Scarcity and abundance of land resources: competing uses and the shrinking land resource base.

SOLAW TR02

SOLAW Background Thematic Report - TR02

G. Fischer, E. Hizsnyik, S. Prieler & D. Wiberg

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Abbreviations and glossary

AEZ	Agro-ecological zones (AEZ)
DM	Dry matter
FAO	Food and Agriculture Organization of the United Nations
GAEZ	Global agro-ecological zones
GIS	Global Information System
GLCC	Global Land Cover Characteristics
GMIA	Global Map of Irrigated Areas
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LGP	Length of growing period
LUT	Land Utilization Types
MDG	Millenium Development Goals
MEA	Millennium Ecosystem Assessment
REDD	Reducing emissions from deforestation and degradation
SQ	Soil quality
SR	Suitability rating
WCMC	World Conservation Monitoring Centre
WDPA	World database of protected areas

Main messages

1. Historical expansion of cultivated land and pastures has largely been at the expense of forests.
2. From the viewpoint of resources point it is possible to produce enough food for a projected 9 billion population in 2050 at the global level; however, one cannot ignore disparities across and within regions. For several countries with a limited resource base and large projected population growth, efforts to develop agriculture would need to be supplemented with interventions in other sectors.
3. To avoid widespread land conversion and reduce the substantial greenhouse gas and environmental effects of deforestation, the required agricultural production increases to 2050 should largely be achieved on current cultivated land. In developing countries output must be doubled until 2050, implying an increase on average of almost 1.4 percent per year, which means an enormous effort for farmers, agricultural researchers, extension workers, irrigation development, fertilizer industry and infrastructure for input transport and market accessibility. It is uncertain whether such output growth per unit of land can indeed be achieved and sustained over a period of 50 years.
4. Per capita availability of prime and good land resources today and in 2050 is plentiful in only a few regions. Therefore, yield gap reductions, technological improvements and efficiency gains will be needed to allow development.
5. Overall there is much lower productivity of crops on potentially available current unprotected grass/woodland and forest ecosystems than in current cultivated land.
6. In most regions, soil nutrient availability is by far the most prevalent soil limitation. Where combined with low nutrient retention capacities of soils, fertilizers alone may prove less effective for increasing crop yields, notably in tropical regions, requiring strategies of integrated plant nutrient management.
7. Within the context of 'land grabbing', information on the agro-ecological potentials of current cultivated and additional potentially available land is a critical need for establishing the fair rental/sale value of land. Sound land evaluation methods, combined with participatory land-use planning, are key to the principle of responsible investment strategies needed for sustainable and mutually beneficial land resources development.
8. There are both negative and positive impacts of climate change, depending on the region. The balanced global picture assumes that farmers adapt (with CO_2 fertilization), but does not account for changed climate variability.
9. While the global balance of crop production potential of the current cultivated land is not much affected by climate change over the next decades, there are a number of regions where climate change poses a significant threat to food production.
10. Scenario results confirm that, with and without CO_2 fertilization, the impacts of projected climate change on crop yields and production could become severe in the second half of this century.
11. The capacity to adapt to climate change impacts is strongly linked to future development paths. Though poverty (and hunger) is negatively affected by climate change, it is likely to be less widespread in 2050, if there is expected economic growth and stable populations.

1. Introduction

Widespread hunger and rising global food demands (FAO, 2009) require better use of the world's water, land and ecosystems. For an estimated world population of about 9 billion in 2050, agricultural production has to increase by about 70 percent globally and by 100 percent in developing countries. An enormous effort is required to achieve the implied annual growth of nearly 1.5 percent (Bruinsma, 2009; Fischer, 2009; Godfray *et al*., 2010). The following policy challenges are of particular concern:

Agricultural water withdrawals amount to 70 percent of total anthropogenic water use, and irrigated crops account for 40 percent of the world's total production (FAO, 2003). This makes the agriculture sector of critical social importance, responsible for massive environmental impacts and vulnerable to competition for land and water resources.

Land and water uses for food production regularly compete with other ecosystem services. Ignoring such conflicts over resource use and tradeoffs can lead to unsustainable exploitation, environmental degradation and avoidable long-term social costs. Overcoming this limitation requires better understanding and management of competing uses of land, water and ecosystem services. This includes robust expansion of food and bio-energy production, sustaining regulating ecosystem functions, protecting and preserving global gene pools and enhancing terrestrial carbon pools.

The prospect of meeting future water demand is limited by the declining possibilities of tapping additional sources of freshwater, and by the decreasing quality of water resources caused by pollution and waste. Freshwater resources are unevenly distributed, and many countries and locations suffer severe water scarcity (MEA, 2005).

Climate change is happening, and further global warming in the coming decades seems unavoidable (IPCC, 2007). Food and water provision, land management, and the protection of nature face the immediate need to develop location-specific coping strategies, to use resources differently, to reduce systemic volatility and to safeguard the full range of ecosystem services.

The range of land uses for human needs is limited by environmental factors including climate, topography, and soil characteristics. Land use is primarily determined by demographic and socio-economic drivers, cultural practices and political factors, such as land tenure, markets, institutions and agricultural policies. Good quality and availability of land and water resources, together with important socio-economic and institutional factors, is essential for food security.

FAO, in collaboration with the International Institute for Applied Systems Analysis (IIASA), has developed a system that enables rational land-use planning based on an inventory of land resources, and evaluation of biophysical limitations and production potentials. The Agro-Ecological Zones (AEZ) approach is based on robust principles of land evaluation. The current Global AEZ (GAEZ-2009) offers a standardized framework for the characterization of climate, soil and terrain conditions relevant to agricultural production, which can be applied at global to subnational levels.

2. Status and trends

Substantial shifts in land use have taken place in the last decades, driven by human needs and technological capabilities. During the last 50 years forest ecosystems have declined by about 15 percent while pastures and cultivated land area have increased. Apart from deforestation, there have been substantial shifts in location of cultivated land and grassland/woodland ecosystems.

2.1 Land use and management: increasing pressure on suitable land

Land resources historical trends

According to FAO statistics from 1961–2007 cultivated land area increased by about 13 percent from 1 370 million ha to 1 559 million ha. The net extent of rainfed land increased by about 3.5 percent, from 1 230 to 1 265 million ha, whereas the area equipped with irrigation doubled from 140 million ha to 275 million ha. Permanent meadows and pastures are reported to have increased over the same period 1961–2007 by almost 10 percent. FAO's world forest inventory 1958 reported a total of 4.4 billion ha accessible plus inaccessible forest land. Compared with the current (2007) forest cover extent of 3.7 billion ha this suggests that during the last 50 years total forest areas have decreased by about 15 percent. The numbers suggest that other land, mainly large areas of sparsely vegetated and barren land and inland water bodies, remained, on balance, fairly constant. Land use for habitation and infrastructure has been growing substantially but occupies a relatively small yet important share of global land.

Land resources degradation

The current 1.6 billion ha of cultivated land represent the better and more productive part of the global land resources. Locally, less suitable and marginal lands have been converted to crop land because of population pressure and lack of prime land and good land. Parts of high quality agricultural land have become degraded as a result of unsustainable use, human-induced water and wind erosion, nutrient mining, compaction of the topsoil, salinization (improper irrigation and drainage practices) and soil pollution.

