2,874	116,803	3,035	188,477	4,787	269,463	47.8
Smallholder rainfed dry/cold	545,489	1,839	2,655	21,345	80,514	2,633	19,204	14,268	196,842	28,041	253,165	46.4
Dualistic	304,111	7,435	1,365	2,702	11,942	1,926	11,187	19,341	97,624	21,432	111,954	36.8
Other	85,538	0.5	0.1	491	44,112	66	618	533	55,286	806	62,377	72.9
Total	3,011,405	9,421	4,831	25,330	205,004	7,974	160,017	48,811	1,171,408	67,120	1,362,656	45.2

Note: data shown in this table differ slightly from those given in Section 3.4 because a different reference map has been used for the farming system analysis.

As explained earlier, however, the presence of severe constraints does not necessarily mean that an area is unsuitable for certain types of rainfed agriculture, unless it is absolutely too cold to support any kind of vegetative growth. Thus, for example, pasture and browse may still be suitable in areas that are generally considered too dry for rainfed agriculture, or fruit trees and pasture may be suitable in areas that are generally considered too steep. Similarly, soils that are generally considered poor may nevertheless be suitable for certain kinds of vegetation with economic value. This explains why 13 percent of the population belonging to the smallholder rainfed dry/cold farming system can survive in areas that are classified as too dry, and 20 percent of the population belonging to the smallholder rainfed highland farming system are found in areas that are classified as too steep.

Because of this, the distribution of rural population by combined agricultural suitability class gives a better indication of the number of people farming in marginal areas, and the farming systems to which they belong. Data given in Table 5.4 show that in the wetland rice-based system, despite the high population densities there, only 11 percent of the rural population belonging to that system lives on marginal land. In the smallholder rainfed humid system the figure is similarly low – only 15 percent. On the other hand, in the smallholder rainfed highland and smallholder rainfed dry/cold the figures are 47.5 percent and 28.2 percent respectively. Across all farming systems, 76 percent of the total rural population in developing and transition countries lives on good or prime agricultural land. However, though only 24 percent of the total live on marginal land, they number more than 700 million people – sufficient to account for a substantial proportion of the world's hungry, currently numbering 852 million, according to latest FAO estimates.

TABLE 5.4

Rural area and rural population of the developing and transition countries, by major farming system class and combined agricultural suitability class at intermediate level of inputs

Farming system class	Data	Unit	A. No rainfed agriculture possible	B. Marginal agricultural land	C. Good agricultural land	D. Prime agricultural land	Total
Wetland rice based	area	km² (1 000)	15	606	2,041	368	3,030
	population	persons (1 000)	2,610	123,019	782,087	194,601	1,102,317
	share on total	%	0.24	11.16	70.95	17.65	100.00
Smallholder rainfed humid	area	km² (1 000)	16	2,639	14,817	1,926	19,398
	population	persons (1 000)	137	61,657	313,227	34,612	409,633
	share on total	%	0.03	15.05	76.47	8.45	100.00
Smallholder rainfed highland	area	km² (1 000)	172	5,275	2,210	92	7,749
	population	persons (1 000)	1,406	262,480	278,257	22,174	564,317
	share on total	%	0.25	46.51	49.31	3.93	100.00
Smallholder rainfed dry/cold	area	km² (1 000)	7,569	21,339	5,345	355	34,608
	population	persons (1 000)	7,964	153,843	322,740	60,942	545,489
	share on total	%	1.46	28.20	59.17	11.17	100.00
Dualistic	area	km² (1 000)	652	16,457	10,958	2,608	30,675
	population	persons (1 000)	2,046	56,858	191,886	53,321	304,111
	share on total	%	0.67	18.70	63.10	17.53	100.00
Other	area	km² (1 000)	64	591	518	87	1,260
	population	persons (1 000)	1,151	50,982	30,093	3,312	85,538
	share on total	%	1.35	59.60	35.18	3.87	100.00
Total	area	km² (1 000)	8,488	46,907	35,889	5,436	96,720
	population	persons (1 000)	15,314	708,839	1,918,290	368,962	3,011,405
	share on total	%	0.5	23.5	63.7	12.3	100.0

Note: data shown in this table differ slightly from those given in Section 4.4 because a different reference map has been used for the farming system analysis.

The distribution of rural population of each farming system class by current dominant land cover type (Table 5.5) shows that rural people are settled mainly on cropland, or at least on land where crops are grown in combination with livestock, fish and/or tree crops. Despite the importance of pastoralism for some farming systems, only 15 percent of the total rural population of developing and transition countries lives on land that is predominantly or mainly pasture and browse, and among those who do, the share is surprisingly highest in the smallholder rainfed humid farming system, and not in the highland or dry/cold systems where pastoralism is more common. The data also confirm the importance of forests, where the share of the rural population living there ranges from two to 16 percent, depending on the system in question.

TABLE 5.5

Rural area and rural population of the developing and transition countries, by major farming system class and dominant land cover type

Farming system class	Data	Unit	Forest 50% or more	Crops 50% or more	Pasture and browse 50% or more	Barren and sparsely vegetated 50% or more	Mixed (no land use dominant)	Total
Wetland rice based	area	km² (1 000)	320	1,831	123	37.0	719	3,030
	population	persons (1 000)	20,402	860,008	13,667	13,550.0	194,690	1,102,317
	share on total	%	1.9	78.0	1.2	1.3	17.7	100.0
Smallholder rainfed humid	area	km² (1 000)	10,532	825	5,947	78.0	2,016	19,398
	population	persons (1 000)	66,367	135,021	121,920	678.0	85,647	409,633
	share on total	%	16.2	33.0	29.8	0.1	20.9	100.0
Smallholder rainfed highland	area	km² (1 000)	2,506	431	2,475	624.0	1,713	7,749
	population	persons (1 000)	84,712	95,260	128,553	7,240.0	248,552	564,317
	share on total	%	15.0	16.9	22.8	1.3	44.0	100.0
Smallholder rainfed dry/cold	area	km² (1 000)	2,649	1,729	9,455	19,382.0	1,393	34,608
	population	persons (1 000)	47,501	252,698	118,020	43,176.0	84,094	545,489
	share on total	%	8.7	46.3	21.6	7.9	15.4	100.0
Dualistic	area	km² (1 000)	12,155	2,885	9,409	1,711.0	4,515	30,675
	population	persons (1 000)	44,241	100,577	56,620	5,010.0	97,663	304,111
	share on total	%	14.5	33.1	18.6	1.6	32.1	100.0
Other	area	km² (1 000)	224	186	429	250.0	171	1,260
	population	persons (1 000)	7,292	48,546	7,985	5,993.0	15,722	85,538
	share on total	%	8.5	56.8	9.3	7.0	18.4	100.0
Total	area	km² (1 000)	28,386	7,887	27,838	22,082.0	10,527	96,720
	population	persons (1 000)	270,515	1,492,110	446,765	75,647.0	726,368	3,011,405
	share on total	%	9.1	49.5	14.8	2.5	24.1	100

Note: data shown in this table differ slightly from those given in Section 4.4 because a different reference map has been used for the farming system analysis.

Further exploration of the significance of the relationships hinted at in this Section is planned as part of the continuing investigation of the influence of geophysical factors on agricultural production performance, rural vulnerability and the prevalence and extent of hunger and poverty in developing countries.

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ANNEX 1

THE AGRO-ECOLOGICAL ZONES (AEZ) METHODOLOGY

An agro-ecological zones methodology has been in use since 1978 for determining agricultural production potentials and carrying capacity of the world's land area. An agro-ecological zone, as originally defined, is comprised of all parts of gridcells on a georeferenced map that have uniform soil and climate characteristics. The suitability of each of these zones for rainfed production of various crops, under different input and management scenarios is then evaluated. The yield potential of the crops most suited to each zone where rainfed crop production is possible, determines the overall agricultural production potential of that zone.

Crops evaluated originally include food, fibre and fodder crops and pasture grasses. The Food and Agriculture Organization of the United Nations (FAO), in collaboration with the International Institute for Applied Systems Analysis (IIASA), has updated its agro-ecological zones (AEZ) methodology (FAO & IIASA, 2002). The updated version permits a more refined evaluation of biophysical limitations than the original, and takes into account the production potential of a larger number of crops.

In conjunction with the updating exercise, a worldwide spatial land resources database has been created that contains both primary datasets and derived datasets for a large number of variables that affect the production potential of the world's land area or reflect the choices that people have made about how to use the land.

The AEZ framework incorporates the following basic elements:

- a georeferenced land resources database that contains some 2.2 million gridcells, and includes (i) an environmental conditions component comprised of georeferenced global databases for climate, soils, terrain and elevation, and (ii) a spatial land use and land cover component covering forests, protected areas, irrigated areas, population distribution and density, land required for habitation and infrastructure, estimates of cropland, grazing land and sparsely vegetated or barren land, and farming systems;
- a standardized framework for the characterization of soil, terrain and climatic conditions relevant to agricultural production, and identification of areas with specific climate, soil and terrain constraints to rainfed crop production;
- 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);
- procedures for calculating the potential agronomically attainable yield and for matching environmental requirements of individual crops and LUTs with the respective environmental characteristics contained in the land resources database, by land unit and gridcell, thus permitting estimation of crop-specific suitability indices for each gridcell in the database, under different levels of inputs and management conditions;
- quantification of crop and land productivity potential under different cropping pattern and LUT assumptions;

- applications for estimating the land's population-supporting capacity and for multiple-criteria optimization of land resource use for sustainable agricultural development, incorporating socioeconomic and demographic as well as environmental factors.

The AEZ starts with climate and uses terrain and soil types as modifiers, that is climate is determining; only if climate is suitable will the suitability of the terrain and the soil type be considered. The AEZ approach, as updated for this report, distinguishes 171 crop types, each of which is assessed at three generic levels of inputs and management for rainfed conditions and at two generic levels of inputs and management for irrigated conditions, making a total of 855 crop LUTs. A complete description of the methodology and results obtained for regions across the globe can be found in FAO & IIASA, 2002 and 2003.

ANNEX 2

GLOBAL LAND COVER AND AVAILABILITY OF LAND FOR RAINFED AGRICULTURE

This Annex contains five global maps showing the part of the world's land area that is currently used for each of the following purposes: (i) forest, (ii) cropland, (iii) pasture and browse, (iv) barren and sparsely vegetated land and (v) built-up area (including urban area and rural settlements) and artificial surfaces. The underlying map databases have been prepared at a resolution of 5 arc-minutes, or 81 square kilometres at the equator and about half that at +/- 60' latitude. Each map database gives the occurrence of one land cover type in every gridcell of the world's land surface, expressed as a percentage of the gridcell area. The percentage occurrences of the land cover types in each gridcell add up to 100 percent. Additional maps show the occurrence of irrigated area within cropland, and the occurrence of protected area globally. It is s not feasible to generate a single visually meaningful map that combines the occurrence of all five land cover types, except by using a simple classification system. The one shown in the Box A2.1 has been used to generate Map A.2.8 and to estimate the distribution of rural population by land cover type. The GIS databases for all eight maps shown in this Annex are available on the DVDs that contain the FGGD Digital Atlas for the year 2000 (FAO, 2006).

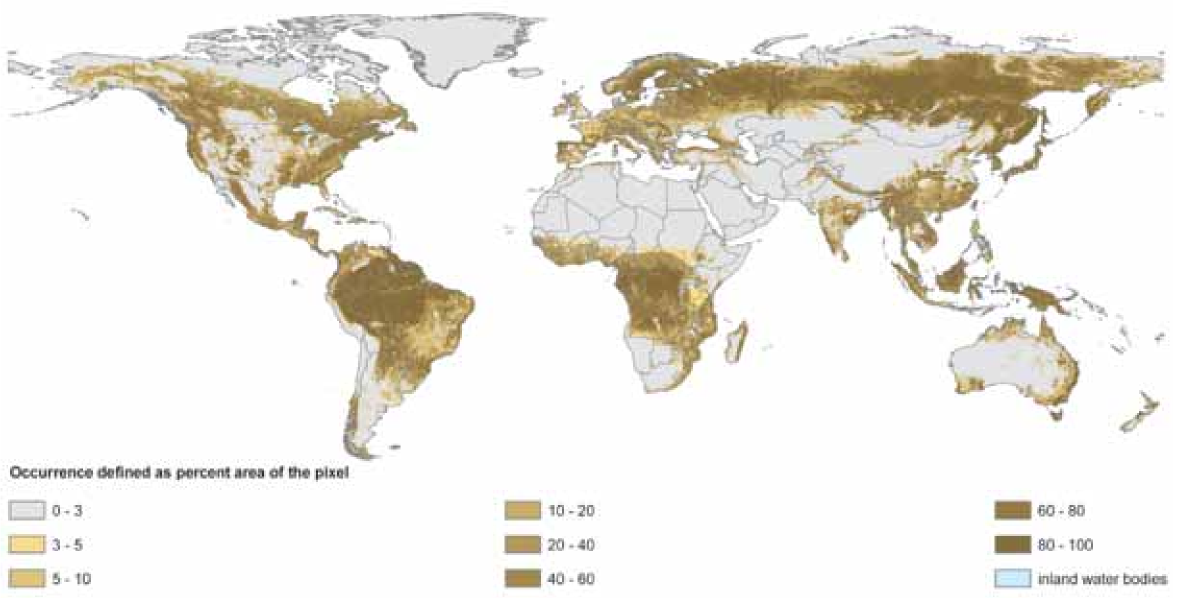
BOX A2.1

DEGREE OF DOMINANCE OF LAND COVER TYPES

- > 50% built-up area and artificial surface
- > 75% forest
- 50-75% forest
- > 75% crops
- 50–75% crops
- > 75% pasture and browse
- 50–75% pasture and browse
- > 75% barren and sparsely vegetated
- 50–75% barren and sparsely vegetated
- mixed (no land cover type dominant)

