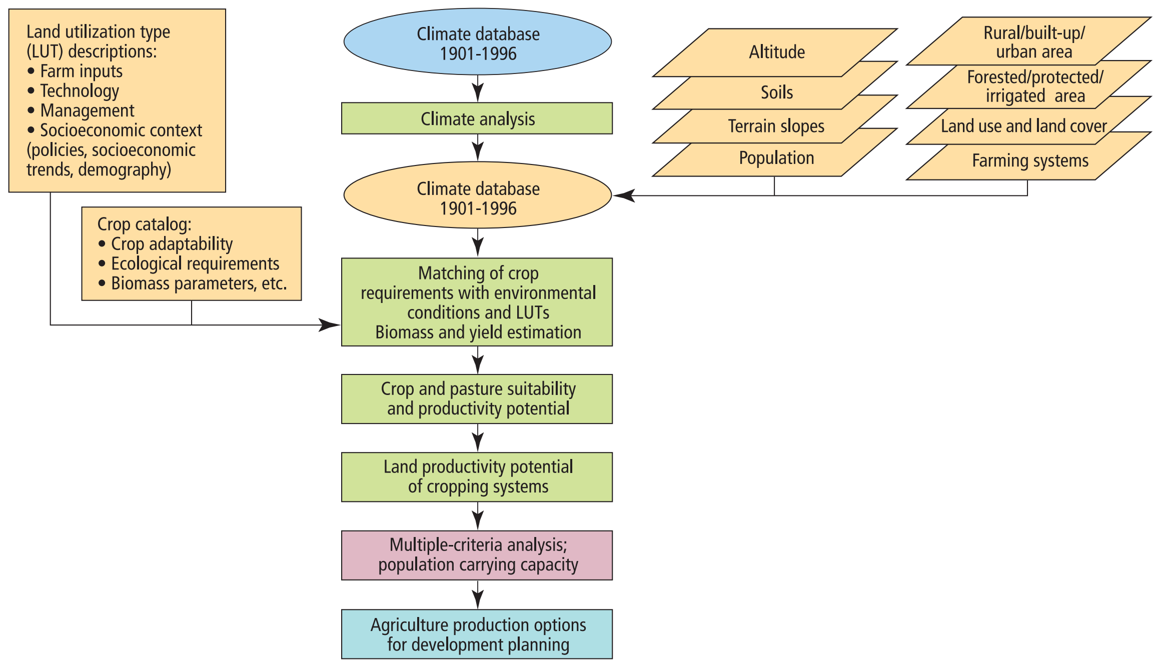
CHAPTER 1

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
	km² (1 000)	km² (1 000)	km² (1 000)	km² (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

Belt	Sub-zones
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*	

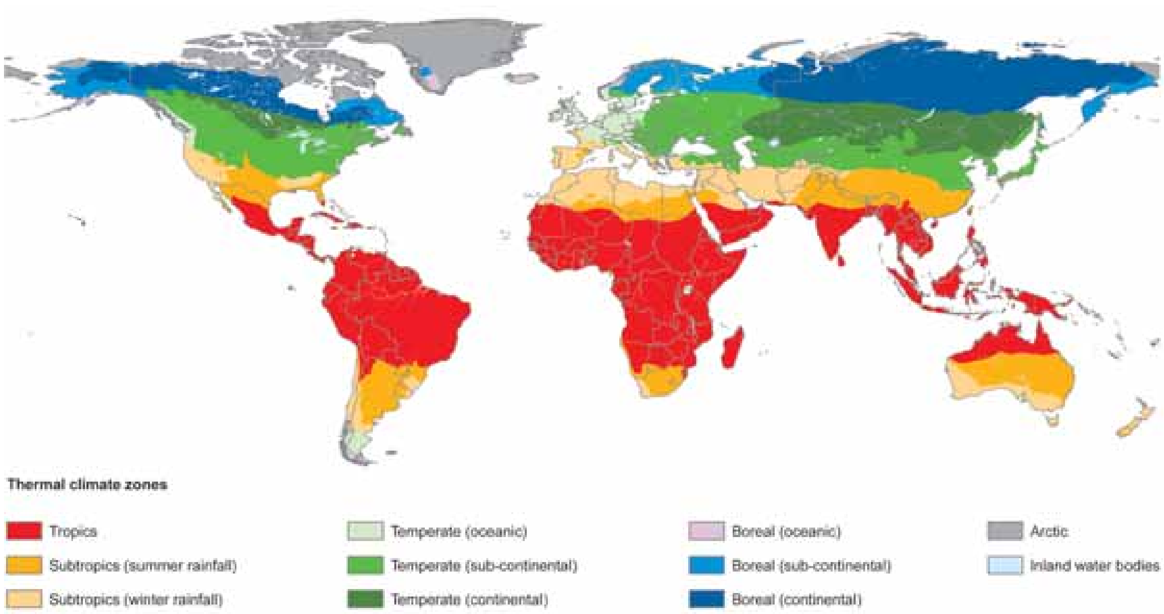
Note: seasonality refers to the difference in mean temperature of the warmest and coldest month, respectively.