Degraded cultivated land resulting from unsustainable use has frequently been abandoned and left as marginal grassland and woodland of which only part has been developed into secondary forest ecosystems. Between 385 and 472 million ha of cultivated land have been abandoned (Campbell *et al*., 2008). This equates to one-quarter to one-third of present cultivated land. It has been estimated that during the last 40 years nearly one-third of the world's arable land has been lost to erosion and continues to be lost at a rate of more than 10 million ha/yr (Pimentel and others, 1995). This degraded land has been replaced by cultivated land, which has been converted from prime and good quality agricultural land resources available as grassland, woodland and forest ecosystems. The conversion of this premium land, and the return of abandoned, degraded agricultural land have resulted in the deterioration of the overall quality of grassland, woodland and forest ecosystems. (For details see Land Degradation by Nachtergaele *et al*. and 'Compilation of selected global indicators of land degradation', FAO/IIASA, 2009).

This process of degradation of cultivated land, grassland, woodland ecosystems (for example overgrazing) and forest ecosystems (e.g. forest degradation and deforestation) will continue as long as current unsustainable land management practices persist.

2.2 Availability of suitable land resources

Current land use/land cover: land balances

Global land cover classification schemes have been devised that allow quantification of each 5′ grid-cell into shares of seven main land-use/land-cover categories. The estimation of shares seeks to formally and consistently integrate up-to-date geographical data sets, obtained from remote sensing and other sources, into statistical information compiled by FAO and/or national statistics bureaus (see Box 1).

The global land mass, excluding Antarctica, comprises 13.3 billion ha. About 11 percent (1.6 billion ha) is currently used to cultivate agricultural crops; 28 percent is under forest; 35 percent comprises grassland/woodland ecosystems; 22 percent is barren or sparsely vegetated, and 3 percent each is used for human settlement or infrastructure and occupied by inland water. The intensity of each land-cover type varies substantially across the globe according to climatic conditions and anthropogenic influences (Figure 1). For example,

BOX 1: DATA AND METHOD USED FOR GLOBAL LAND COVER DATA COMPILATION

The global inventory of major land use and land cover categories is based on the following geographic datasets:

- GLC2000 land cover database at 30 arc-sec using regional and global legends (JRC, 2006);
- an IFPRI global land cover categorization providing 17 land cover classes at 30 arc-sec. (IFPRI, 2002), based on a reinterpretation of the Global Land Cover Characteristics Database (GLCC version 2.0), EROS Data Centre (EDC, 2000);
- FAO's Global Forest Resources Assessment 2000 and 2005 (FAO, 2001; FAO, 2006b) at 30 arc-sec. resolution;
- digital Global Map of Irrigated Areas (GMIA) version 4.0 of (FAO/University of Frankfurt) at 5′ by 5′ latitude/longitude resolution, provides by grid-cell the percentage land area equipped with irrigation infrastructure (Siebert et al., 2007);
- a spatial population density inventory (30-arc seconds) for 2000 developed by FAO-SDRN, based on spatial data of LANDSCAN 2003, with calibration to United Nations 2000 population figures.
- An iterative calculation procedure has been implemented to estimate land cover class weights, consistent with aggregate FAO land statistics and spatial land cover patterns obtained from (the above-mentioned) remotely sensed data, allowing the quantification of major land-use/land-cover shares in individual 5′ by 5′ latitude/longitude grid cells. The estimated class weights define the presence of cultivated land and forest for each land cover class. Starting values of class weights used in the iterative procedure were obtained by cross-country regression of statistical data of cultivated and forestland against land cover class distributions obtained from Global Informations System (GIS), aggregated to national level. The percentage of urban/built-up land in a grid-cell was estimated based on the presence of respective land cover classes as well as regression equations relating built-up land with number of people and population density. Remaining areas were allocated to grassland and other vegetated areas, barren or very sparsely vegetated areas and water bodies. Barren or very sparsely vegetated areas were delineated through use of the respective land cover information in GLC 2000 and by applying a minimum bioproductivity threshold.
- The resulting seven land-use or land-cover categories in individual 5′ resolution grid-cells are:
- rainfed cultivated land;
- irrigated cultivated land;
- forestland;
- grassland and woodland;
- barren and sparsely vegetated land;
- water; and
- urban land and that required for housing and infrastructure

while cultivated land is less than 10 percent in most African regions, it accounts for more than one-third of the land in the countries of Southern Asia. Summary statistics by region, derived from the respective GIS layers, are provided in Table 1 and Figure 2.

The highest share of cultivated land in total land, about one-third, are found for Southern and Western Europe, the Caribbean and Southern Asia. Cultivated land area, in terms of per capita use in 2000, were highest in Australia (more than 2.2 ha per person), in Northern America and the region of Eastern Europe and Russia (in both regions about 0.7 ha per person). A comparison of per capita cultivated land use in 2000 across regions, and the equivalent amount when dividing current cultivated land by 2050 projected populations is shown in Figure 3. Use of cultivated land per capita in the more developed countries was on average 0.5 ha in 2000 – ranging from 0.2 ha in Western Europe to 0.7 ha in Northern America and more than 2.2 ha in Australia. This figure will change little owing to population dynamics until 2050. In contrast, current cultivated land used per capita is only 0.2 ha in less developed countries, a value which would further decrease to 0.1 ha in 2050 in the absence of further cultivated land expansion.

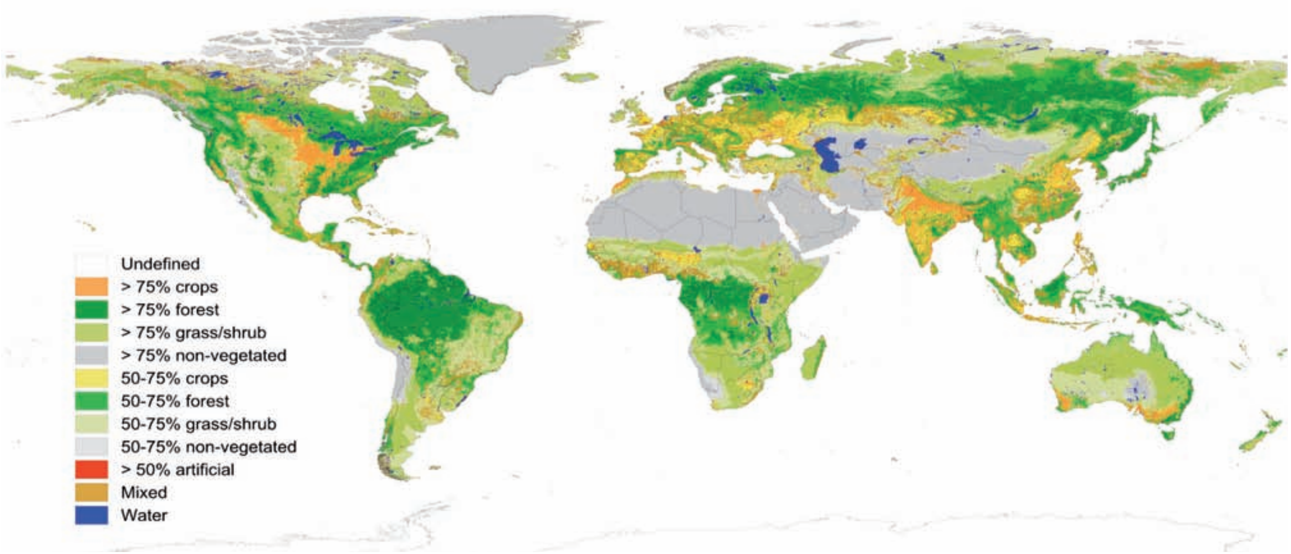
It has been suggested that the minimum arable land required to sustainably support one person is 0.07 ha (Myers, 1998). This is a threshold used by United Nations organizations to evaluate the land's carrying capacity. Arable land is less than 0.1 ha per person so it would be difficult to maintain a minimal nutrition level (Uitto and Ono, 1996).