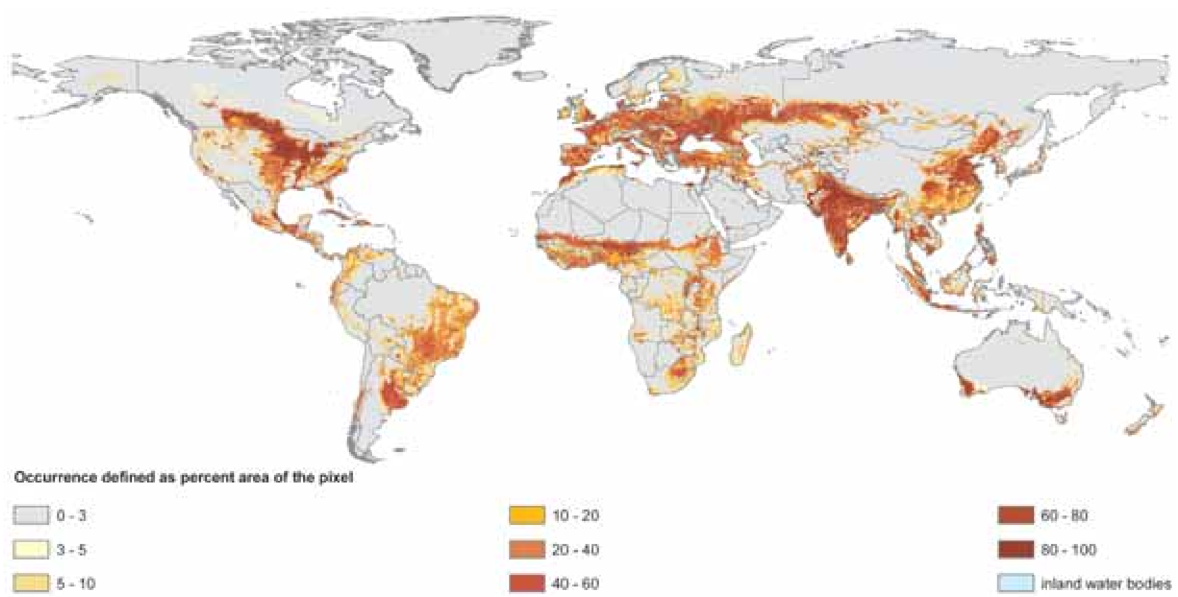
MAP A2.1

Occurrence of forest



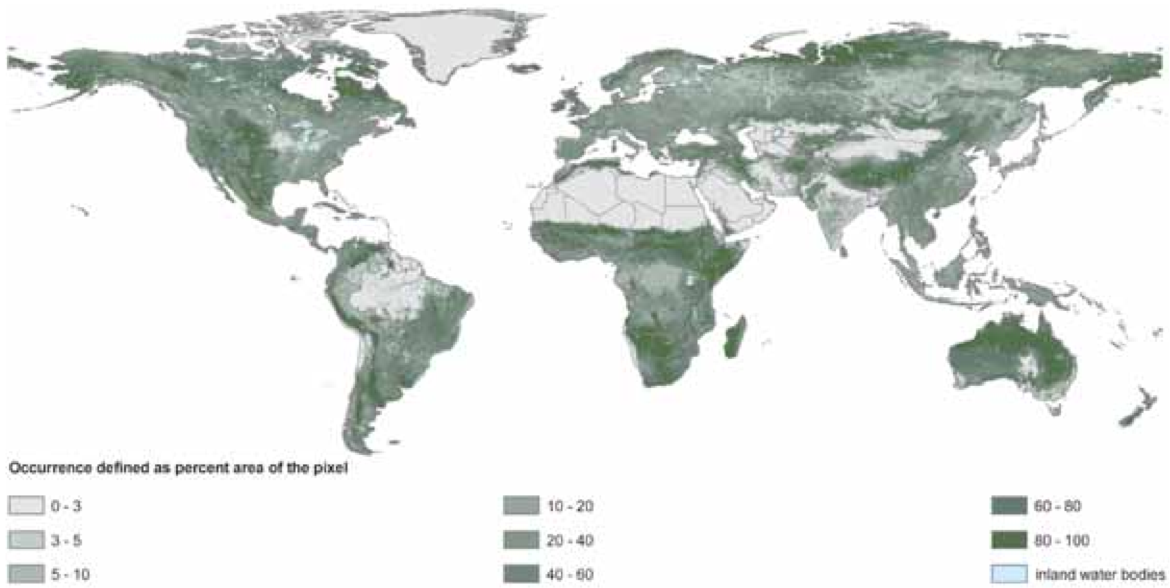
MAP A2.2

Occurrence of cropland



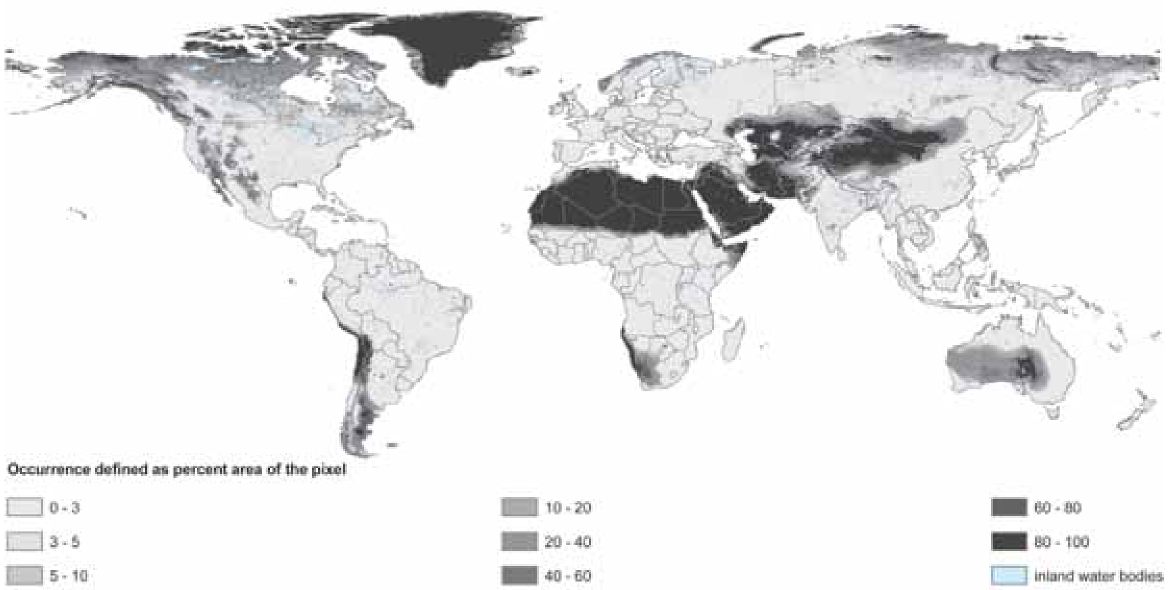
MAP A2.3

Occurrence of pasture and browse



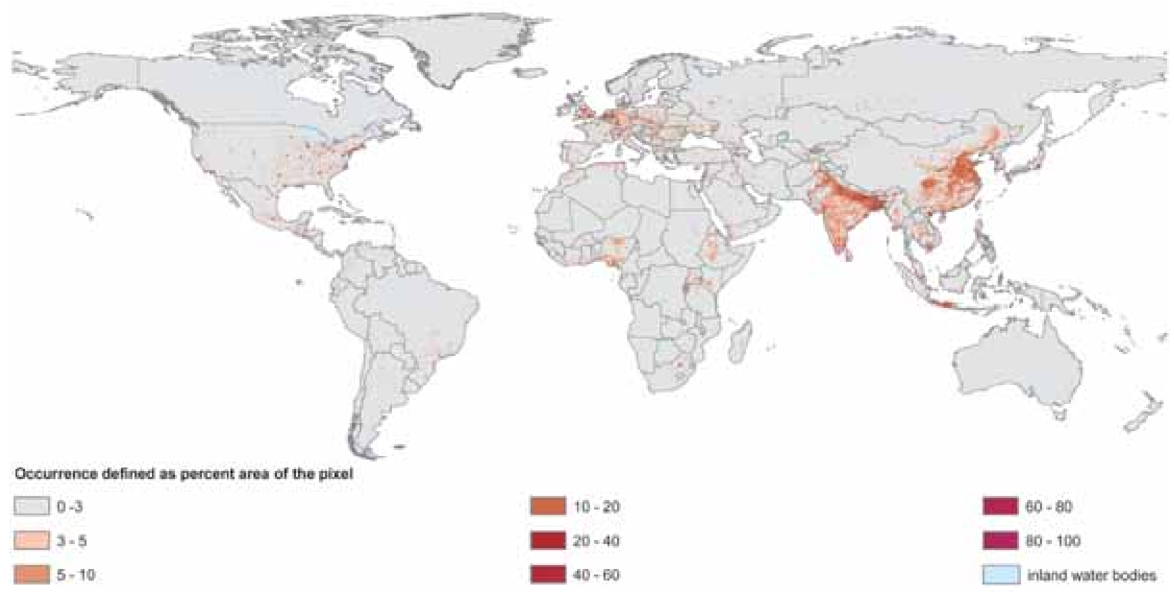
MAP A2.4

Occurrence of barren and sparsely vegetated land



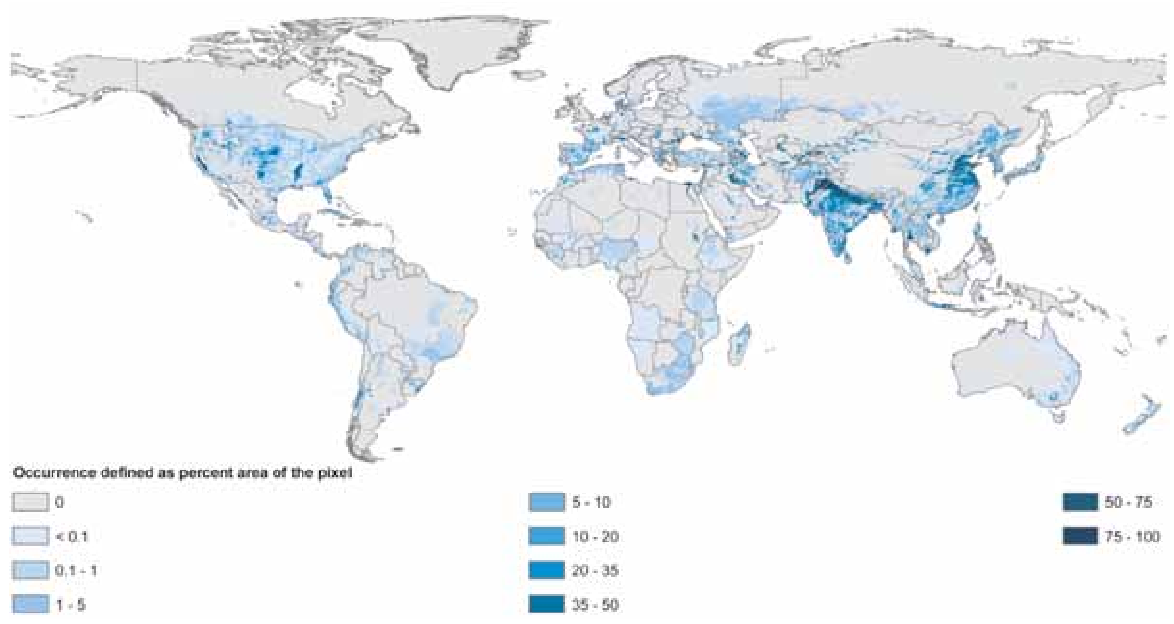
MAP A2.5

Occurrence of built-up area and artificial surface



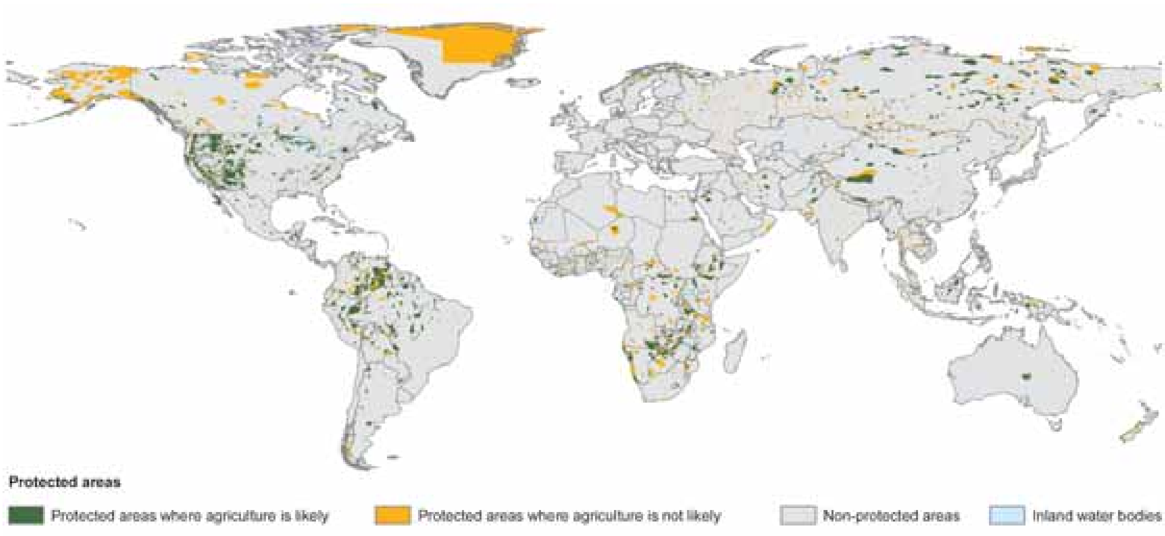
MAP A2.6

Occurrence of irrigated area



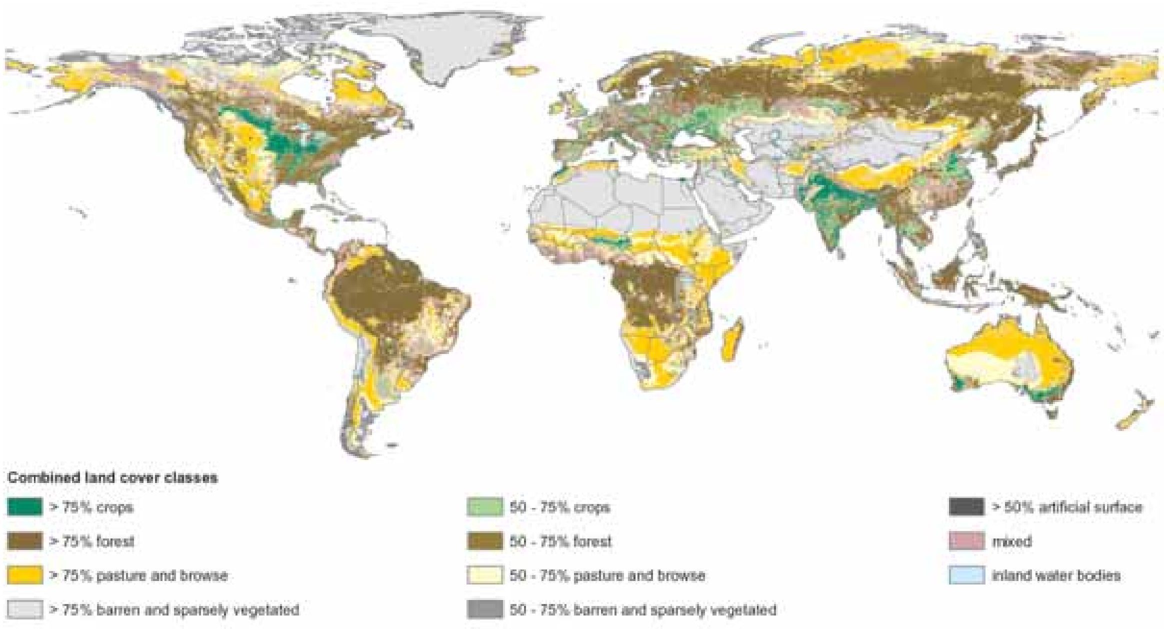
MAP A2.7

Protected area



MAP A2.8

Global land cover distribution, by dominant land cover type



A2.1 METHOD USED TO ESTIMATE THE DISTRIBUTION OF GLOBAL LAND COVER

The land cover databases are based on the GAEZ study (FAO & IIASA, 2002); for this report, they have been updated and refined, following the method described below.

The primary objective of the work was to determine the land area actually in use for rainfed crop cultivation and pasture at the time of the study. For this purpose the GAEZ assessment first created the land cover databases for built-up area, barren and sparsely vegetated land, forest cover, protected area with and without agriculture and irrigated area, and excluded these from its estimation of land currently used for rainfed crops and pasture. The remaining area was allocated to cropland or pasture and browse according to its suitability characteristics.