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

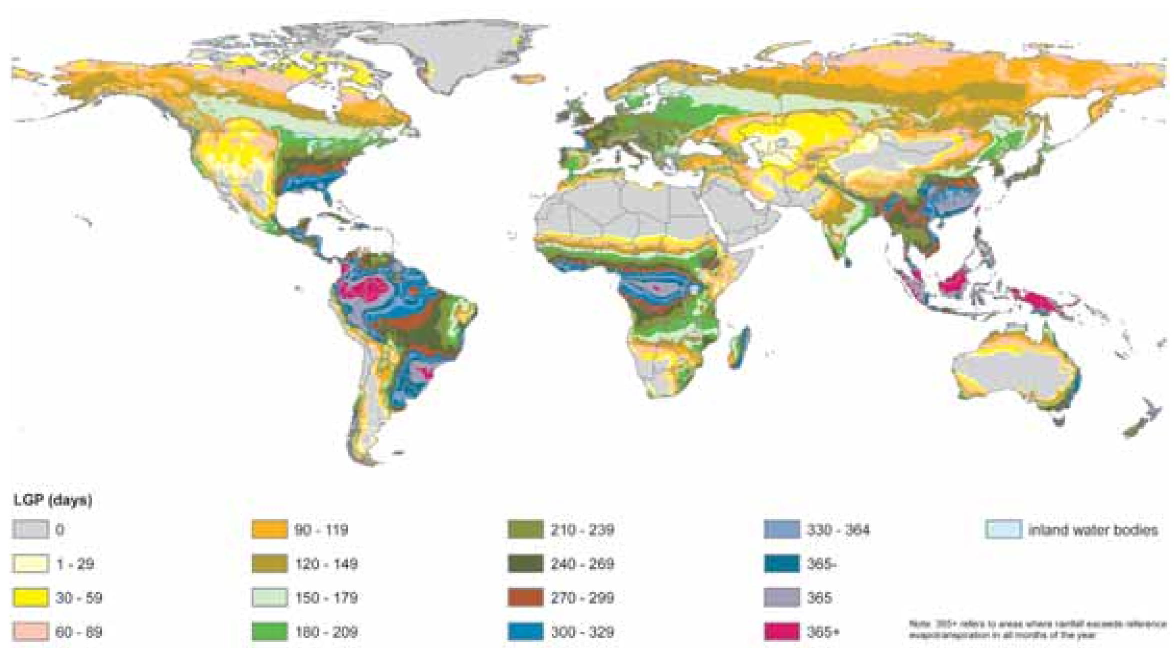
Rural area and rural population of the world, by length of growing period (LGP) zone