Protected areas

Outside the current cultivated land, especially in less populated areas, substantial areas of productive land may be available for conversion to cultivated land. Part of this land is to be excluded, such as land that is legally protected, otherwise reserved for nature conservation, for safeguarding genetic resources, biodiversity and areas with special nature values.

However, land suitable for conversion into cultivated land is almost exclusively in forest and grassland/woodland ecosystems. Much research is being done to classify forestland and, to a lesser extent, grassland/

FIGURE 1: DOMINANT LAND USE OR COVER



Source: GAEZ 2009; compilation by authors based on procedures and data as outlined in Box 1.

TABLE 1: REGIONAL DISTRIBUTION OF MAIN LAND-USE/COVER CATEGORIES AROUND 2000

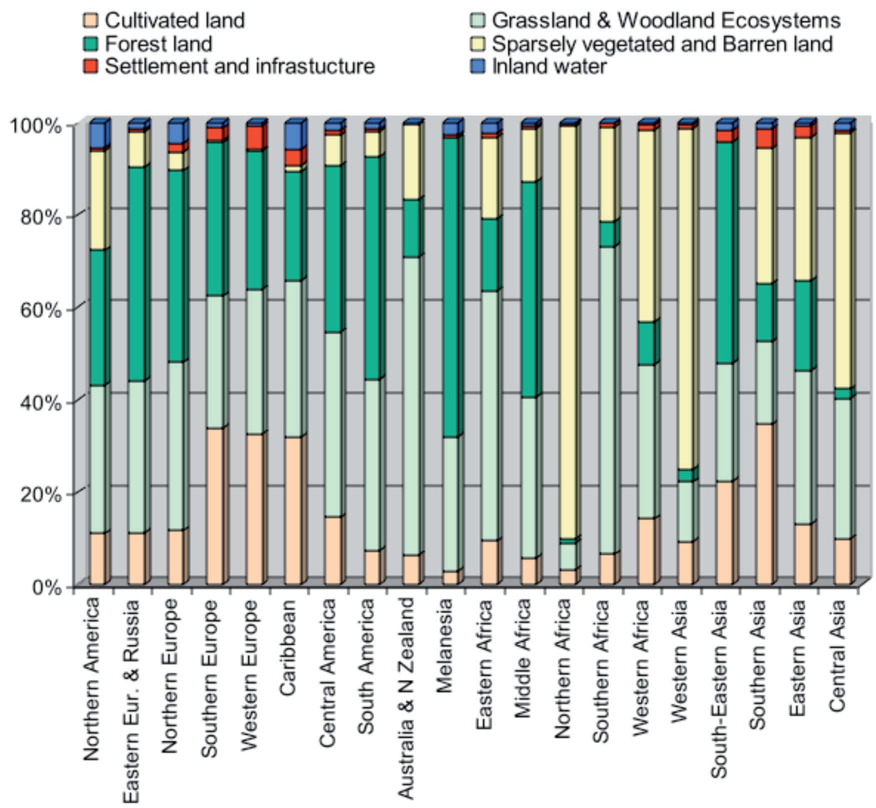
	Cultivated land		Grassland and woodland ecosystems		Forest land		Sparsely vegetated and barren land		Settlement and infrastucture		Inland water		Total
	Million ha	%	Million ha	%	Million ha	%	Million ha	%	Million ha	%	Million ha	%	Million ha
Northern America	230	11	673	32	609	29	451	22	15	0.7	112	5.4	2 090
Eastern Europe & Russia	205	11	604	33	850	46	142	8	10	0.6	27	1.5	1 838
Northern Europe	20	12	61	36	70	41	7	4	3	1.9	7	4.4	168
Southern Europe	44	34	37	29	43	33	1	1	3	2.6	2	1.2	129
Western Europe	35	33	34	31	32	30	0	0	6	5.3	1	0.6	108
Caribbean	7	32	7	34	5	24	0	1	1	3.5	1	5.8	22
Central America	36	15	99	40	89	36	16	6	3	1.1	4	1.6	246
South America	129	7	657	37	851	48	96	5	10	0.5	26	1.4	1 768
Australia & New Zealand	51	6	510	65	98	12	127	16	1	0.2	3	0.4	790
Melanesia	1	3	15	29	34	65	0	0	0	0.5	1	2.8	52
Eastern Africa	83	9	478	54	138	16	156	18	10	1.1	19	2.2	884
Central Africa	38	6	229	35	305	46	75	11	4	0.6	5	0.8	657
Northern Africa	19	3	33	6	5	1	514	89	3	0.5	2	0.3	575
Southern Africa	18	7	176	66	15	6	54	21	2	0.8	0	0.1	265
Western Africa	86	14	202	33	56	9	251	41	7	1.2	3	0.5	605
Western Asia	40	9	56	13	11	3	318	74	4	0.9	2	0.5	431
Southeastern Asia	97	22	111	25	210	48	0	0	11	2.5	7	1.6	436
Southern Asia	229	35	118	18	83	13	193	29	29	4.4	8	1.2	659
Eastern Asia	151	13	386	33	224	19	359	31	29	2.5	8	0.7	1 156
Central Asia	41	10	125	30	9	2	229	55	2	0.5	7	1.8	414
More developed	590	11	1 923	37	1 726	33	728	14	40	0.8	152	2.9	5 160
Less developed	969	12	2 689	33	2 009	25	2 261	28	112	1.4	94	1.2	8 135
World total	1 559	12	4 612	35	3 736	28	2 989	22	152	1.1	246	1.9	13 295

Source: GAEZ 2009; data compiled by authors.

woodland for its biodiversity and nature values. So far there is a lack of consolidated assessment methods and tools to enable differentiation and selection of 'no-go areas' for land conversion. Research into complex rainforest ecosystems is most advanced and is being used by nature protection organizations such as the International Union for Conservation of Nature (IUCN), World Conservation Monitoring Centre (WCMC) and regional and national organizations to advise on land protection and conservation.