For the estimation of land cover shares in individual 5 arc-minute gridcells, data from several land cover datasets have been used, namely:

i. the GLC2000 land cover regional and global classifications (European Commission – Joint Research Centre. 2003);

ii. the global land cover categorization, compiled by IFPRI (IFPRI, 2002), based on a reinterpretation of the *Global Land Cover Characteristics Database* (GLCC) version 2.0 (EDC, 2000);

iii. the *Global Forest Resources Assessment* of FAO (FAO, 2001);

iv. a refinement of the global 5 arc-minute inventories of irrigated land (FAO & University of Kassel, 2002);

v. an interpretation of the IUCN-WCMC protected areas inventory at 5 arc-minutes (along with other convention types of legally protected areas to distinguish protected land in two categories, namely areas where some restricted agricultural use is permitted from areas where cultivation is strictly prohibited) (UNEP-WCMC Online);

vi. a 30 arc-second population density inventory for year 2000 which provided the basis for estimating land required for housing and infrastructure (population density map developed by FAO/SDRN, based on spatial data of LandScan 2002, with calibration to UN 2000 population figures) (FAO, 2005).

Land cover interpretation schemes have been devised that allow a quantification of each 30-arc-second gridcell into seven main land use/land cover shares. These shares are: cultivated land, subdivided into (i) rainfed land and (ii) irrigated land, (iii) forest, (iv) pasture and other vegetation, (v) barren and very sparsely vegetated land, (vi) water and (vii) urban land and land required for housing and infrastructure.

An iterative calculation procedure has been implemented to estimate consistent land cover class weights that allow the quantification of major land use/land cover shares in individual 5 arc-minute gridcells. Starting values of class weights used in the iterative procedure were obtained by cross-country regression of statistical data of cultivated and forest land against aggregated national land cover class distributions obtained from the geospatial analysis.

A2.2 METHOD USED TO ESTIMATE LAND CURRENTLY AVAILABLE FOR RAINFED AGRICULTURE

The suitability of all global land area for rainfed cultivation of nine individual crop types and pasture grasses has been evaluated by the study team (see Section 4.2), and individual suitability maps that contain the results for nine crop groups and pasture are included in the DVDs that accompany the FGGD Digital Atlas for the year 2000 (FAO, 2006). However, this report gives results only for land cover classes not already in use for human settlements, forests or irrigated agriculture.

In order to determine the land area currently available for rainfed crop cultivation and pasture in year 2000, irrespective of suitability, the following land cover classes were considered to be not currently available: urban area, closed forest, protected area where agriculture should not be occurring and irrigated area. From FAO's 5 arc-minute urban area grid, all pixels where urban area exceeds 25 percent of the area have been excluded from estimation of currently available land. From the land cover grids, all pixels where forest cover exceeds 75 percent of the area, all pixels classified by WCMC as pixels where agriculture should not be occurring and all pixels where irrigated area exceeds 50 percent have been excluded. The suitability of the remaining area for rainfed agriculture and the distribution of rural population in this area are reported here. Table A.2.1 shows the distribution of total rural population by region and dominant land cover type for rural area considered to be not currently available for rainfed agriculture and for rural area considered to be currently available for rainfed agriculture, irrespective of suitability.

TABLE A2.1

Distribution of rural population, by region and dominant land cover type

Major area and region	Rural population in pixels not considered to be currently available for rainfed agriculture					Rural population in pixels considered to be currently available for rainfed agriculture						Rural population
	Urban area > 25%	Forest > 75%	Protected area where agriculture should not be occurring	Irrigated area > 50%	Sub-total	Forest 50-75%	Crops 50% or more	Pasture and browse 50% or more	Barren and sparsely vegetated 50% or more	Mixed (no land use dominant)	Sub-total	Total
	persons (1 000)	persons (1 000)	persons (1 000)	persons (1 000)	persons (1 000)	persons (1 000)	persons (1 000)	persons (1 000)	persons (1 000)	persons (1 000)	persons (1 000)	persons (1 000)
AFRICA												
Eastern Africa	2,425	2,914	5,753	106	11,198	19,230	18,497	101,654	3,450	38,631	181,462	192,660
Middle Africa	395	16,486	1,998	-	18,879	15,570	2,760	15,771	354	10,480	44,935	63,814
Northern Africa	4,596	261	264	32,371	37,492	1,288	8,661	26,028	8,066	5,585	49,628	87,120
Southern Africa	817	12	564	-	1,393	383	492	19,013	258	2,205	22,351	23,744
Western Africa	3,772	1,728	1,931	34	7,465	4,941	30,341	51,812	1,538	41,204	129,836	137,301
AMERICAS												
Caribbean	933	9	96	199	1,237	345	2,307	3,553	156	5,184	11,545	12,782
Central America	1,904	183	505	1,425	4,017	8,312	6,592	9,466	442	14,729	39,541	43,558
Northern America	6,081	729	315	316	7,441	22,612	18,883	5,529	801	13,476	61,301	68,742
South America	6,196	8,863	1,118	369	16,546	14,223	2,959	34,073	2,495	23,509	77,259	93,805
ASIA												
Eastern Asia	57,433	15,470	4,918	82,627	160,448	48,348	258,838	96,361	9,751	256,859	670,157	830,605
Japan	3,842	4,822	262	4,150	13,076	5,575	-	250	492	8,166	14,483	27,559
South-central Asia	43,111	10,639	14,081	228,528	296,359	39,151	521,040	31,806	27,459	124,770	744,226	1,040,585
South-eastern Asia	19,086	5,593	4,478	10,229	39,386	20,772	121,882	14,511	3,022	120,937	281,124	320,510
Western Asia	3,178	585	178	6,957	10,898	1,718	8,152	22,286	11,371	9,723	53,250	64,148
EUROPA												
Eastern Europe	5,318	7,026	1,946	2,313	16,603	9,401	45,717	2,999	343	19,909	78,369	94,972
Northern Europe	2,141	1,169	84	-	3,394	1,855	3,457	4,711	161	2,585	12,769	16,163
Southern Europe	2,993	3,649	125	3,922	10,689	5,259	16,327	3,482	390	13,107	38,565	49,254
Western Europe	5,252	1,285	36	284	6,857	3,267	7,766	3,655	63	8,879	23,630	30,487
OCEANIA												
Australia and New Zealand	223	365	36	20	644	367	1,197	1,519	57	384	3,524	4,168
Melanesia	44	897	-	-	941	1,926	-	592	86	1,031	3,635	4,576
Developed	**25,850**	**19,045**	**2,804**	**11,005**	**58,704**	**48,336**	**93,347**	**22,145**	**2,307**	**66,506**	**232,641**	**291,345**
Developing	**143,890**	**63,640**	**35,884**	**362,845**	**606,259**	**176,207**	**982,521**	**426,926**	**68,448**	**654,847**	**2,308,949**	**2,915,208**
World	**169,740**	**82,685**	**38,688**	**373,850**	**664,963**	**224,543**	**1,075,868**	**449,071**	**70,755**	**721,353**	**2,541,590**	**3,206,553**

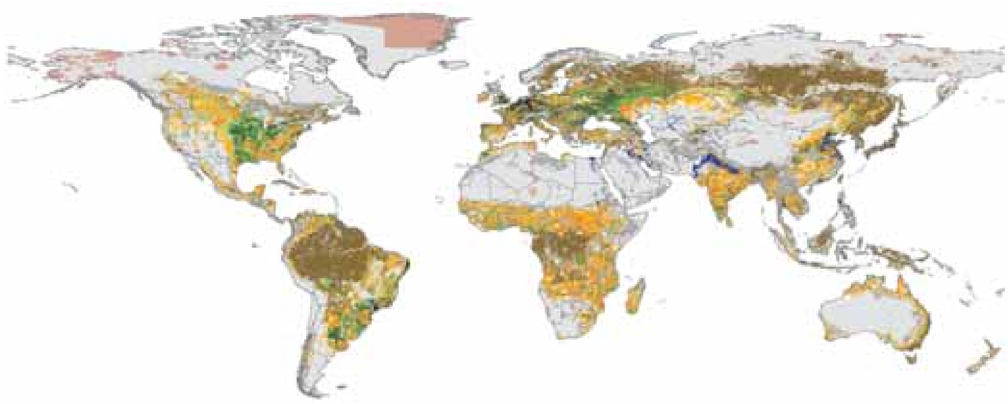
ANNEX 3

SUITABILITY OF CURRENTLY AVAILABLE LAND FOR CROPS GROUPS

In this Annex, suitability maps at three levels of inputs and management are presented for nine crop groups under rainfed conditions. They are: cereals (wheat, rice, maize, barley, sorghum, millet, rye); fibre crops (cotton); oil crops (soybean, rape, groundnut, sunflower, oil palm, olive); pulses (phaseolus bean, chickpea, cowpea); roots and tubers (white potato, cassava, sweet potato, yam); stimulants (cocoa, coffee, tobacco); sugar crops (cane, beet); tree fruits (banana/plantain, citrus); vegetables (cabbage, onion, tomato). The method used to calculate the crop suitability index (CSI) is explained in Section 4.1.5. In these maps, the CSI for irrigated area and land that is not currently available for rainfed agriculture are not shown, although they have been calculated, and are available on the DVD that contains the FGGD Digital Atlas for the year 2000 (FAO, 2006).

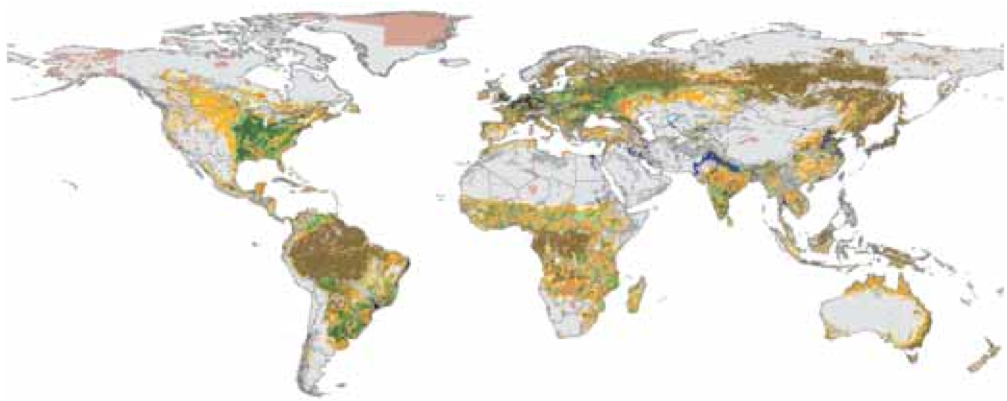
MAP A3.1a

Suitability of currently available land for cereals (low level of inputs)



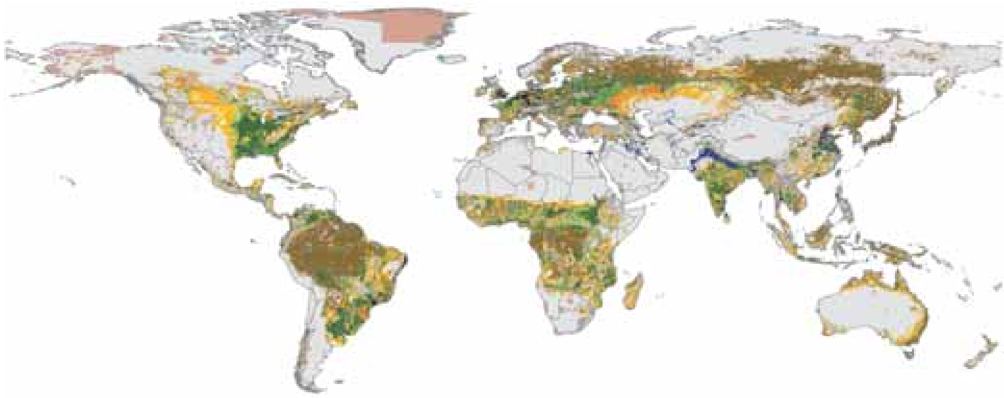
MAP A3.1b

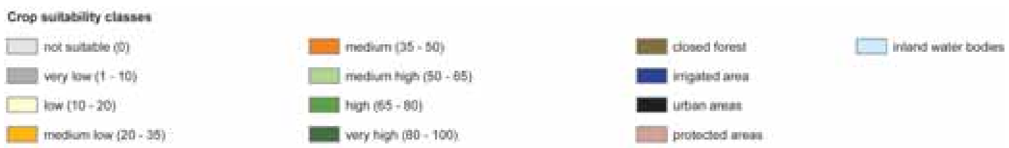
Suitability of currently available land for cereals (intermediate level of inputs)



MAP A3.1c

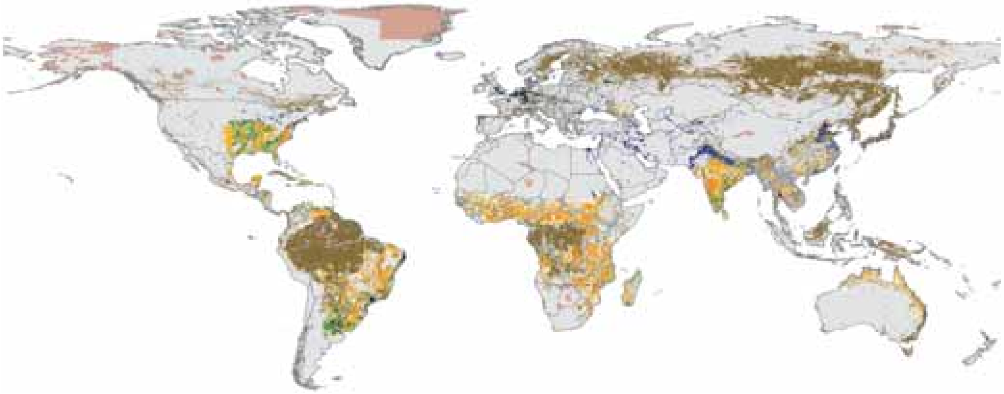
Suitability of currently available land for cereals (high level of inputs)





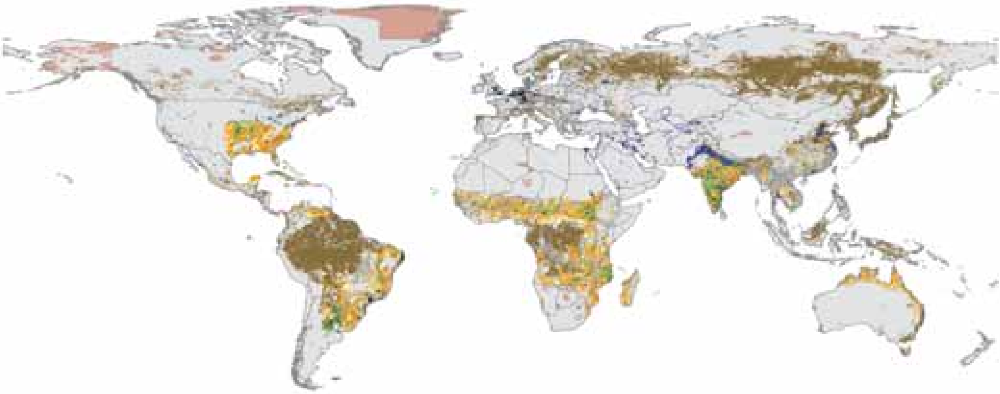
MAP A3.2a

Suitability of currently available land for fibre crops (low level of inputs)