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

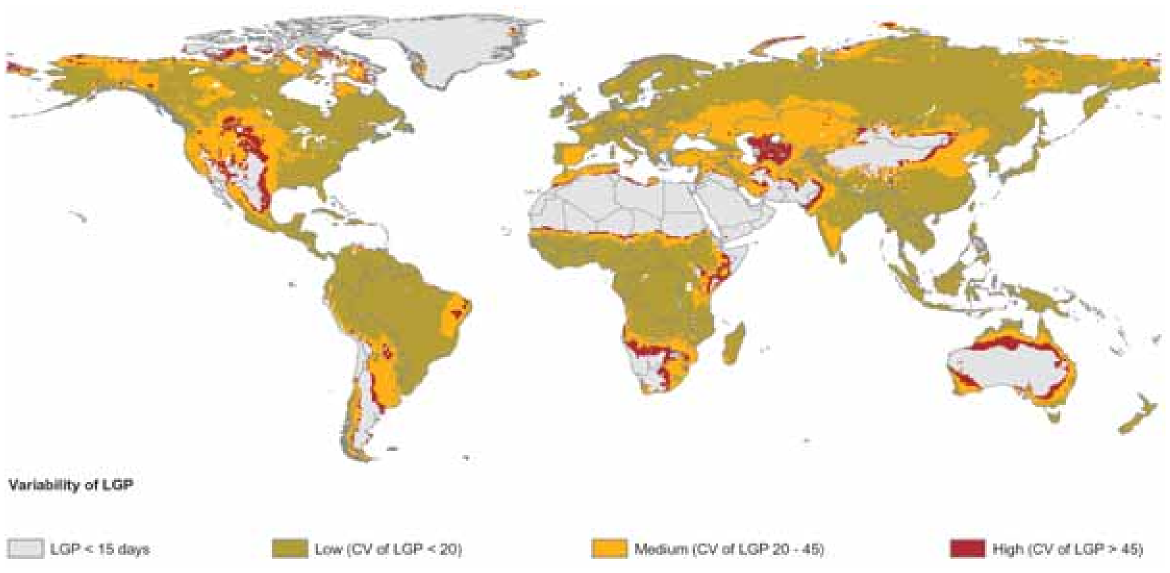
Rural area and rural population of the world, by variability of LGP

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

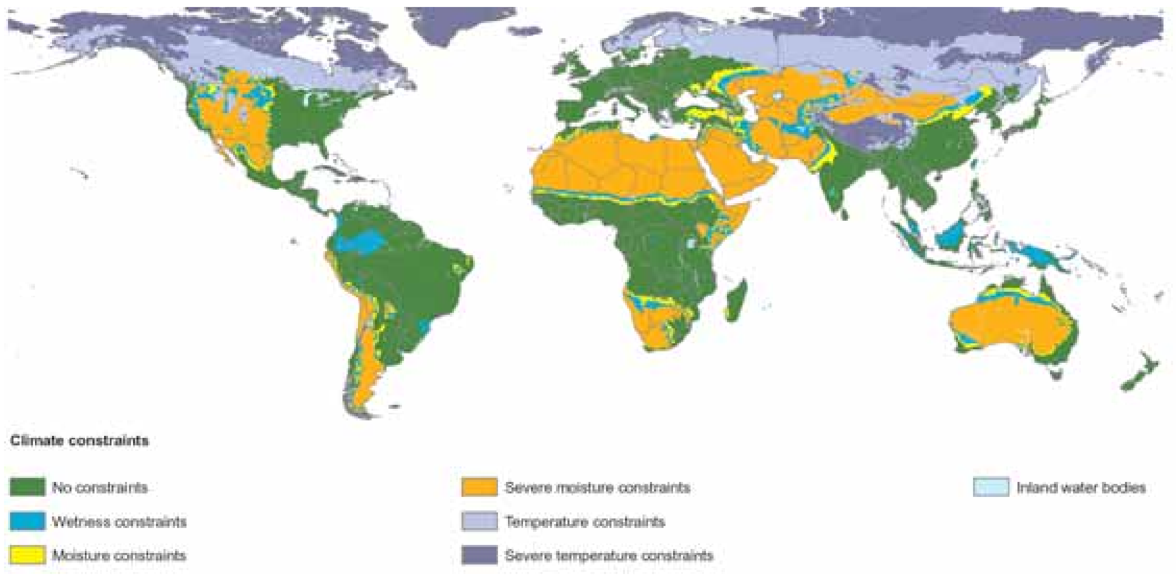


3.1.4 Climate constraints

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.