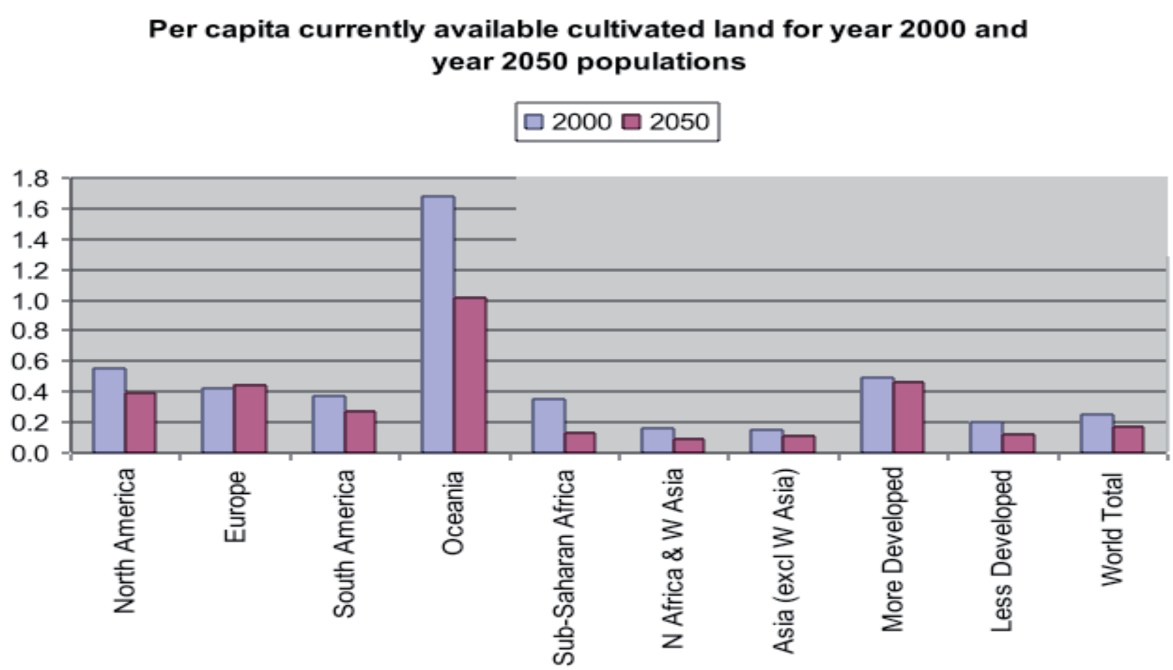
The geographic layer compiled for the GAEZ–2009 assessment uses the World Database of Protected Areas Annual Release 2009 (WDPA, 2009), and for the territory of the European Union the NATURA 2000 network, to place current protected areas into two main categories: strictly protected land and no agricultural use permitted, and a less restricted protected land category where sustainable agricultural practices may be permitted in support of retaining small-scale traditional agricultural landscapes, subsistence farming/livestock keeping by indigenous people and personnel engaged in nature protection. Globally the two categories comprise 1 035 million ha of strictly protected areas and 437 million ha of protected areas where certain

FIGURE 2: REGIONAL DISTRIBUTION OF MAIN LAND USE/COVER CATEGORIES



Source: GAEZ 2009; data compilation by authors.

FIGURE 3: REGIONAL AVAILABILITY OF PER CAPITA CURRENT CULTIVATED LAND



Source: GAEZ 2009; United Nations (2009); data compiled by authors.

TABLE 2: PER CAPITA LAND BY MAJOR CURRENT LAND COVER TYPE FOR 2000 AND 2050 POPULATIONS (HA/PERSON)										
Regions	Cultivated land		Grassland and woodland		Forest land		Sparsely vegetated and barren land		Settlement and infrastructure	
	2000	2050	2000	2050	2000	2050	2000	2050	2000	2050
Northern America	0.72	0.51	2.11	1.50	1.91	1.36	1.42	1.01	0.05	0.03
Eastern Europe & Russia	0.68	0.86	1.99	2.52	2.80	3.54	0.47	0.59	0.03	0.04
Northern Europe	0.21	0.17	0.65	0.54	0.74	0.62	0.07	0.06	0.03	0.03
Southern Europe	0.30	0.28	0.25	0.24	0.29	0.28	0.00	0.00	0.02	0.02
Western Europe	0.19	0.19	0.19	0.18	0.18	0.18	0.00	0.00	0.03	0.03
Caribbean	0.18	0.14	0.19	0.15	0.13	0.10	0.01	0.01	0.02	0.02
Central America	0.26	0.18	0.73	0.50	0.66	0.45	0.12	0.08	0.02	0.01
South America	0.37	0.27	1.89	1.36	2.45	1.76	0.28	0.20	0.03	0.02
Australia & New Zealand	2.21	1.49	22.1	15.0	4.24	2.87	5.53	3.74	0.05	0.04
Melanesia	0.18	0.08	1.86	0.88	4.14	1.95	0.01	0.00	0.03	0.02
Eastern Africa	0.33	0.12	1.89	0.67	0.55	0.19	0.62	0.22	0.04	0.01
Central Africa	0.39	0.14	2.34	0.84	3.11	1.12	0.77	0.28	0.04	0.01
Northern Africa	0.10	0.06	0.18	0.10	0.03	0.02	2.86	1.60	0.02	0.01
Southern Africa	0.34	0.26	3.40	2.59	0.28	0.22	1.05	0.80	0.04	0.03
Western Africa	0.36	0.14	0.85	0.32	0.24	0.09	1.06	0.40	0.03	0.01
Western Asia	0.23	0.11	0.32	0.16	0.07	0.03	1.82	0.90	0.02	0.01
Southeastern Asia	0.19	0.13	0.21	0.15	0.41	0.27	0.00	0.00	0.02	0.01
Southern Asia	0.16	0.09	0.08	0.05	0.06	0.03	0.13	0.08	0.02	0.01
Eastern Asia	0.10	0.09	0.26	0.24	0.15	0.14	0.24	0.22	0.02	0.02
Central Asia	0.58	0.43	1.76	1.31	0.12	0.09	3.22	2.39	0.03	0.02
More developed	**0.49**	**0.46**	**1.61**	**1.51**	**1.44**	**1.35**	**0.61**	**0.57**	**0.03**	**0.03**
Less developed	**0.20**	**0.12**	**0.55**	**0.34**	**0.41**	**0.26**	**0.46**	**0.29**	**0.02**	**0.01**
World total	**0.25**	**0.17**	**0.75**	**0.50**	**0.61**	**0.41**	**0.49**	**0.33**	**0.02**	**0.02**

Source: GAEZ 2009; data compiled by authors.

forms of agriculture are permitted. Table 3 below presents an overview of the share of protection status of main land cover categories.

Land suitability

The global availability and quality of land resources can be reflected by the land's suitability and productivity for the cultivation of major agricultural crops, bio-ethanol and biodiesel feedstocks.

The following section summarizes the GAEZ methodologies and procedures used. Land suitability and productivity potentials for various uses under different assumptions for input and management are presented and discussed, for specific land cover and land use categories, in particular for current rainfed and irrigated cultivated land and 'land balances' in unprotected grassland and woodland and unprotected forest ecosystems.