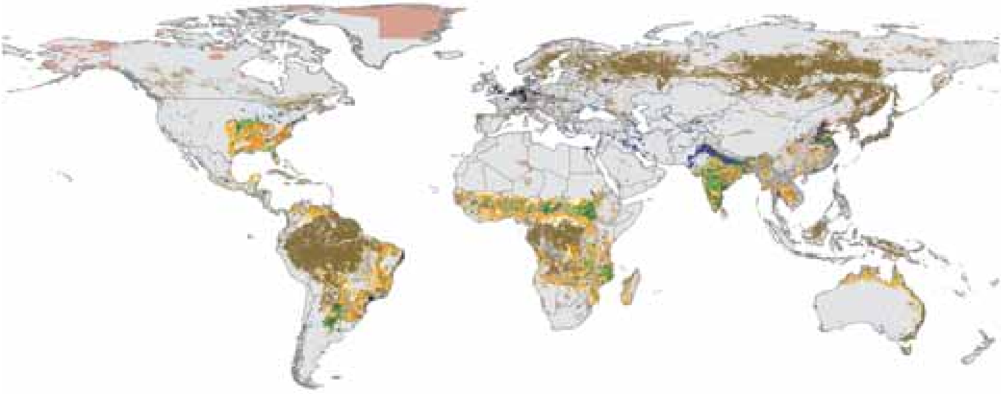
MAP A3.2b

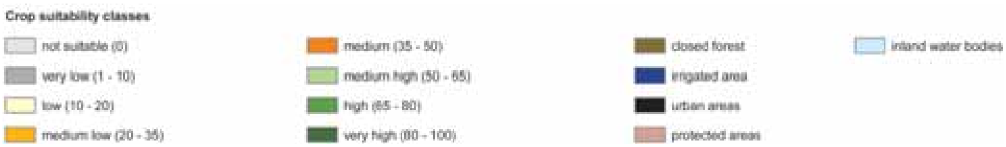
Suitability of currently available land for fibre crops (Intermediate level of inputs)



MAP A3.2c

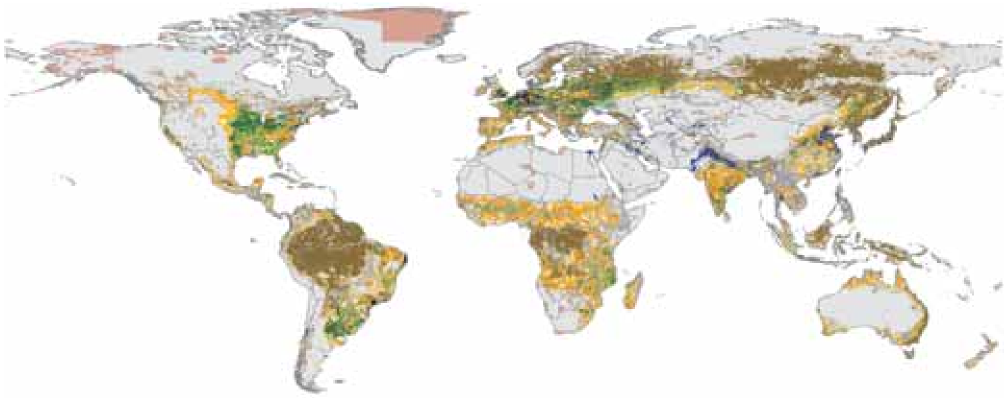
Suitability of currently available land for fibre crops (high level of inputs)





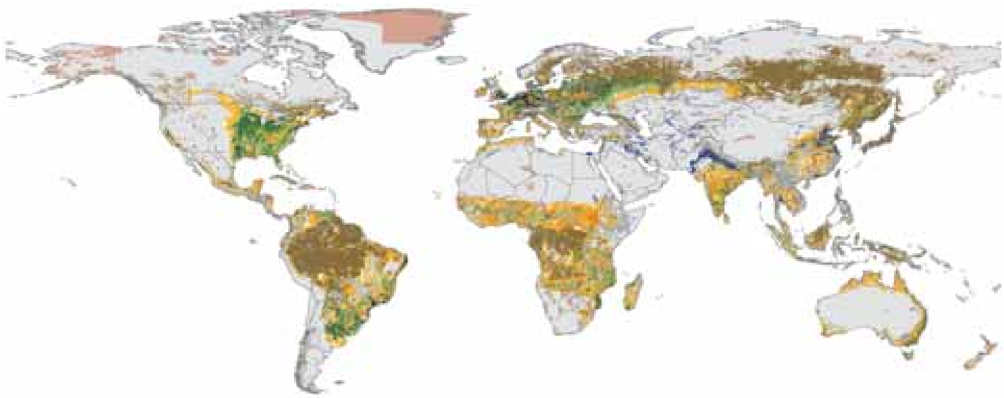
MAP A3.3a

Suitability of currently available land for fibres (low level of inputs)



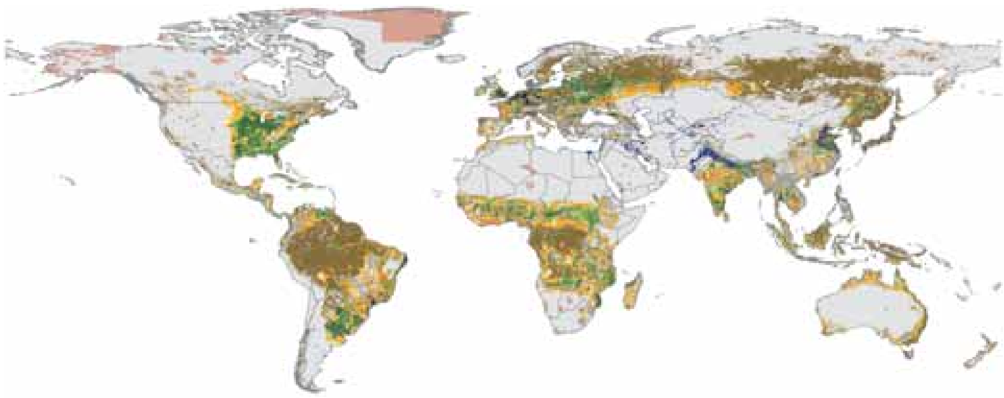
MAP A3.3b

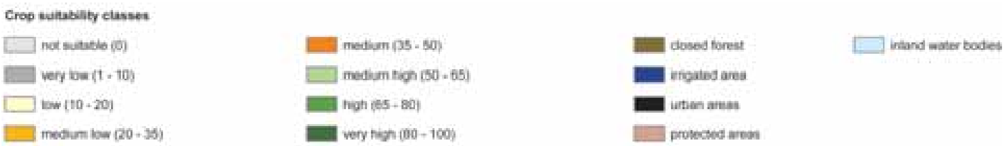
Suitability of currently available land for fibres (Intermediate level of inputs)



MAP A3.3c

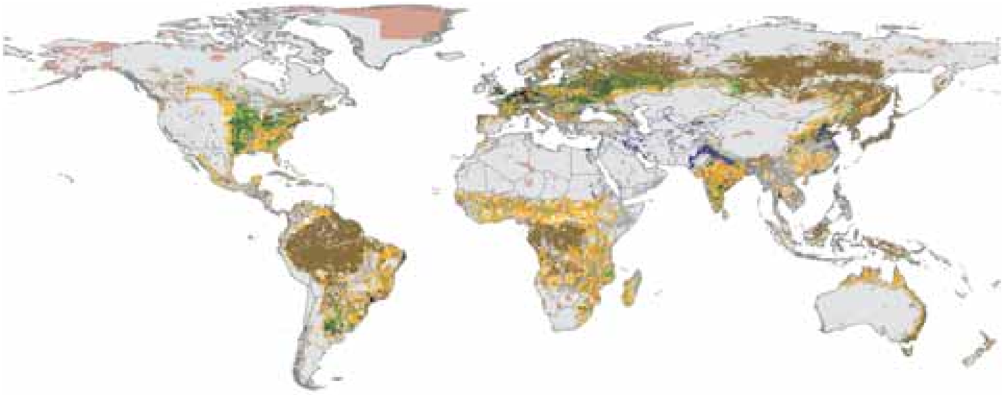
Suitability of currently available land for fibres (high level of inputs)





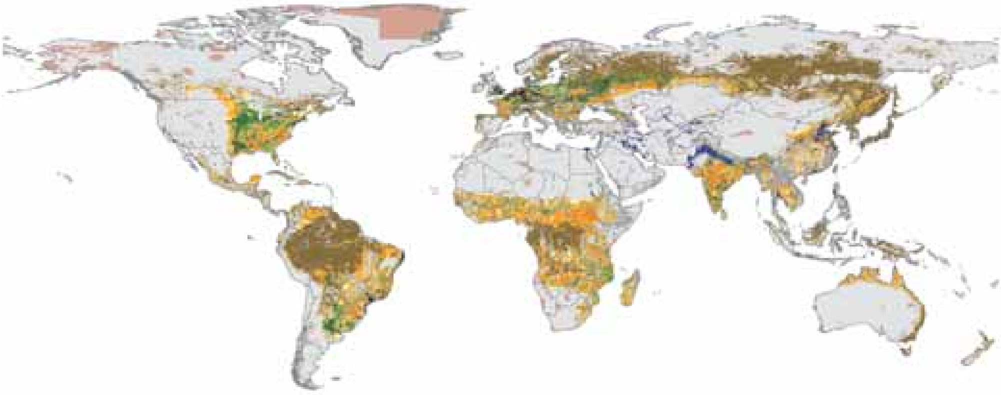
MAP A3.4a

Suitability of currently available land for oil crops (low level of inputs)



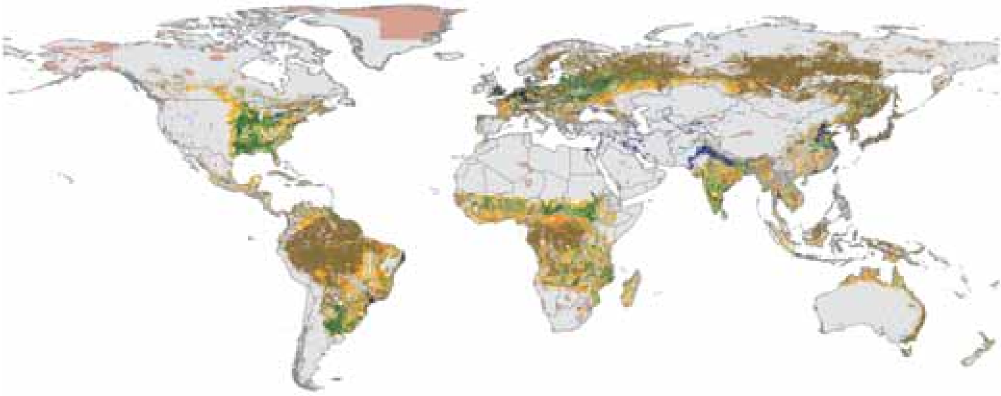
MAP A3.4b

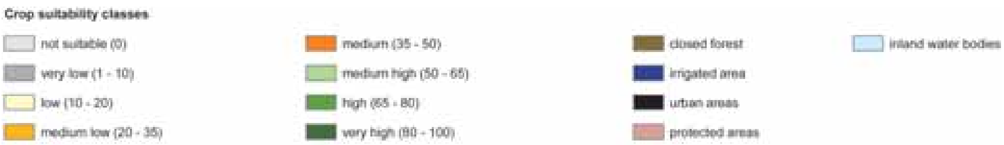
Suitability of currently available land for oil crops (Intermediate level of inputs)



MAP A3.4c

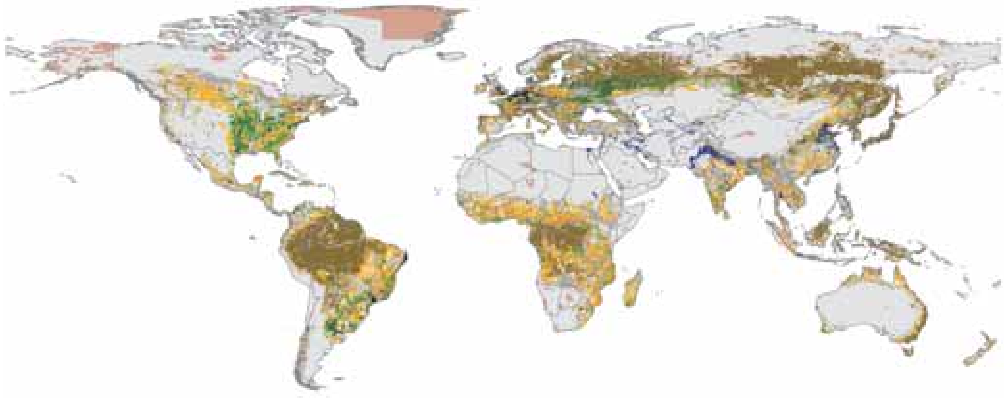
Suitability of currently available land for oil crops (high level of inputs)





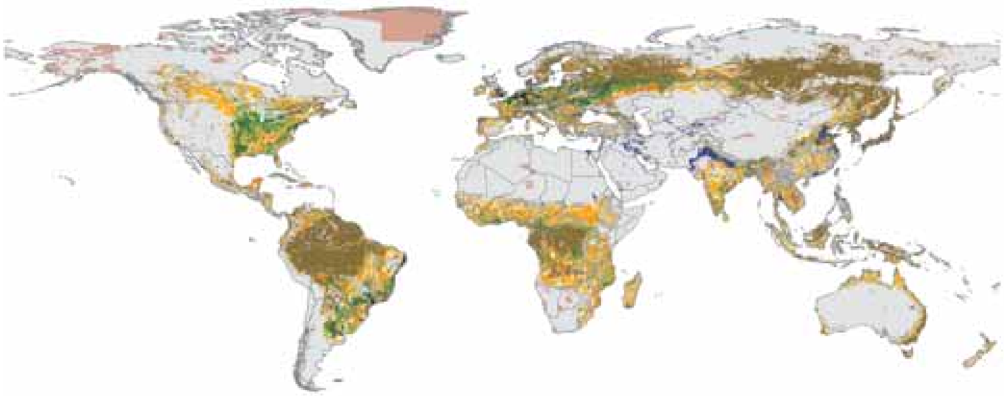
MAP A3.5a

Suitability of currently available land for pulses (low level of inputs)



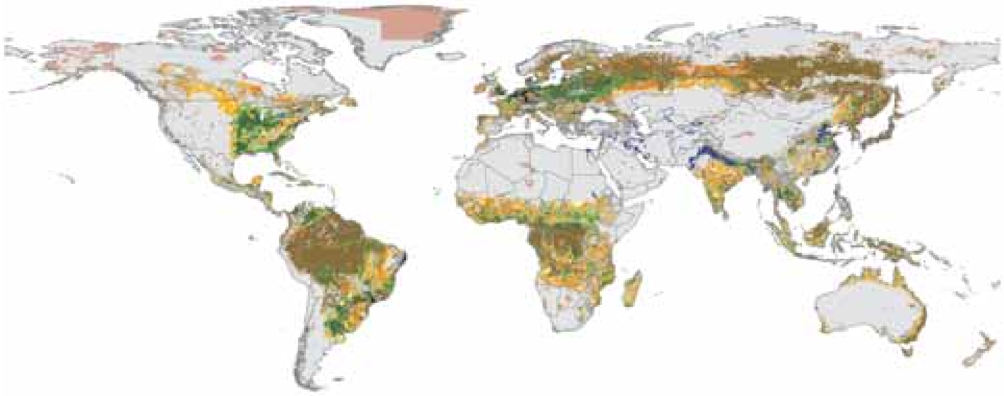
MAP A3.5b

Suitability of currently available land for pulses (Intermediate level of inputs)