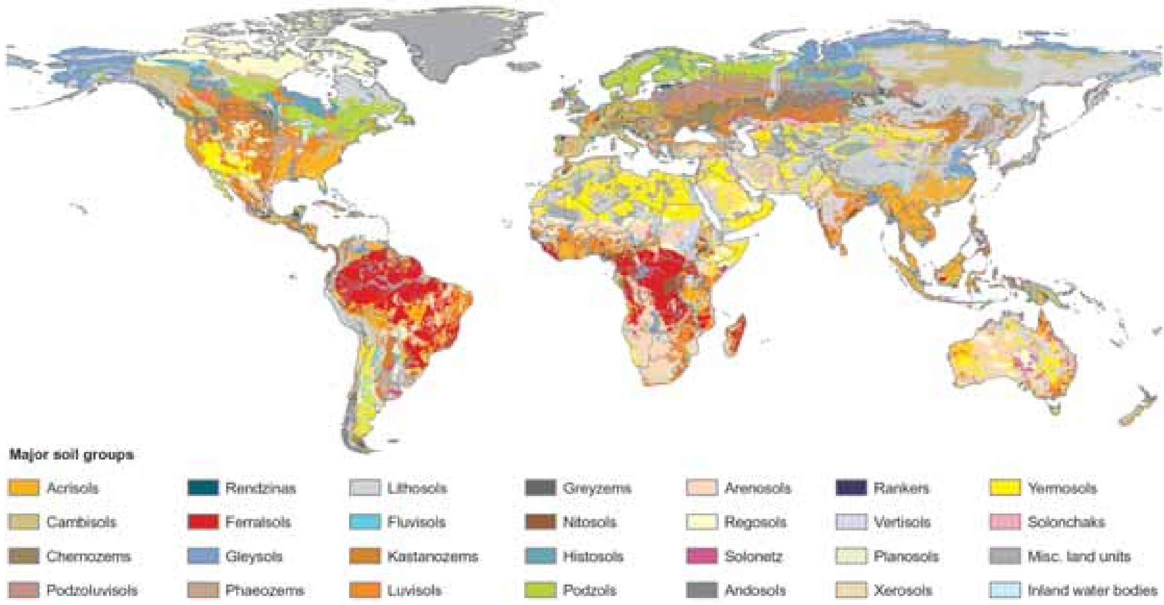
TABLE 3.4

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		km^2 (1 000)	persons (1 000)	persons/km^2
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