TABLE 3: PROTECTED LAND BY BROAD LAND USE / COVER CATEGORIES

Regions	Total land	Protected land			Grassland and woodland ecosystems	Forest ecosystems	Barren and sparsely vegetated ecosystems
	Million ha	Total Million ha	Protected (%)	Strictly protected (%)	Protected and strictly protected (%)	Protected and strictly protected (%)	Protected and strictly protected (%)
Northern America	2 090	271	1	12	12	8	29
Eastern Europe & Russia	1 838	180	1	9	10	10	15
Northern Europe	168	18	1	10	14	9	22
Southern Europe	129	24	4	14	25	28	24
Western Europe	108	13	2	10	16	19	36
Caribbean	22	2	3	7	11	19	7
Central America	246	25	5	5	7	13	30
South America	1 768	231	6	7	7	19	10
Australia & New Zealand	790	88	3	8	8	22	18
Melanesia	52	1	0	3	4	2	0
Eastern Africa	884	117	4	10	15	24	1
Central Africa	657	73	1	10	14	10	12
Northern Africa	575	19	1	3	0	3	4
Southern Africa	265	42	0	15	15	20	22
Western Africa	605	38	0	6	9	13	4
Western Asia	431	64	13	2	0	1	20
Southeastern Asia	436	60	2	12	16	19	49
Southern Asia	659	40	1	5	10	10	7
Eastern Asia	1 156	155	11	2	17	9	18
Central Asia	414	11	0	3	3	6	2
More developed	5 160	598	1	10	11	11	24
Less developed	8 135	874	4	6	11	16	9
World total	13 295	1 472	3	8	11	13	13

Source: GAEZ 2009; data compiled by authors.

Method

The land suitability assessment has been undertaken with the IIASA/FAO GAEZ 2009 modelling framework (see Box 2). The results comprise spatially detailed, quantified potentials for individual crops and quality of land resources. The assessments account for population density, land requirements and feasibility of land conversion for agricultural production and market access. It excludes land from conversion if it is protected for the following reasons: environmental, biodiversity and nature value.

The agro-ecological zones analysis is carried out in four separate assessments for low, intermediate, high and mixed level of inputs and management (see definitions in Box 3).

The suitability assessment is carried out at the level of crop subtypes (e.g. 120-day spring wheat). Results are subsequently combined for crop types (e.g. spring wheat), crops (e.g. wheat) and crop groups (e.g. cereals).

BOX 2: **AGRO-ECOLOGICAL (AEZ) METHODOLOGY**

The AEZ modelling uses detailed agronomic-based knowledge to simulate land resources availability, assess farm-level management options and estimate crop production potentials. It employs detailed spatial biophysical and socio-economic datasets to distribute its computations at fine gridded intervals over the entire globe (Fischer et al., 2002a; 2005). This land-resources inventory is used to assess, for specified management conditions and levels of inputs, the suitability of crops in relation to both rainfed and irrigated conditions, and to quantify expected attainable production of cropping activities relevant to specific agro-ecological contexts. The characterization of land resources includes components of climate, soils, landform and current land cover. Crop modelling and environmental matching procedures are used to identify crop-specific environmental limitations, under various levels of inputs and management conditions.

To summarize, the AEZ framework contains the following basic elements:

- land resources database, containing geo-referenced climate, soil and terrain data;
- land utilization types (LUT) database of agricultural production systems, describing crop-specific environmental requirements and adaptability characteristics, including input level and management;
- mathematical procedures for matching crop LUT requirements with agro-ecological zones data and estimating potentially attainable crop yields, by land unit and grid-cell (AEZ global assessment includes 2.2 million land grid cells at 5′ by 5′ latitude/longitude);
- assessments of crop suitability and quantification of land productivity; and
- applications for agricultural development planning.

International price weights have been used to combine various crop groups. The overall land suitability for rainfed crops has been assessed by using five major crop groups (i.e. cereals, roots and tubers, pulses, sugar crops and oil crops).

The suitability assessments provide extents for a range of suitability classes: very suitable, suitable, moderately suitable, marginally suitable, very marginally suitable and not suitable. The information has been condensed into three classes for presentation: (i) prime land, (ii) good land and (iii) marginal and not suitable land. Prime land is characterized by very suitable yields within 80 percent of potentially attainable yields. Good land represents suitable and moderately suitable land within 40 to 80 percent of maximum attainable yield levels and marginal and not suitable land includes all land with estimated yields that are less than 40 percent of maximum attainable yields for that crop type. Results are generated by 5 arc-minute resolution grid cells and are aggregated to administrative divisions or any other spatial differentiation.

Results

Total land resources suitable for agricultural production globally comprise 1.3 billion ha of prime land (this estimate includes 0.8 billion ha of current grassland, woodland and forestland ecosystems), 3.1 billion ha of good land (includes 2.2 billion ha grassland, woodland and forest land), and 1.1 billion ha of marginal land (of which 0.8 billion ha is grassland, woodland and forest land).

Very clearly, a large fraction of this suitable land is not available for crop production because of its nature protection status (about 0.6 billion ha), its carbon and biodiversity value (some 1.9 billion ha of forest assessed as suitable for crops), and because of its current use for feeding a large part of the world's 3.5 billion ruminant livestock (see below: Fodder production versus food production).

BOX 3: ASSUMED LEVELS OF INPUTS AND MANAGEMENT

Low-level inputs/traditional management

Under the low 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 inputs/improved management

Under the intermediate 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. It is medium labour intensive, uses some fertilizer application and chemical pest, disease and weed control, adequate fallows and some conservation measures.

High-level inputs/advanced management

Under the high 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.

Mixed level of inputs

Under mixed level of inputs only the best land is assumed to be used for high level input farming, moderately suitable and marginal lands are assumed to be used at intermediate or low level input and management circumstances. The following procedures were applied to individual 5-minute grid-cells.

(1) determine all very suitable and suitable land at high level of inputs;
(2) of the balance of land after (1), determine all land very suitable, suitable or moderately suitable at intermediate level of inputs, and
(3) of the balance of land after (1) and (2), determine all suitable land (i.e. very suitable, suitable, moderately suitable or marginally suitable) at low level of inputs.

Of the remaining global balance of 7.7 billion ha assessed as not suitable at all for crop production owing to poor soils, steep slopes or areas that are too dry or too cold, about 3.4 billion ha are barren, built-up land or water, and 1.8 billion ha is forest (very marginal and unsuitable for crop production). From the 2.6 billion ha of grassland/woodland, which is unsuitable for crops, some 1.6 billion ha is unproductive land (below 0.2 tonnes dry matter/ha) and the remainder, about 1.0 billion ha, can produce herbaceous biomass that can extensively support ruminant livestock (natural yield in the range 0.2–1.0 tonnes dry matter/ha).

A summary of the balance of land suitable for agricultural production, calculated across land qualities and broad land use/cover types, is presented in Table 4.

Table 5 presents results for rainfed crops overall as well as for crop-based bio-ethanol and biodiesel feedstocks at mixed and low level inputs in all land, current cultivated land, unprotected grassland/woodland ecosystems, and unprotected forest ecosystems. These results are aggregated for three regional levels including 'more developed' and 'less developed' countries and global totals.