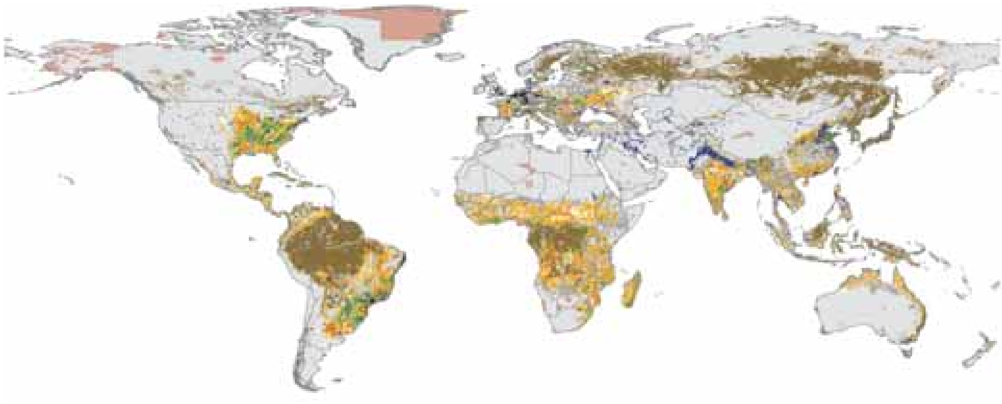
MAP A3.5c

Suitability of currently available land for pulses (high level of inputs)



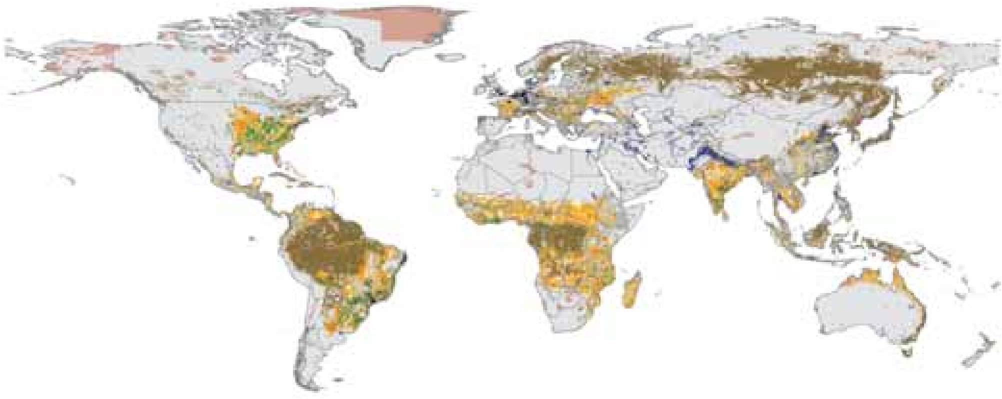
MAP A3.6a

Suitability of currently available land for roots and tubers (low level of inputs)



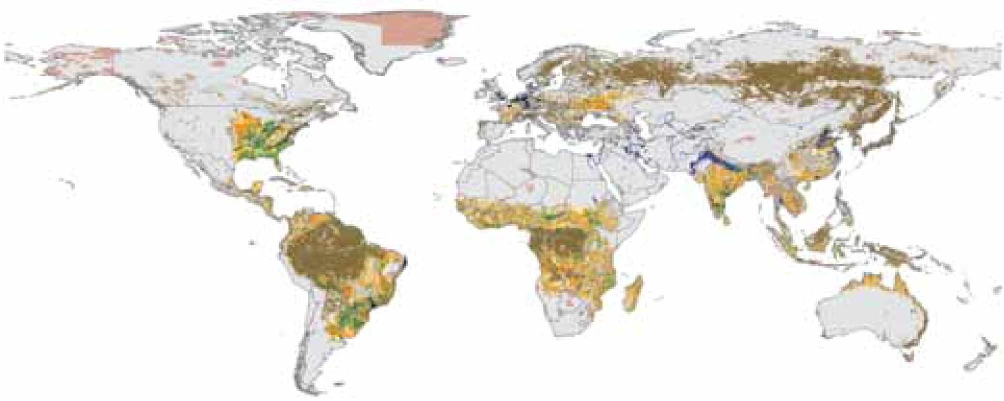
MAP A3.6b

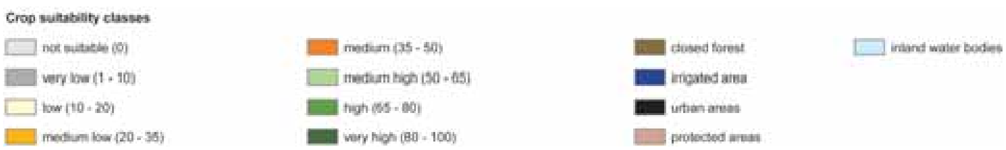
Suitability of currently available land for roots and tubers (Intermediate level of inputs)



MAP A3.6c

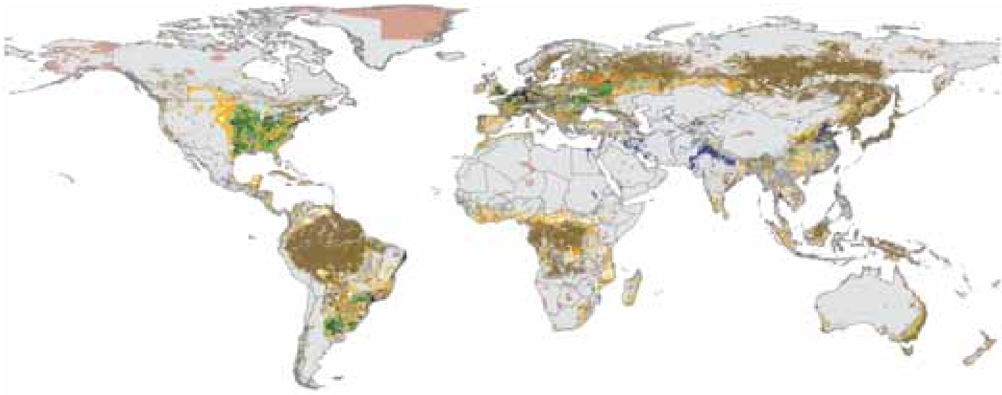
Suitability of currently available land for roots and tubers (high level of inputs)





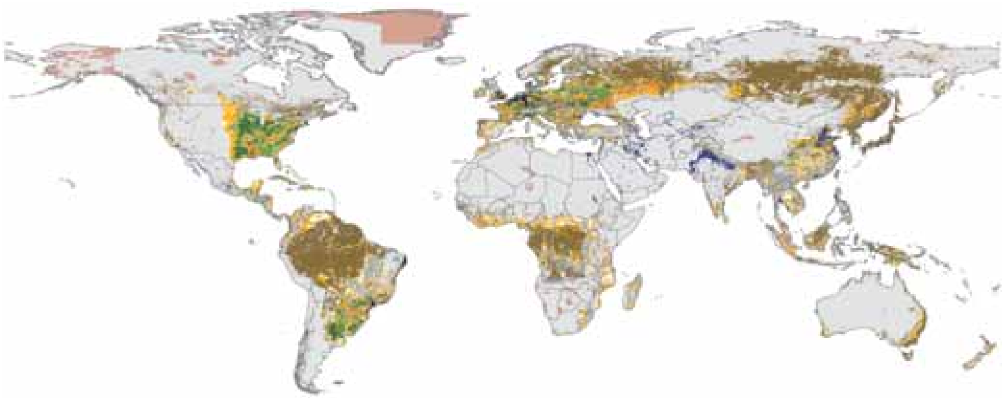
MAP A3.7a

Suitability of currently available land for sugar crops (low level of inputs)



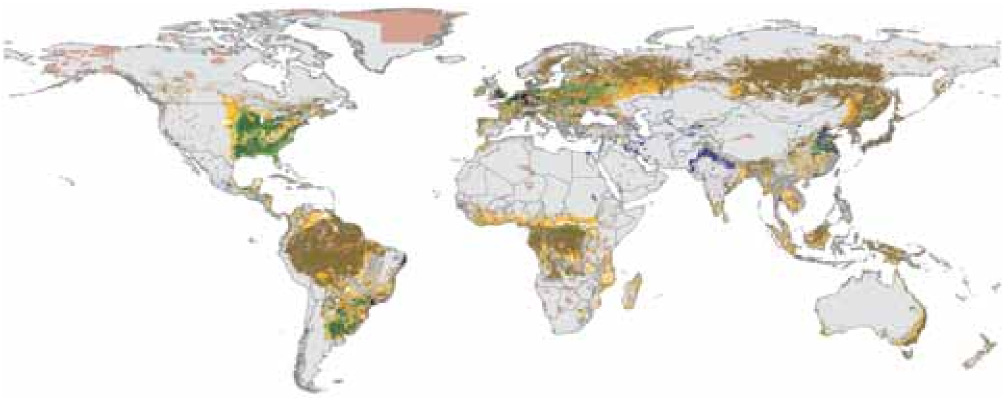
MAP A3.7b

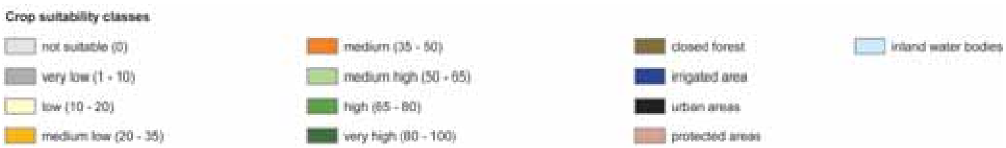
Suitability of currently available land for sugar crops (Intermediate level of inputs)



MAP A3.7c

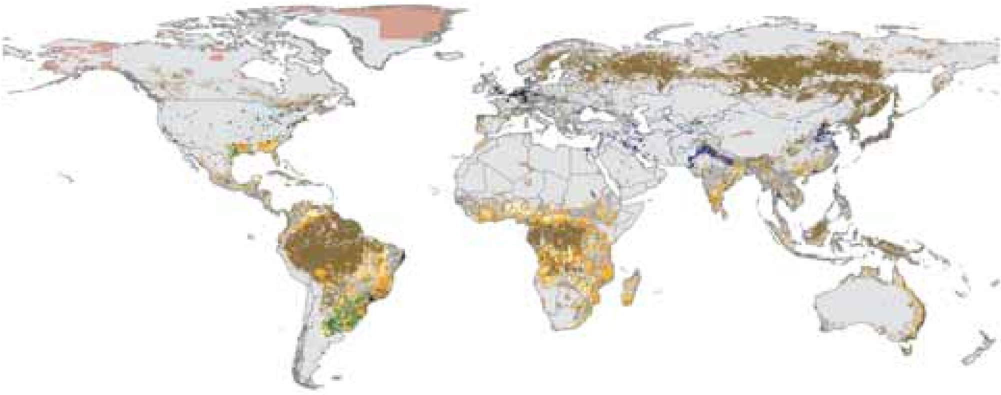
Suitability of currently available land for sugar crops (high level of inputs)





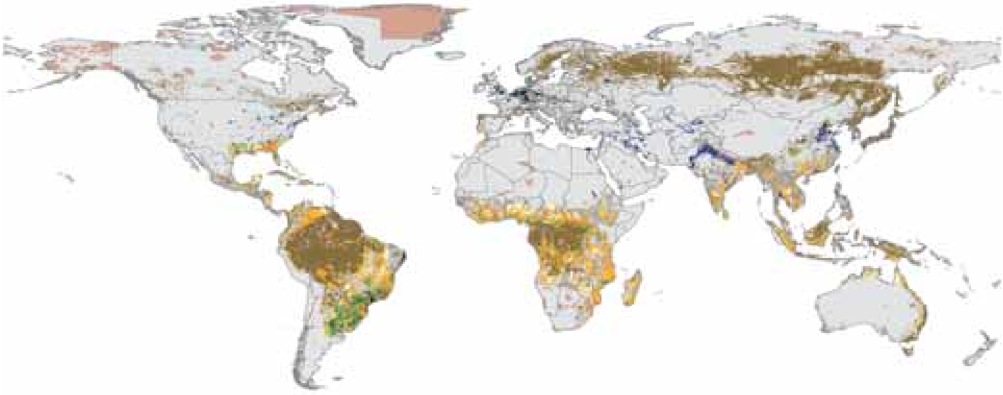
MAP A3.8a

Suitability of currently available land for tree fruits (low level of inputs)



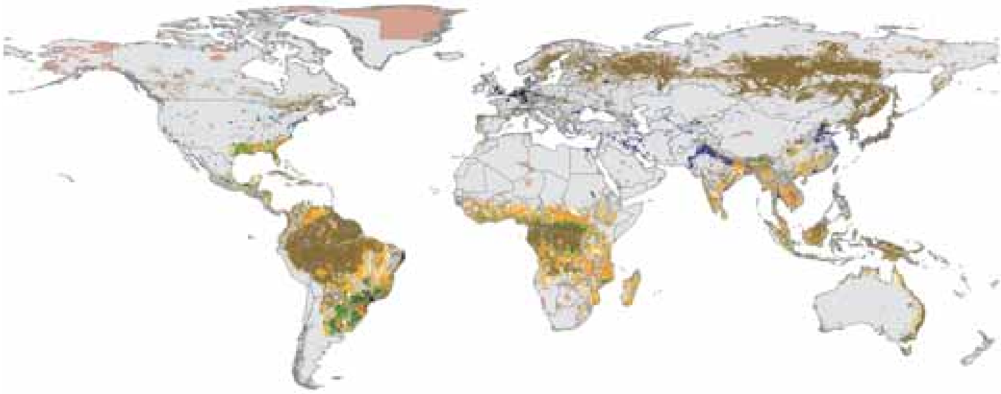
MAP A3.8b

Suitability of currently available land for tree fruits (Intermediate level of inputs)



MAP A3.8c

Suitability of currently available land for tree fruits (high level of inputs)

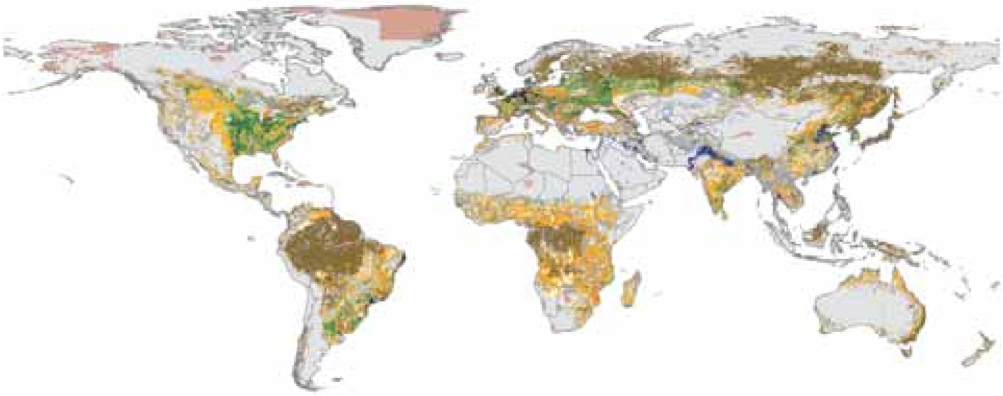


Crop suitability classes

- not suitable (0)
- very low (1 - 10)
- low (10 - 20)
- medium low (20 - 35)
- medium (35 - 50)
- medium high (50 - 65)
- high (65 - 80)
- very high (80 - 100)
- closed forest
- irrigated area
- urban areas
- protected areas
- inland water bodies