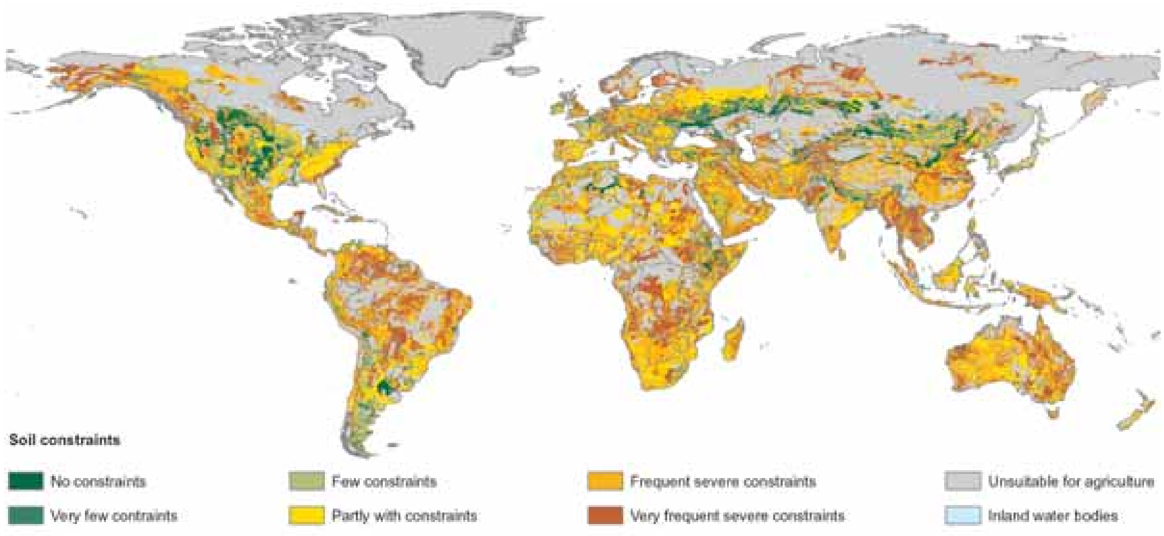
3.2.2 Soil constraints

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

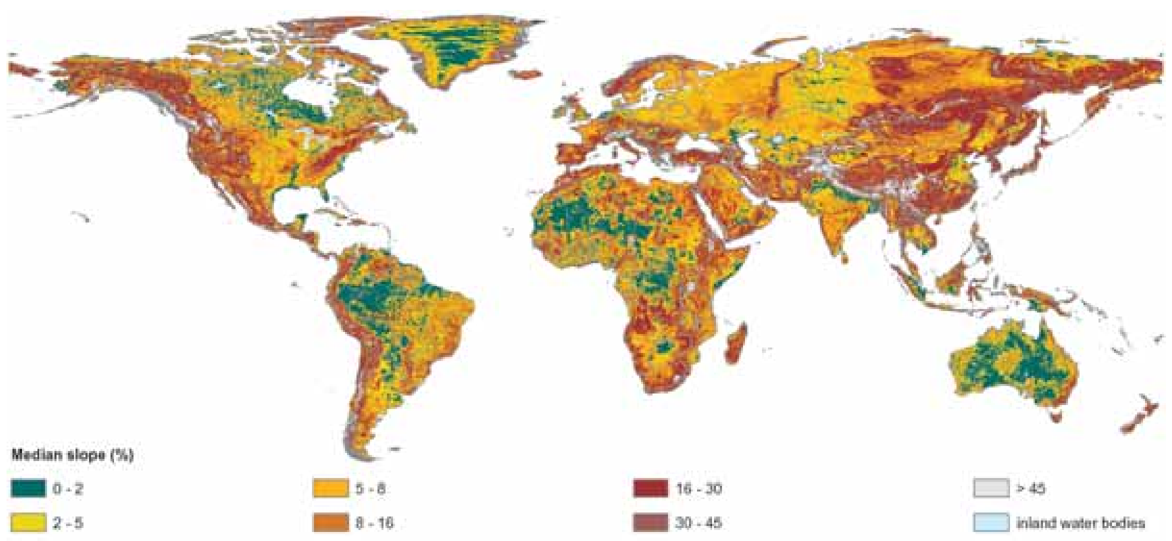
The slope thresholds applied in the GAEZ study to define the degree of constraint to productivity of different categories of agricultural land are as shown below. Map 3.8 depicts the extent of terrain slope constraints on the world's land surface, while Table 3.5 shows the distribution of global rural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

- **For non-terraced land with gravity irrigation:** 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.
- **For land with sprinkler irrigation:** 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