TABLE 4: GLOBAL AVAILABILITY AND QUALITY OF LAND RESOURCES SUITABLE FOR CROP PRODUCTION					
Land quality	Cultivated land (billion ha)*	Grass/woodland (billion ha)*	Forestland (billion ha)*	Other land[a] (billion ha)*	Total (billion ha)*
Prime land	0.4	0.4 / 0.3	0.5 / 0.4	0.0	1.3 / 1.2
Good land	0.8	1.1 / 1.0	1.1 / 1.0	0.0	3.1 / 2.8
Marginal land	0.3	0.5 / 0.5	0.3 / 0.3	0.0	1.1 / 0.9
Not suitable	0.0	2.6 / 2.3	1.8 / 1.5	3.4 / 3.0	7.8 / 6.9
Total	1.6 / 1.5	4.6 / 4.1	3.7 / 3.2	3.4 / 3.0	13.3 / 11.8

Source: GAEZ 2009 simulations for all crop types of cereals, roots and tubers, sugar crops, pulses, and oil crops.

** Second value excludes land with protection status.*

TABLE 5: LAND SUITABILITY FOR RAINFED CROPS, BIO-ETHANOL AND BIODIESEL FEEDSTOCKS AT MIXED INPUTS IN ALL LAND										
	Mixed Inputs – ALL LAND									
Region	Area Million ha	Rainfed crops (%)			Rainfed ethanol feedstocks (%)			Rainfed biodiesel feedstocks (%)		
		Prime land	Good land	Marginal land	Prime land	Good land	Marginal land	Prime land	Good land	Marginal land
Northern America	2 090	9	20	71	7	18	75	8	16	76
Eastern Europe & Russia	1 838	12	18	70	9	19	73	8	18	75
Northern Europe	168	7	13	80	5	11	84	6	13	82
Southern Europe	129	10	22	67	10	20	70	6	21	72
Western Europe	108	27	27	46	26	24	50	18	32	50
Caribbean	22	28	43	29	19	42	39	22	32	46
Central America	246	12	25	63	9	21	70	8	20	72
South America	1 768	15	41	44	9	38	53	11	39	51
Australia & New Zealand	790	3	16	81	2	11	87	1	8	91
Melanesia	52	15	25	60	2	30	68	16	22	62
Eastern Africa	884	17	32	51	13	29	58	11	27	61
Central Africa	657	11	55	34	16	43	41	4	54	42
Northern Africa	575	1	4	95	1	3	96	0	3	97
Southern Africa	265	6	21	73	1	11	87	3	16	82
Western Africa	605	10	20	70	8	16	76	3	19	78
Western Asia	431	1	9	90	1	9	90	0	6	93
Southeastern Asia	436	18	26	56	2	32	66	20	21	59
Southern Asia	659	12	21	67	5	25	70	3	20	77
Eastern Asia	1 156	5	15	80	2	15	84	2	14	84
Central Asia	414	1	24	75	1	17	82	0	11	89
More developed	**5 160**	**9**	**19**	**72**	**7**	**17**	**75**	**7**	**16**	**77**
Less developed	**8 135**	**10**	**27**	**62**	**7**	**25**	**69**	**6**	**24**	**70**
World total	**13 295**	**10**	**24**	**66**	**7**	**22**	**71**	**6**	**21**	**73**

Note: 'Prime land' represents areas assessed as very suitable or suitable for some crop production. 'Good land' includes areas assessed as suitable or moderately suitable for crop production. The residual category 'Marginal Land' refers to areas assessed as marginally suitable or not suitable for crop cultivation.

a. About 0.1 billion ha of land classified as built-up, sparsely vegetated or water was assessed as marginally suitable and is assumed to be unavailable for crop production.

TABLE 6: LAND SUITABILITY FOR RAINFED CROPS AT MIXED INPUTS CURRENT CULTIVATED LAND, UNPROTECTED GRASSLAND/WOODLAND ECOSYSTEMS AND UNPROTECTED FOREST ECOSYSTEMS

Mixed inputs – RAINFED CROPS

Region	Cultivated land				Unprotected grassland/woodland				Unprotected forest land			
	Total	Prime land	Good land	Marginal land	Total	Prime land	Good land	Marginal land	Total	Prime land	Good land	Marginal land
	Million ha		%		Million ha		%		Million ha		%	
North America	230	39	52	9	593	3	20	77	562	11	27	62
Easter Europe & Russia	205	37	56	6	543	7	12	81	763	11	16	73
Northern Europe	20	34	44	22	53	4	11	85	63	3	8	90
Southern Europe	44	18	43	39	28	9	13	79	31	6	11	83
Western Europe	35	48	39	12	28	19	21	59	26	11	20	69
Caribbean	7	40	56	4	7	23	41	37	4	22	37	41
Central America	36	24	51	24	92	7	22	71	77	13	21	66
South America	129	32	60	8	608	15	37	49	686	17	47	36
Australia & NZ	51	8	51	41	468	2	13	85	76	10	36	54
Melanesia	1	31	55	14	15	13	24	63	33	15	25	60
Eastern Africa	83	36	49	14	408	17	34	49	105	24	43	33
Central Africa	38	20	75	5	198	13	56	31	275	10	68	22
Northern Africa	19	16	49	35	33	4	29	68	5	7	30	64
Southern Africa	18	34	54	11	150	4	22	74	12	15	38	47
Western Africa	86	31	57	12	184	13	23	64	49	13	33	54
Western Asia	40	7	58	35	56	1	21	77	11	3	18	79
South-East Asia	97	28	55	17	93	13	18	69	171	16	17	67
Southern Asia	229	25	42	33	106	3	12	85	74	10	19	72
Eastern Asia	151	17	48	35	319	2	17	81	204	7	15	78
Central Asia	41	3	74	23	121	2	42	56	8	5	36	59
More developed	590	34	52	14	1 716	5	15	80	1 543	10	21	69
Less developed	969	25	53	22	2 386	11	31	59	1 694	14	40	46
World total	1 559	28	52	19	4 102	8	24	68	3 237	12	31	57

Source: GAEZ 2009; data compilation by authors.

The extent of suitable area varies substantially according to assumed management levels. Important conclusions are: (i) where food crops can be grown, biofuel feedstocks can be produced with almost the same success rate; (ii) there is a significantly lower share of prime land and good land, i.e. overall much lower productivity for crops, in unprotected grassland/woodland and forest ecosystems as compared to current cultivated land; and (iii) the impact of agricultural inputs on soil suitability is substantial in all regions. Globally, the estimated extent of prime land and good quality land increases from 26 percent at low input level to 34 percent at mixed levels of input and management when considering all land. For current cultivated land the assessed share of prime and good land increases from 70 to 81 percent. It can be concluded that current cultivated