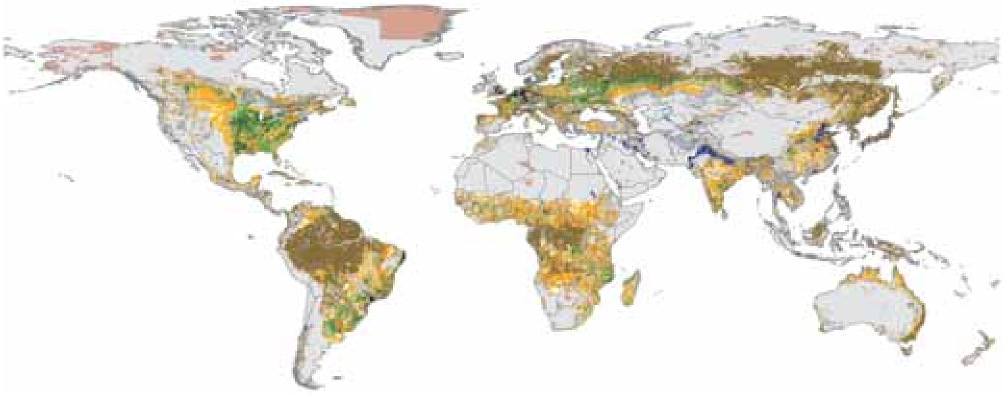
MAP A3.9a

Suitability of currently available land for vegetables (low level of inputs)



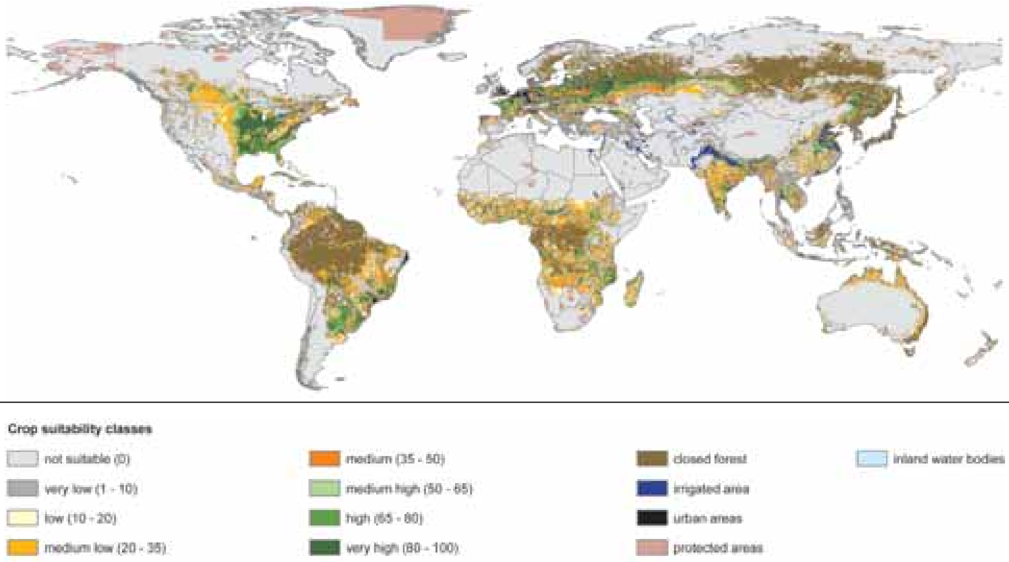
MAP A3.9b

Suitability of currently available land for vegetables (Intermediate level of inputs)



MAP A3.9c

Suitability of currently available land for vegetables (high level of inputs)



ANNEX 4

MAIN CHARACTERISTICS OF FARMING SYSTEMS

An FAO-World Bank study, Farming systems and poverty (FAO & World Bank, 2001), contains information about cropping, livestock-keeping, fishing, agro-forestry, and hunting and gathering activities of households belonging to each of 44 unique farming systems in developing and transition countries. It also provides information on the existing social, economic and institutional environments within which each farming system is practiced, and about other sources of off-farm income that help to sustain rural households.

The tables contained in this Annex have been developed by the study team, based on the authors' knowledge of the agro-ecological zones where each farming system is practiced, plus information contained in the above-mentioned study about principal sources of livelihood, level of farm technology used, and prevalence of poverty (where the terms limited, moderate and extensive refer to the number in poverty while the term refers to the depth of poverty) for each farming system found in each of the six regions listed below:

- Latin America and Caribbean
- East Asia and Pacific
- South Asia
- Eastern Europe and Central Asia
- Middle East and North Africa
- Sub-Saharan Africa

The regional maps shown in this Annex are enlarged extracts from a global map (Map A4.7) that was initially prepared for the FAO-World Bank study. The FGGD Digital Atlas for the year 2000 (FAO, 2006) contains the complete global farming systems database and a printable version showing the 44 farming systems collapsed into seven classes (see Section 5.1).

MAP A4.1

Farming systems in Latin America and Caribbean

TABLE A4.1

Characteristics of farming systems in Latin America and Caribbean

Farming system	Location	Principal livelihood sources (secondary sources)	Level of technology and organization	Prevalence of poverty
Irrigated	Arid lands across northern and central Mexico, and coastal and inland valley areas of Peru, Chile and western Argentina	Horticulture, fruit, cattle (rice, cotton, vines)	Irrigation infrastructure allows a relatively high degree of intensification of production	Limited to moderate
Forest based	Centred on the Amazon basin	Subsistence agriculture, cattle	Low: scattered indigenous and low-input settler agricultural activity	Limited to moderate
Pastoral	South Argentina	Sheep, cattle	Low: no reported irrigation	Limited to moderate
Dryland mixed	Northeast Brazil and Yucatan peninsula of Mexico	Livestock, maize, cassava, wage labour, seasonal migration (rice, beans, squash, sugarcane)	High: well established economic and productive structure, but land degradation is a serious problem	Extensive among small-scale producers
Temperate mixed (Pampas)	Central and eastern Argentina and Urugay	Livestock, wheat, soybean (sunflower horticulture)	Medium: further intensification of production is expected	Limited
Sparse (forest)	Southern end of the Andes	Livestock grazing, forestry, tourism	No data	Limited to moderate
Coastal plantation and mixed	Coasts of Central America, northern part of South America and east Brazil	Tree crops, fishing, tubers, tourism	Small-scale family farms and large-scale plantations, often internationally owned	Extensive among labourers, otherwise not prevalent
Intensive mixed	Centred on eastern and central Brazil	Coffee, horticulture, fruit, off farm work	High	Limited
Cereal-livestock (Campos)	Southern Brazil and Paraguay, northern Uruguay and Argentina	Rice, livestock	No data	Limited to moderate
Maize-beans (Mesoamerica)	From central Mexico to the Panama Canal	Maize, beans, coffee, horticulture, off-farm work (rubber, cut-flowers, vegetables, tree fruits)	Medium: installation of non indigenous settlers, serious land degradation	Extensive and severe among the indigenous population
Extensive mixed (Cerrados and Llanos)	Central-western Brazil and eastern Colombia, Venezuela and Guyana	Livestock, oilseeds, grains, coffee (soybean, maize, rice, upland rice, beans)	Medium: recently developing	Moderate among landless migrants
Intensive highland mixed (north Andes)	Northern Andes	Vegetables, maize, coffee, cattle, pigs, other cereals, potatoes, off-farm work	High in the well developed intermontane valleys and lower slope; traditional methods in the highlands and upper valleys	Moderate in the lower areas, extensive and often severe at higher altitudes
High altitude mixed (central Andes)	Southern Peru, western Bolivia, northern Chile and Argentina	Indigenous grains, potatoes, vegetables, sheep ans llamas, off-farm work (maize, lima beans, barley, sugar beet)	Low: very strong indigenous culture	Extensive and severe
Moist temperate mixed forest	Coastal zone of central Chile	Dairy, beef, cereals, forest, extraction, tourism (sheep, sugar, beet)	No data	Limited
Extensive dryland mixed (Gran Chaco)	From northern central Argentina to Paraguay and eastern Bolivia	Livestock, cotton, subsistence crops	No data	Moderate to extensive

MAP A4.2

Farming systems in East Asia and Pacific

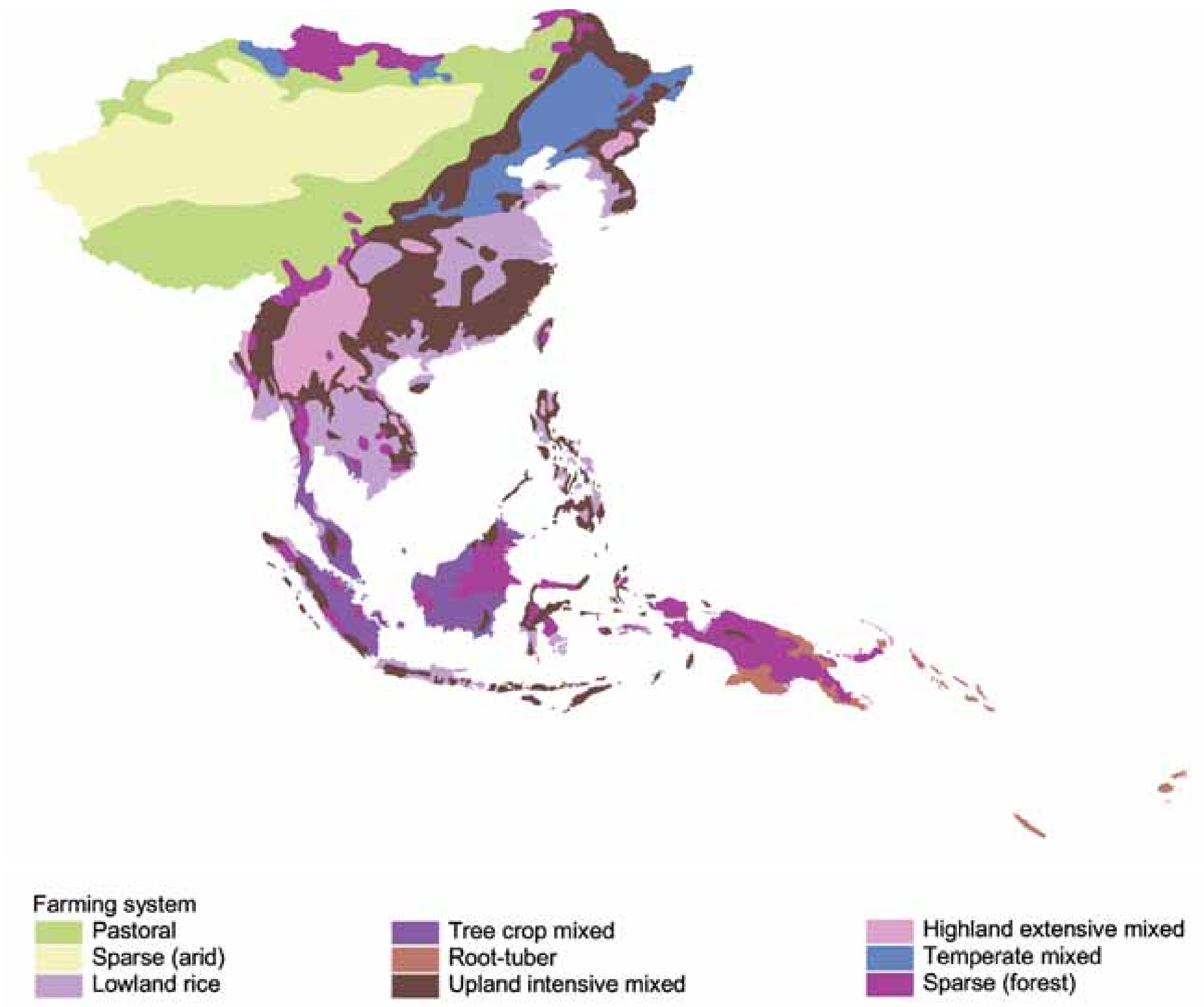


TABLE A4.2

Characteristics of farming systems in East Asia and Pacific

Farming system	Location	Principal livelihood sources (secondary sources)	Level of technology and organization	Prevalence of poverty
Pastoral	Western China and much of central and northern Mongolia	Transhumant pastoralism, e.g. camels, cattle, sheep and goats, with irrigated crops in suitable areas (wheat, barley, pulses, peas, broad beans, potatoes, grapes, cotton)	No data	Extensive, especially triggered by drought or severe winter
Sparse (arid)	Western China and southern Mongolia	Local grazing where water is available, off-farm work (large-scale irrigation concentrated in the west)	No data	Extensive and severe especially after droughts
Lowland rice	Large areas in Thailand, Vietnam, Cambodia, Myanmar, South and Central-east China, western Korea, Philippines and Indonesia	Rice, maize, pulses, sugarcane, oil seeds, vegetables, livestock, aquaculture, off-farm work (sweet potato, cotton, fruits, some wheat in Central-east China)	No data	Moderate overall, extensive in Myanmar and Cambodia
Tree crop mixed	Significant areas in Malaysia, southern Thailand, Indonesia and Papua New Guinea	Rubber, oil palm, coconuts, coffee, tea, cocoa, spices, rice, livestock, off-farm work (pepper, upland rice, maize)	Medium: both large private estate and smallholder management	Moderate
Root-tuber	Papua New Guinea and Indonesia	Root crops, vegetables, fruits, livestock, off-farm work (coconut, hunting, gathering)	No data	Limited
Upland intensive mixed	All countries of East and Southeast Asia	Rice, pulses, maize, sugarcane, oil seeds, fruits, vegetables, livestock, off-farm work (wheat, upland rice, cotton, soybean, citrus)	Very heterogeneous, some remnant shifting cultivation	Extensive, somewhat to very severe
Highland extensive mixed	Laos, Central and North Vietnam, northern Thailand, northern and eastern Myanmar, Southwest China, Philippines and parts of Indonesia	Upland rice, pulses, maize, sugarcane, oil seeds, fruits, forest products, livestock, off-farm work	Low: permanent and shifting cultivation	Moderate and severe
Temperate mixed	Central North China and restricted areas of Mongolia	Wheat, maize, pulses, oil crops, livestock (small areas of rice, potato, cabbage, fruits)	No data	Moderate
Sparse (forest)	Scattered locations in East Asia and present in the major islands of Indonesia and Papua New Guinea	Hunting, gathering, off-farm work (potatoes and buckwheat, plus cattle and yak herds on the mainland of Asia; in the dense tropical forest upland rice, root crops, large ruminants)	Low: small, scattered settlements	Moderate