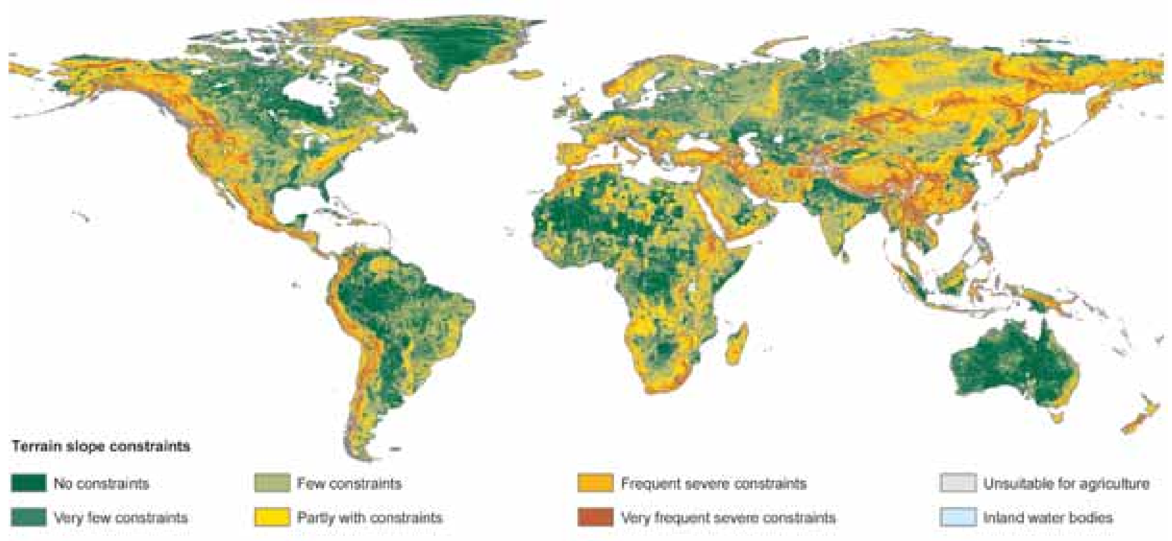


TABLE 3.5

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

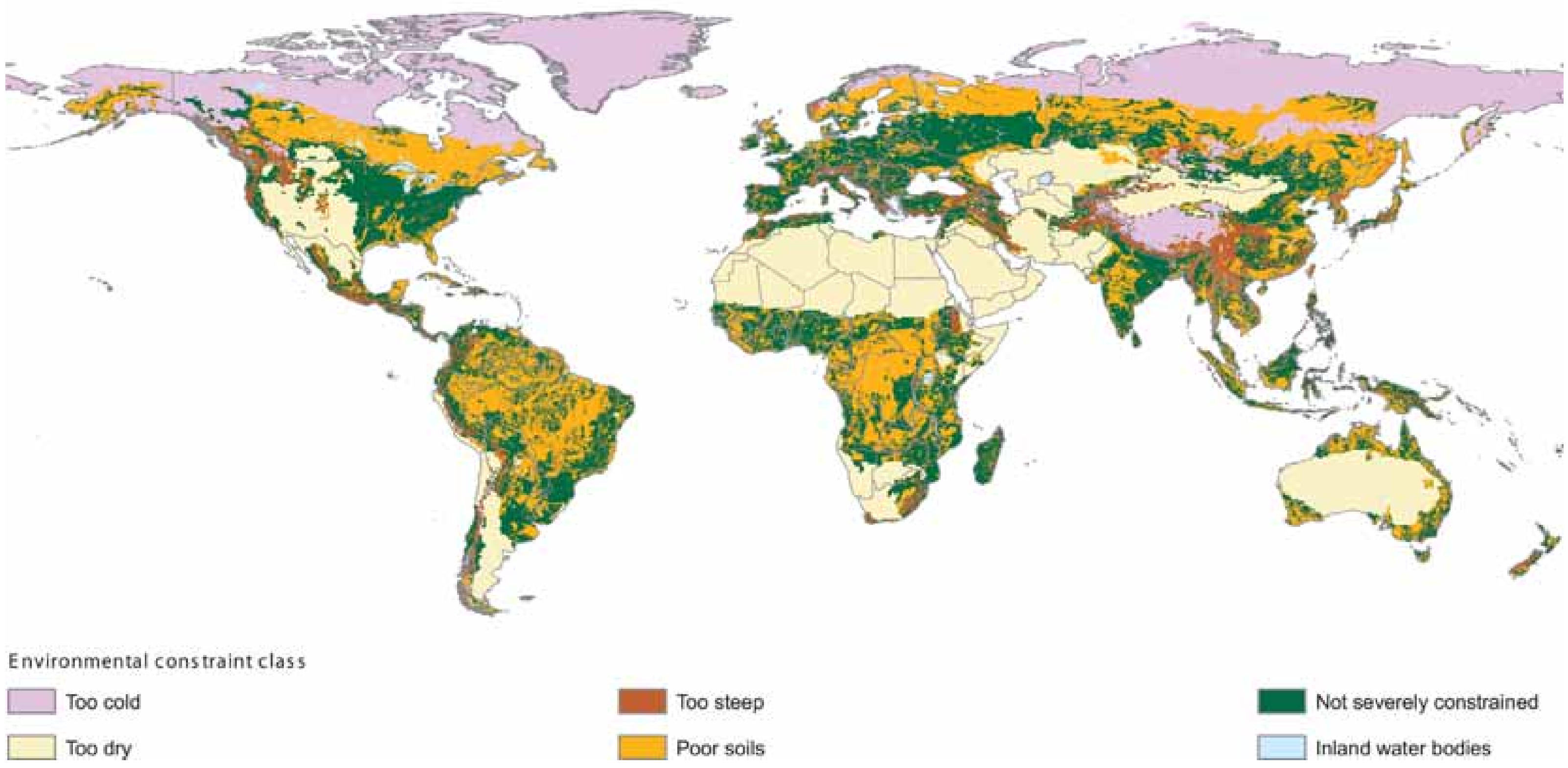


TABLE 3.6

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)							km² (1 000)	share of total %
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 slopes	0–8%		17,238	7,598	10,725	11,658	11,274	12,352	1,608	72,453	54.1
	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 constraints	None		19,062	9,579	21,023	21,604	20,926	20,399	2,639	115,233	86.0
	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.