TABLE 7: LAND SUITABILITY FOR RAINFED CROPS, BIO-ETHANOL AND BIODIESEL FEEDSTOCKS AT LOW INPUTS

Low inputs – ALL LAND

Region	Area (Million ha)	Rainfed crops (%)			Rainfed ethanol feedstocks (%)			Rainfed biodiesel feedstocks (%)		
		Prime land	Good land	Marginal land	Prime land	Good land	Marginal land	Prime land	Good land	Marginal land
Northern America	2 090	5	20	75	4	17	79	4	17	79
Eastern Europe & Russia	1 838	7	17	76	7	15	78	3	19	78
Northern Europe	168	1	12	87	1	8	91	1	11	88
Southern Europe	129	7	21	72	7	18	75	3	21	76
Western Europe	108	9	33	58	9	30	62	2	35	63
Caribbean	22	14	38	48	11	40	50	11	34	55
Central America	246	8	21	71	5	18	77	6	19	75
South America	1 768	4	36	60	3	17	79	3	29	68
Australia & New Zealand	790	1	13	85	1	9	91	1	8	91
Melanesia	52	4	21	75	1	14	85	3	18	78
Eastern Africa	884	7	30	64	5	23	72	4	27	69
Central Africa	657	1	53	47	1	27	73	0	44	56
Northern Africa	575	1	4	95	1	3	96	0	3	97
Southern Africa	265	2	21	76	1	9	90	2	15	83
Western Africa	605	2	20	78	2	12	85	0	15	84
Western Asia	431	2	8	90	2	8	91	0	6	93
Southeastern Asia	436	2	22	76	0	14	86	1	18	80
Southern Asia	659	3	21	76	3	19	78	0	18	82
Eastern Asia	1 156	2	14	84	1	12	87	1	12	86
Central Asia	414	2	21	77	1	14	84	0	10	90
More Developed	5 160	5	18	77	5	15	80	3	17	81
Less Developed	8 135	3	25	72	2	16	82	2	20	78
World Total	13 295	4	22	74	3	15	81	2	19	79

Note: 'Prime land' represents areas assessed as very suitable or suitable for some crop production. 'Good land' includes areas assessed as suitable or moderately suitable for crop production. The residual category 'Marginal land' refers to areas assessed as marginally suitable or not suitable for crop cultivation.

land is already concentrated in the world's prime land resources. Nevertheless, 328 million ha of unprotected grassland/woodland ecosystems and 492 million ha of forest ecosystems are assessed to be prime land for rainfed crop production under mixed inputs management system. Converting forests or grassland/woodland ecosystem to cultivated land often implies the substantial risk of the adverse impact of greenhouse gas and loss of biodiversity.

The suitability map presented in Figure 4 uses an index to combine and classify the obtained suitability distribution. This index is calculated as follows:

$$SI = VS*0.9 + S*0.7 + MS*0.5 + mS*0.3 + VmS*0.1$$

TABLE 8: SUITABILITY OF LAND FOR RAINFED CROPS AT LOW INPUTS IN CURRENT CULTIVATED LAND, UNPROTECTED GRASSLAND/WOODLAND ECOSYSTEMS AND UNPROTECTED FOREST ECOSYSTEMS

Low inputs – Rainfed crops

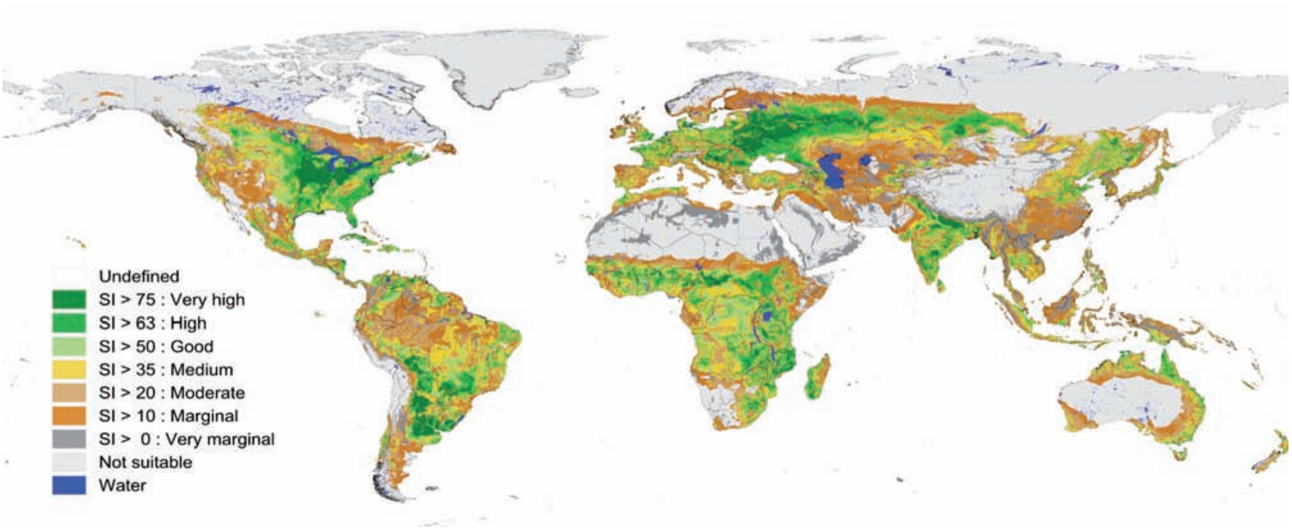
Region	Cultivated land				Unprotected grassland/woodland				Unprotected forest land			
	Total	Prime land	Good land	Marginal land	Total	Prime land	Good land	Marginal land	Total	Prime land	Good land	Marginal land
	Million ha	Percentage of total			Million ha	Percentage of total			Million ha	Percentage of total		
North America	230	30	55	16	593	2	19	79	562	4	26	70
Eastern Europe & Russia	205	32	56	12	543	4	11	85	763	4	16	80
Northern Europe	20	9	52	39	53	0	7	93	63	0	7	93
Southern Europe	44	13	40	47	28	4	12	85	31	4	10	86
Western Europe	35	19	56	25	28	3	22	74	26	3	19	78
Caribbean	7	24	54	22	7	10	31	59	4	9	35	56
Central America	36	18	44	38	92	5	17	78	77	10	18	72
South America	129	17	68	15	608	5	33	62	686	3	39	58
Australia & New Zealand	51	5	48	47	468	1	10	90	76	5	31	64
Melanesia	1	11	69	20	15	3	18	79	33	4	21	75
Eastern Africa	83	19	55	26	408	6	29	65	105	7	48	46
Central Africa	38	2	81	17	198	1	52	47	275	0	63	37
Northern Africa	19	15	45	40	33	4	27	69	5	8	24	67
Southern Africa	18	16	65	19	150	1	22	77	12	5	43	53
Western Africa	86	6	69	25	184	3	19	78	49	3	28	70
Western Asia	40	12	49	38	56	3	18	79	11	4	15	81
Southeast Asia	97	3	52	44	93	1	12	87	171	1	14	85
Southern Asia	229	7	43	51	106	1	10	90	74	3	15	82
Eastern Asia	151	6	42	52	319	1	16	83	204	4	16	80
Central Asia	41	5	68	28	121	3	36	61	8	9	29	62
More developed	590	26	53	21	1 716	2	13	84	1 543	4	20	76
Less developed	969	9	54	37	2 386	4	27	70	1 694	3	36	62
World total	1 559	16	54	31	4 102	3	21	76	3 237	3	28	68

Source: GAEZ 2009; data compiled by authors.