MAP A4.3

Farming systems in South Asia

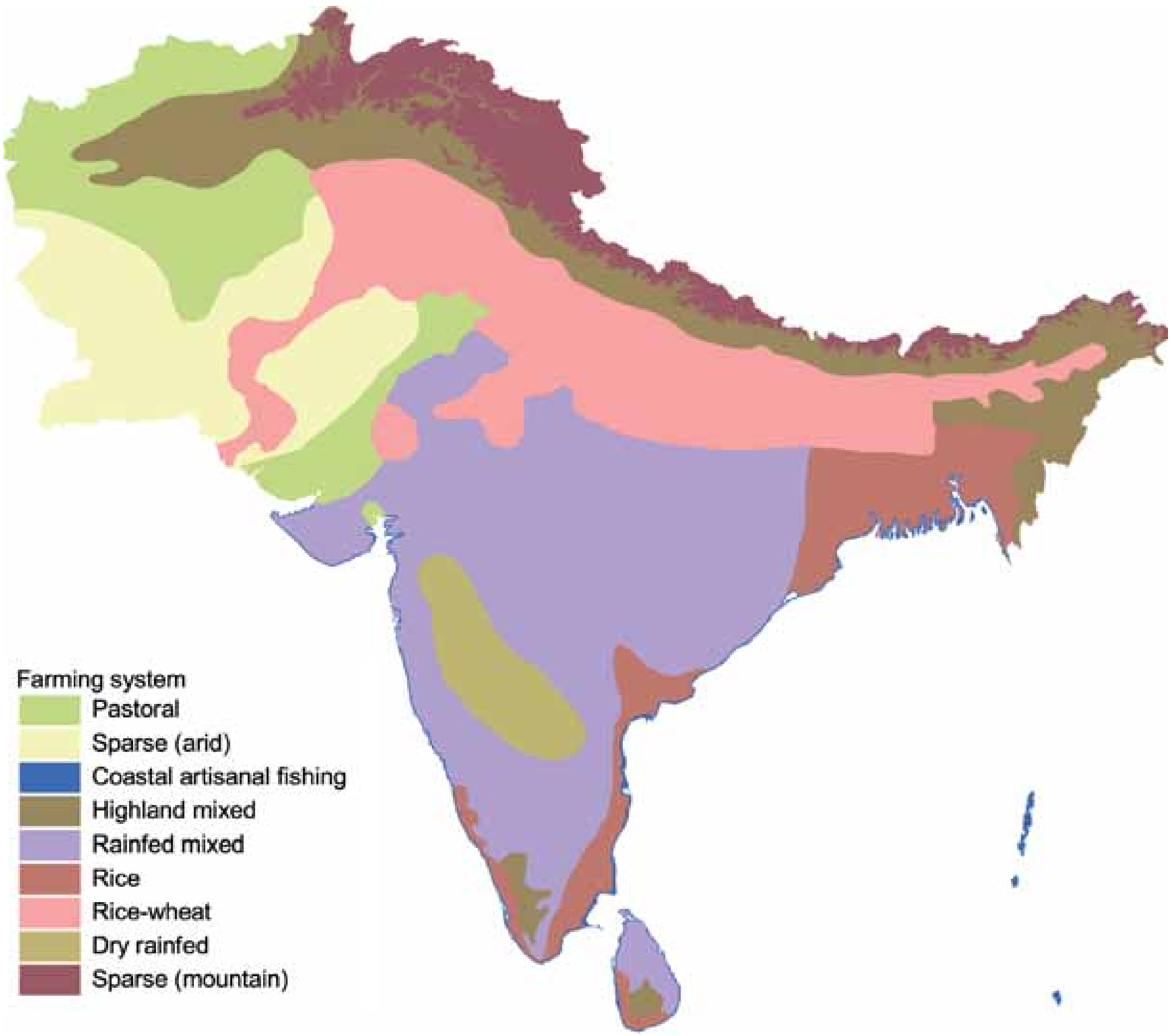


TABLE A4.3

Characteristics of farming systems in South Asia

Farming system	Location	Principal livelihood sources (secondary sources)	Level of technology and organization	Prevalence of poverty
Pastoral	Semiarid and arid zones from Rajasthan in India through Pakistan and Afghanistan	Livestock, irrigated cropping, migration, off-farm work (rice, wheat, fodder crops)	No data	Moderate to extensive, periodically accentuated by drought
Sparse (arid)	Pakistan, southwest Afghanistan and northwest India	Livestock where seasonal moisture permits, scattered irrigation settlements (irrigated cropping, rice, wheat)	No data	Moderate to extensive, often severe after droughts
Coastal artisanal fishing	Narrow band along the major part of the coast of Bangladesh and India, and around the Maldives	Fishing, coconuts, rice, legumes, livestock (vegetables)	Medium: over-exploitation of the common resources, stakeholder with conflicting objectives	Moderate to extensive
Highland mixed	Lower slopes across the entire length of the Himalayan range, from Afghanistan to the extreme northeast of India, Kerala and Central Sri Lanka	Cereals, livestock, horticulture, seasonal migration (legumes, tubers, vegetables, potato, fodder crops, fodder trees, orchards)	Low: remoteness and lack of social service	Moderate to extensive
Rainfed mixed	India and a small area in northern Sri Lanka	Rice and some wheat, barley, maize, millet, sorghum, a wide variety of pulses and oilseeds, sugarcane, vegetables and fruit, fodder crops, livestock, off-farm work	Medium: recently, irrigation has contributed to an elevated level and stability of cereal production	Extensive, severe after droughts
Rice	Bangladesh and West Bengal, smaller areas in Tamil Nadu and Kerala states of India, and southern Sri Lanka	Wetland rice (both seasons), vegetables, legumes, off-farm work (coarse grains oil seeds)	No data	Extensive and also quite severe in small farms
Rice-wheat	Northern Pakistan and Indian from the Indus irrigation area in Sindh and Punjab, across the Indo-Gangetic plain to the northeast of Bangladesh	Irrigated rice, wheat, vegetables, livestock including dairy, off-farm work (cotton)	Medium: significant level of crop-livestock integration	Moderate to extensive
Dry rainfed	Western Deccan in India	Coarse cereals, irrigated cereals, legumes, off-farm work	Medium: 36 percent of the cultivated area is under irrigation	Moderate
Sparse (mountain)	Along the mid level and upper slopes of the Himalayan Range	Potatoes and buckwheat plus cattle and yak herd, sheep and goats, seasonal migration and tourism	No data	Moderate to extensive, especially in remote areas

MAP A4.4

Farming systems in Eastern Europe and Central Asia

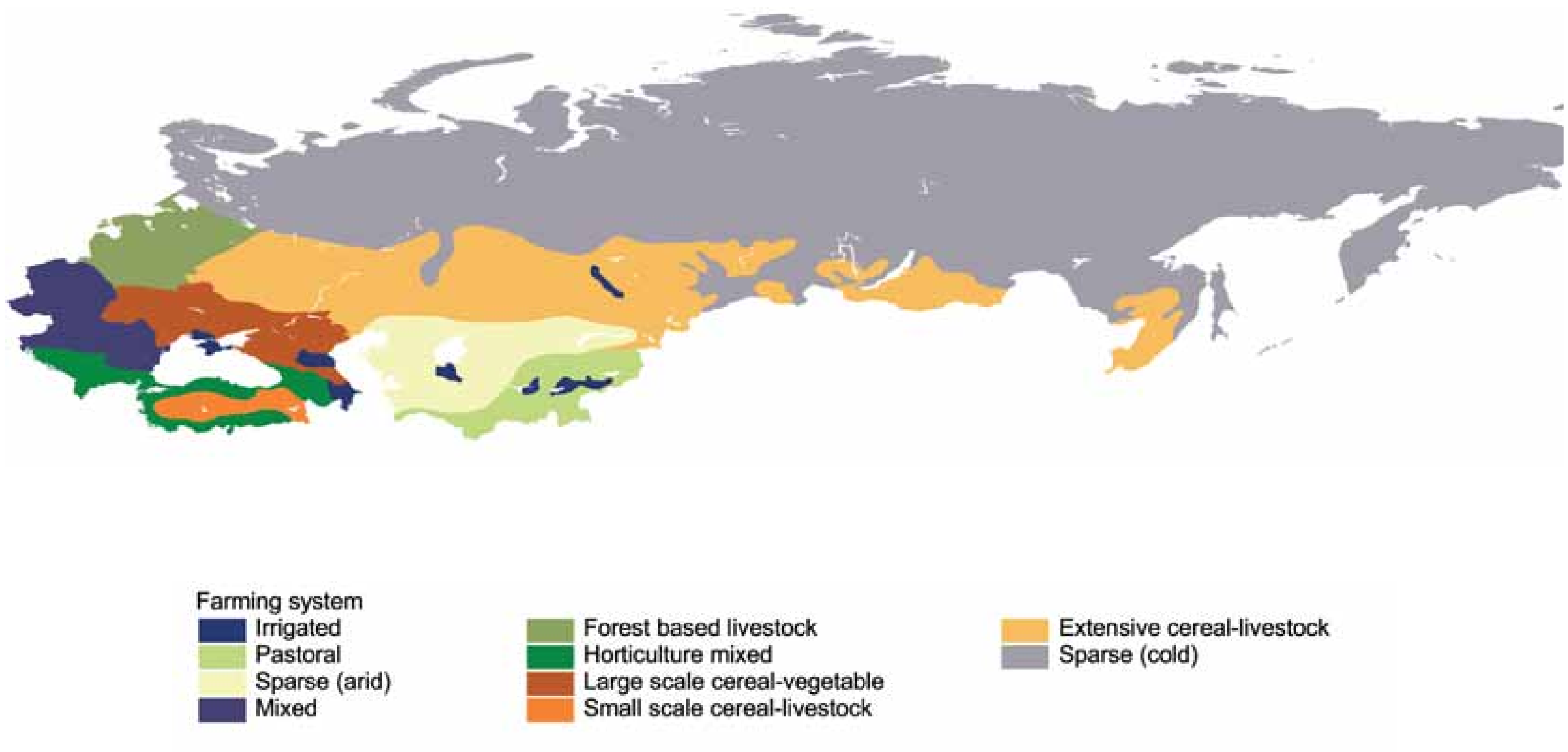


TABLE A4.4

Characteristics of farming systems in Eastern Europe and Central Asia

Farming system	Location	Principal livelihood sources (secondary sources)	Level of technology and organization	Prevalence of poverty
Irrigated	Crimea, west of Caspian sea, south of Aral Sea, eastern Uzbekistan, central Kyrgyzstan, and the Ertis valley in the northeast of Kazakhstan	Cotton, rice, other cereals, tobacco, fruit, vegetables, off-farm work (wheat, barley)	Medium	Moderate to extensive, especially widespread in the Caucasus
Pastoral	Typical of much of southeaster part of Central Asia	Sheep, cattle, cereals, fodder crops, potatoes	Low: excessive animal population, poor pasture management and overgrazing	Moderate to extensive, particularly widespread in this system
Sparse (arid)	South of Eurasian steppe, including most of Turkmenistan and Uzbekistan, as well as a large strip of Kazakhstan	In the most favourable areas, extensive cereal cultivation (barley) complemented by sheep raising (cereals)	Low: heavily indebted farms, water resources over-exploited	Extensive
Mixed	Central european countries as Poland, Czech Rep., Slovakia, Hungary, Romania, Slovenia and Croatia	Wheat, maize, oil crops, barley, livestock (sunflower, rapeseed, fodder crops, sugar beet, pumpkin, alfalfa, fruit)	Medium: small to medium-scale private family farms and medium to large corporate or co-operative farms	Low to moderate, concentrated among ethnic minorities, unemployed and unskilled workers
Forest based livestock	Belarus, Northwest Russia and Baltic states	Forest, hay, cereals, industrial crops, potatoes. Little or no cash income, use of barter	Low: co-operative or corporate ownership	Moderate
Horticulture mixed	Southern Balkans, northern Turkey and the Caucasus	Wheat, maize, oil crops, fruit, intensive vegetables, livestock	Medium to high: use of greenhouses, partial irrigation	Moderate to extensive, partly arising from armed conflicts
Large-scale cereal-vegetable	Ukraine and southwest part of Russian Federation and Republic of Moldova	Wheat, barley, maize, sunflower, sugarbeet, vegetables. Little cash income, large dependance on own production and barter	No data	Moderate to extensive
Small-scale cereal-livestock	Semiarid and dry sub-humid and mountainous zones of Turkey	Wheat, barley, sheep and goats	No data	Moderate, but increasing
Extensive cereal-livestock	Semiarid areas of the Russian Federation and northern Kazakhstan, and substantial areas in southern Kazakhstan, Turkmenistan and Uzbekistan	Wheat, hay, fodder, cattle, sheep (barley, sunflower, vegetables)	Fallow every two year	Moderate to extensive, increasing among old people, young families and former co-operative members
Sparse (cold)	Northern part of the Russian Federation	Rye, oats, reindeer, potatoes, pigs, forestry (vegetables)	Low	Extensive

MAP A4.5

Farming systems in Middle East and North Africa

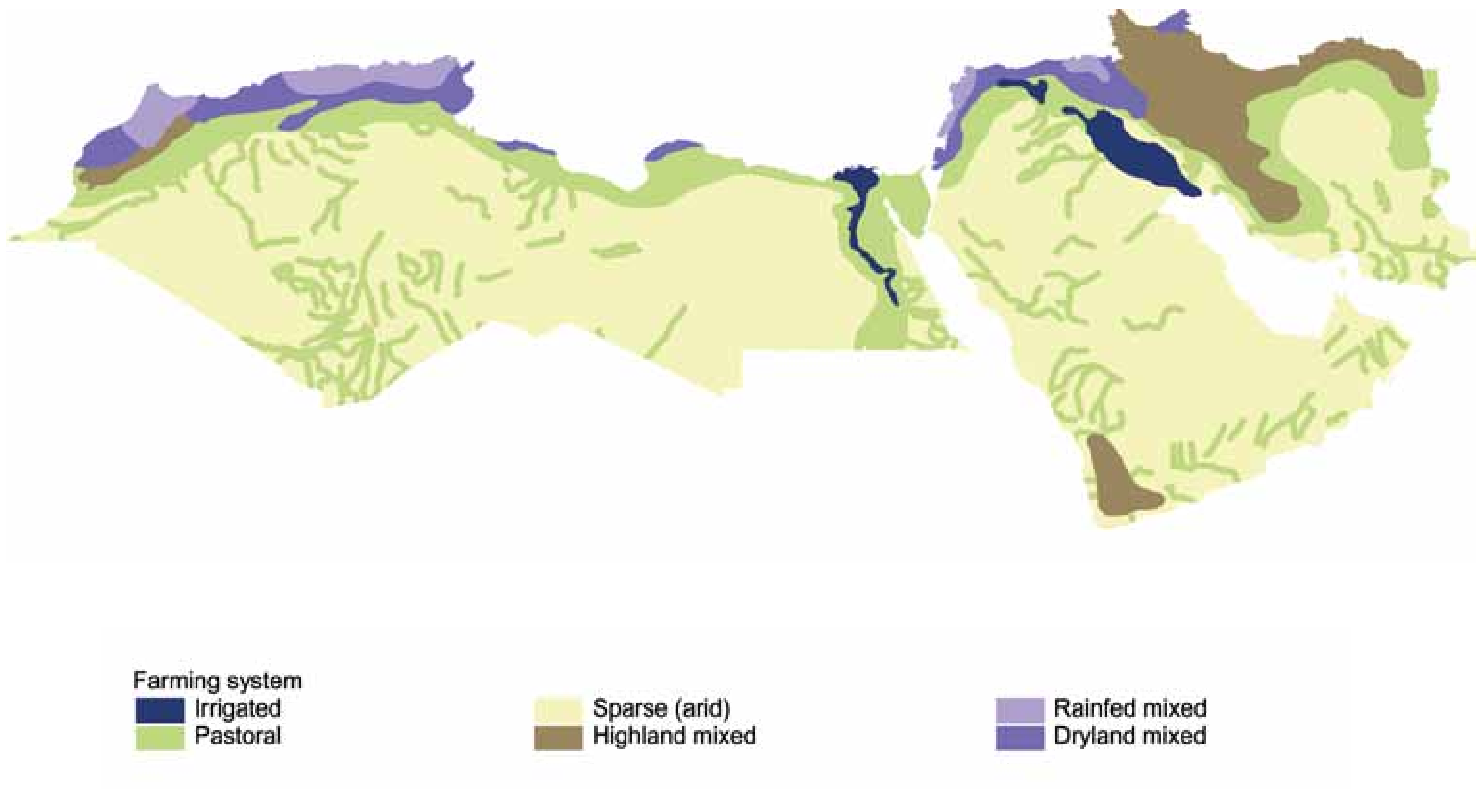


TABLE A4.5
Characteristics of farming systems in Middle East and North Africa

Farming system	Location	Principal livelihood sources (secondary sources)	Level of technology and organization	Prevalence of poverty
Irrigated	Nile and Euphrates valleys	Fruits, vegetables, cash crops (cereals, cotton, sugar beet, fodder, date palm)	Seldom efficient use of water; cases of excessive utilisation of non-recharged aquifers	Moderate
Pastoral	Scattered trough Middle East and North Africa, including large areas of semiarid steppe lands	Sheep, goats, barley, off-farm work	Medium	Extensive
Sparse (arid)	Covers more than 60 percent of the Middle East and North Africa, including vast desert zones	Camels, sheep, off-farm work (dates and other palms, fodder and vegetables)	Many irrigation schemes	Limited, as limited population pressure
Highland mixed	Western Yemen, northern and western Iran, central Morocco	Cereals, legumes, off-farm work (tree crops, vines, fruits, vegetables, olive, qat, coffee)	Infrastructure poorly developed, serious problem of degradation of natural resources	Extensive
Rainfed mixed	Coastal areas in Marocco, Algeria, Tunisia and Syria, and northern part of Iraq	Tree crops, cereals, legumes, off-farm work (olive, fruits, nuts, melons, vines, fodder crops, cattle, cash crops, grapes, potato, sugar beet, faba beans, oil crops, vegetables, flowers, vetches, medics)	An increasing area benefits from new irrigation technologies	Moderate thanks to income from seasonal labour migration
Dryland mixed	Coastal areas in Marocco, Algeria, Tunisia, Syria and Jordan and northern part of Iran and Iraq	Wheat and barley, sheep, off-farm work (lentils, chickpeas, vegetables)	Medium: relatively poor market linkages	Extensive among small farmers

MAP A4.6

Farming systems in Sub-Saharan Africa

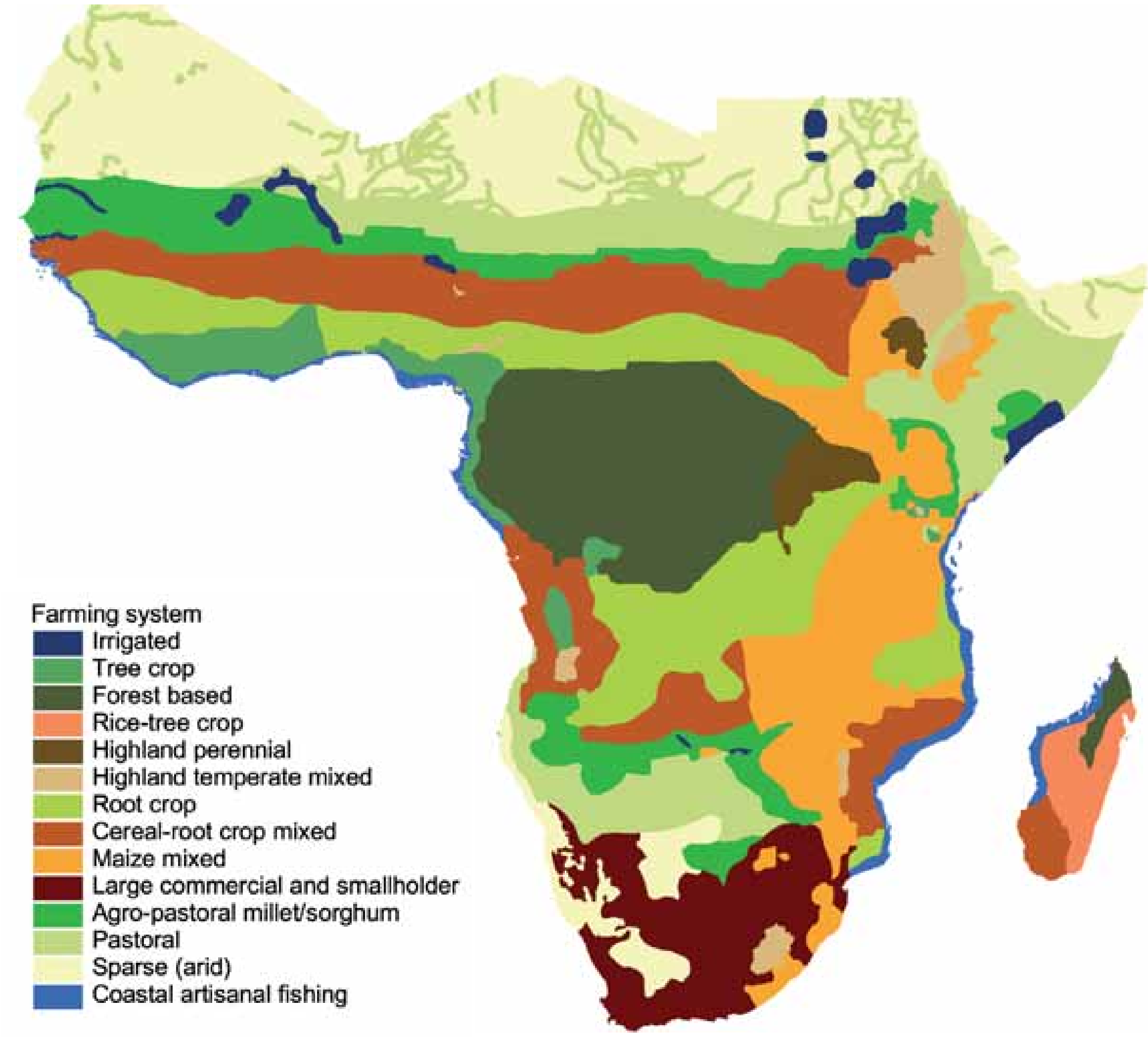


TABLE A4.6

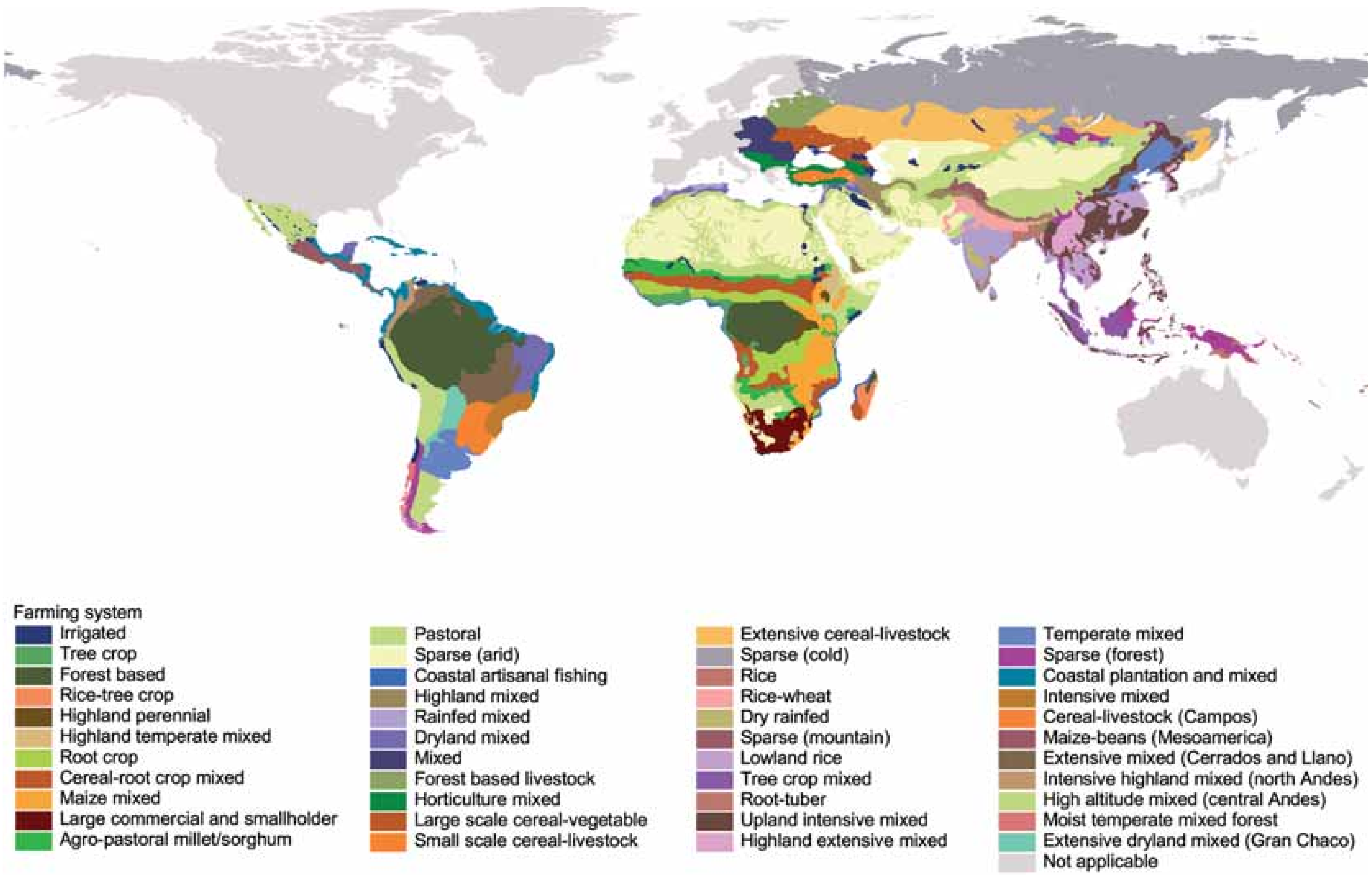
Characteristics of farming systems in Sub-Saharan Africa

Farming system	Location	Principal livelihood sources (secondary sources)	Level of technology and organization	Prevalence of poverty
Irrigated	Gezira Scheme in Sudan, extensive riverine and flood recession-based irrigation, e.g. West African fadama areas and the Wabi Shebelle in Somalia	Rice, cotton, vegetables, rainfed crops, cattle, poultry (sorghum, groundnuts, sugarcane)	High	Limited
Tree crop	Coastal areas of western and central Africa	Cocoa, coffee, oil palm, rubber, yams, maize, off-farm work (cocoyam, cassava, cereals, pulses)	No data	Limited to moderate, concentrated among very small farmers and agricultural workers
Forest based	Humidest zones of the Congo Democratic Republic, the Congo Republic, southeast Cameroon, Equatorial Guinea, Gabon, southern Tanzania and northern tips of Zambia, Mozambique and Angola	Cassava, maize, beans and cocoyams (groundnut, sorghum)	Low: physical isolation, lack of roads and market	Extensive, in places very severe
Rice-tree crop	Moist sub-humid and humid agro-ecological zones of Madagascar	Rice, banana, coffee, maize, cassava, legumes, livestock, off-farm work	Low: small farm size, shortage of appropriate technologies, poor development of market and off-farm activities	Moderate
Highland perennial	Sub-humid and humid agroecological zones of Ethiopia, Uganda, Rwanda and Burundi	Banana, plantain, enset, coffee, cassava, sweet potato, beans, cereals, livestock, poultry, off-farm work	Low: very small farm size, shortage of appropriate technologies, poor infrastructure and few opportunities of off-farm activities	Extensive increasing and severe
Highland temperate mixed	Mostly in the high lands and mountains of Ethiopia, smaller areas in Eritrea, Lesotho, Angola, Cameroon and Nigeria	Wheat, barley, teff, peas, lentils, broad beans, rape, potatoes, sheep, goats, livestock, poultry, off-farm work (oilseed)	Low: lack of input, soil erosion and shortage of biomass	Moderate to extensive
Root crop	Large parts of Angola, Benin, Cameroon, Côte d'Ivoire, Ghana, Nigeria, northern Mozambique, Sierra Leone, southern Tanzania, Togo, Zambia	Yams, cassava, legumes, off-farm work (oil palm)	Low to medium: technologies not yet developed, but relatively good linkage to markets and off-farm activities	Limited to moderate
Cereal-root crop mixed	Northern parts of Benin, Cameroon, Côte d'Ivoire, Ghana, Guinea, Togo, the mid-belt states of Nigeria, similar zone in central and southern Africa	Maize, sorghum, millet, cassava, yams, legumes, cattle (groundnut, sweet potato, cowpea, pigeon pea, cotton)	Medium: poor transport and communication infrastructure	Limited, some drought-induced
Maize mixed	Plateau and highland areas of Kenya, Lesotho, Malawi, South Africa, Swaziland, Tanzania, Zambia, Zimbabwe	Maize, tobacco, cotton, cattle, goats, poultry, off-farm work (sorghum, millet, sweet potato, oil seeds, groundnuts, pulses, sunflower, coffee)	Medium: input use has fallen due to the shortage of seed, fertiliser and agro-chemicals, plus the high price of fertiliser relative to the maize price	Moderate, linked to drought and market volatility

Farming system	Location	Principal livelihood sources (secondary sources)	Level of technology and organization	Prevalence of poverty
Large commercial and smallholder	Southern part of Namibia, northern part of South Africa	Maize, pulses, sunflower, cattle, sheep, goats, remittances (sorghum, millet)	High in the large-scale commercial farming sector, low otherwise	Moderate
Agro-pastoral millet/ sorghum	Semiarid zone of West Africa, from Senegal to Niger and in East and Southern Africa, from Somalia and Ethiopia to South Africa	Sorghum, pearl millet, pulses, sesame, cattle, sheep, goats, poultry, off-farm work (cotton, vegetables)	Low	Extensive, often severe, mainly due to drought
Pastoral	Arid and semiarid zones from Mauritania to the northern parts of Chad, Ethiopia, Eritrea, Kenya, Mali, Niger, Sudan, Uganda; arid zones in Botswana, Namibia, southern Angola	Cattle, camels, sheep, goats, remittances	Low	Extensive, mainly due to the great climatic variability and the incidence of drought
Sparse (arid)	Parts of Chad, Botswana, Mauritania, Namibia, Niger, Sudan	Irrigated maize, vegetables, date palms, cattle, off-farm work	Low	Extensive and often severe, especially after droughts
Coastal artisanal fishing	Coastal East Africa: from Kenya to Mozambique; coastal areas of Zanzibar, Comoros and Madagascar Coastal West Africa: southern Gambia, Casamance region of Senegal, coastal areas of Cameroon, Côte d'Ivoire, Gabon, Ghana, Guinea Bissau, Liberia, Nigeria, Sierra Leone	Marine fish, coconuts, cashew, banana, yams, fruit, goats, poultry, off-farm work (rice)	Medium	Moderate, although socio-economic differentiation is considerable

MAP A4.7

Farming systems in developing and transition countries, 2000



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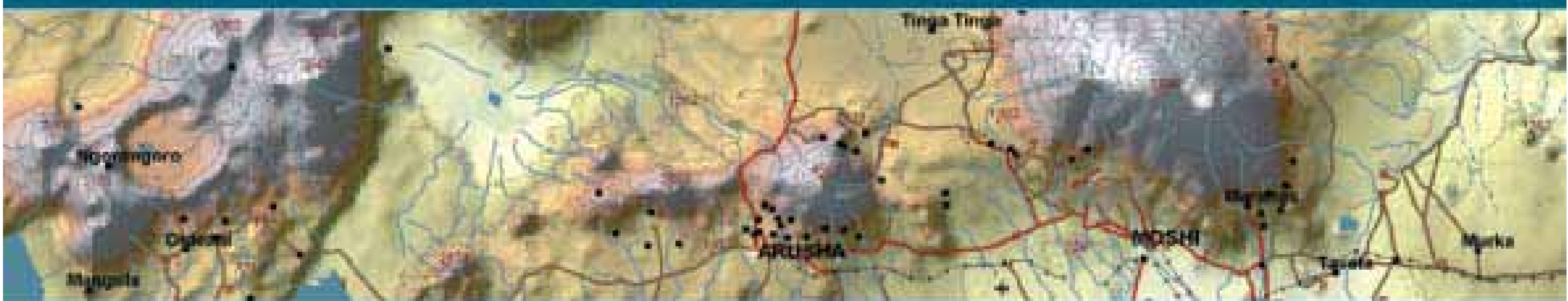

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ISBN 978-92-5-105689-9 ISSN 1684-8241

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TC/M/A1075E/1/04.07/1100