Where:

VS represents the share of very suitable land (80–100 percent of maximum attainable yield)
S represents the share of suitable land (60–80 percent of attainable yield)
MS represents the share of moderately suitable land (40–60 percent of maximum attainable yield)
mS represents the share of marginally suitable land (20–40 percent of maximum attainable yield)
VmS represents the share of very marginally suitable land (5–20 percent of maximum attainable yield)

FIGURE 4: GLOBAL SUITABILITY FOR RAINFED CEREAL PRODUCTION (BASED ON WHEAT, BARLEY, RYE, RICE, MAIZE, SORGHUM, MILLET AND BUCKWHEAT)



Source: GAEZ 2009

Grasses and pasture legume productivity

The production of grasses and pasture legumes depends on ecological suitability as well as the number of growing days, i.e. days when both temperature and moisture supply are conducive to growth. Although adapted grass and pasture legumes species can grow well in most climatic zones, with comparable per day growth rates and biomass production, total annual production is related to number of days available. For this reason, even in ecologically very suitable temperate zones annual production is substantially lower as compared to areas with year-round growing periods, as for instance in humid tropical areas. Grasses and pasture legumes have been evaluated in terms of per hectare agronomically attainable production. Figure 5 shows potential grass and pasture legume yields under low input/natural conditions in tonnes/dry matter (DM)/ha.

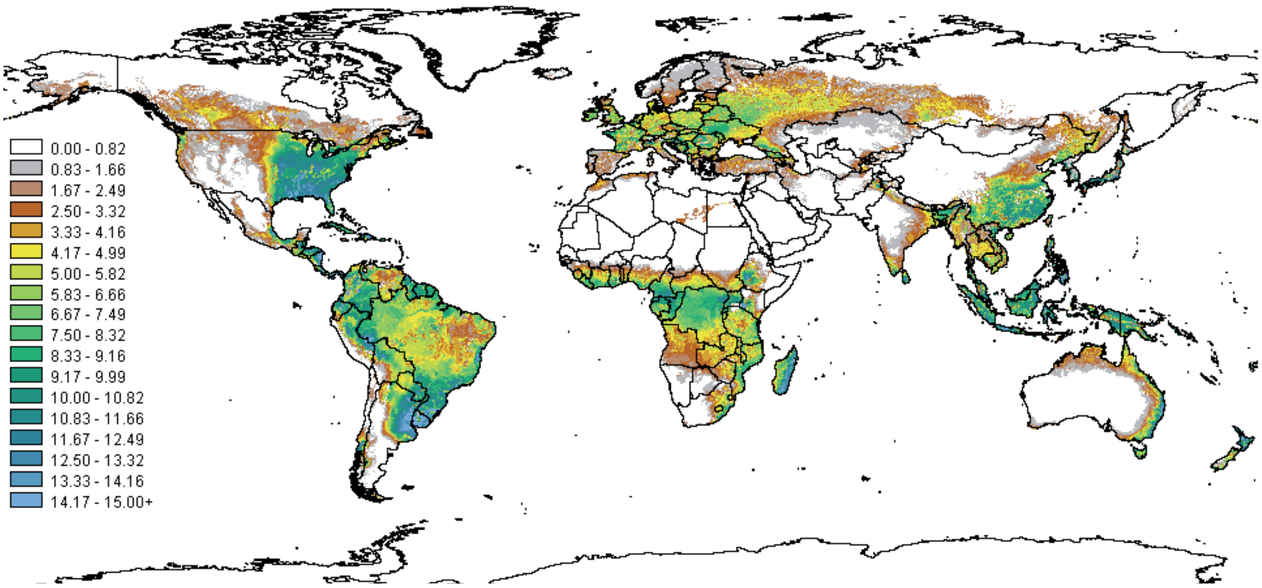
Table 9 summarizes the availability and estimated productivity of land with grassland/woodland ecosystems in 2000. In other words, this category includes all vegetated non-forest and non-cultivated land. As a cutoff point at the lower end an annual productivity of 0.2 tonnes/DM/ha has been taken, roughly corresponding with a carrying capacity of 0.1 tropical livestock units per hectare.

Soil and terrain

Constraining soil and terrain-slope conditions are accounted for and factored into the analysis by means of soil quality ratings (SQ, percent). Soil characteristics are read from 30 arc-second grid-cells from the Harmonized World Soil Databases (FAO *et al.*, 2009).

Seven different SQs are calculated and combined in a soil index rating (see Box 4), which represents the percentage of crop productivity realized in each specific soil type depending on input/management level and sloping conditions. As each grid-cell may contain several soils with dominant and secondary soil types, GAEZ calculates a distribution of possible yields for each grid-cell by considering all possible LUT/soil-type combinations.

FIGURE 5: POTENTIAL GRASS AND PASTURE LEGUMES PRODUCTION (TONNES/DM)HA), LOW INPUT



Source: GAEZ 2009, biomass simulation of pasture LUTs assuming a low level of inputs.

All soil quality ratings are then combined to calculate a single agro-edaphic yield factor named soil unit suitability rating (SR, fractional). The SR for each LUT/soil-unit combination is differentiated by input/management levels. The following five guiding principles form the basis for the rationale used to combine SQs for different levels of input/management:

- Nutrient availability and nutrient retention capacity are key soil qualities.
- Nutrient availability is of utmost importance for low level input farming, as nutrient retention capacity is for high level inputs.
- Nutrient availability and nutrient retention capacity are considered of equal importance for intermediate level inputs farming.
- Nutrient availability and nutrient retention capacity are strongly related to rooting depth and soil volume available.
- Oxygen available to roots, excess salts, toxicity and workability are regarded equally important soil qualities.

To calculate SR, each SQ has been rated between 0 (absolutely not suitable) and 100 (perfectly suitable), and the combination of SQs is achieved by multiplication of the most limiting SQ with the average of the remaining less limiting SQs.

Figure 6 and Figure 7 show dominant soil and terrain constraints for respectively low input and high input farming conditions. Obviously, agricultural input and management increases can help to overcome soil and terrain constraints to some degree in all regions. For example, refer to the maps, in particular Eastern Africa, India and Australia.

TABLE 9: EXTENTS OF GRASSLAND/WOODLAND ECOSYSTEMS BY PRODUCTIVITY CLASSES UNDER LOW INPUT

	Grassland and Woodland	Area by productivity class (%)				
	Million ha	< .2 tonnes/ha	.2-1 tonnes/ha	1-5 tonnes/ha	5-10 tonnes/ ha	>10 tonnes/ha
Northern America	673	50	14	30	4	2
Eastern Europe & Russia	604	65	7	21	7	0
Northern Europe	61	21	21	44	13	0
Southern Europe	37	10	22	55	9	4
Western Europe	34	8	4	51	29	8
Caribbean	7	3	1	29	40	27
Central America	99	32	32	20	7	8
South America	657	9	11	32	34	14
Australia & New Zealand	510	44	26	24	5	1
Melanesia	15	18	2	8	25	47
Eastern Africa	478	25	13	33	24	5
Central Africa	229	12	6	47	31	5
Northern Africa	33	14	47	39	0	0
Southern Africa	176	27	33	35	5	1
Western Africa	202	50	13	26	10	1
Western Asia	56	24	34	40	2	0
South-Eastern Asia	111	16	3	31	27	23
Southern Asia	118	41	27	29	2	1
Eastern Asia	386	49	18	20	7	7
Central Asia	125	9	33	56	2	0
More developed	**1 923**	**50**	**15**	**27**	**6**	**1**
Less developed	**2 689**	**25**	**16**	**32**	**19**	**7**
World total	**4 612**	**36**	**16**	**30**	**14**	**5**

Source: GAEZ 2009; data compilation by authors.

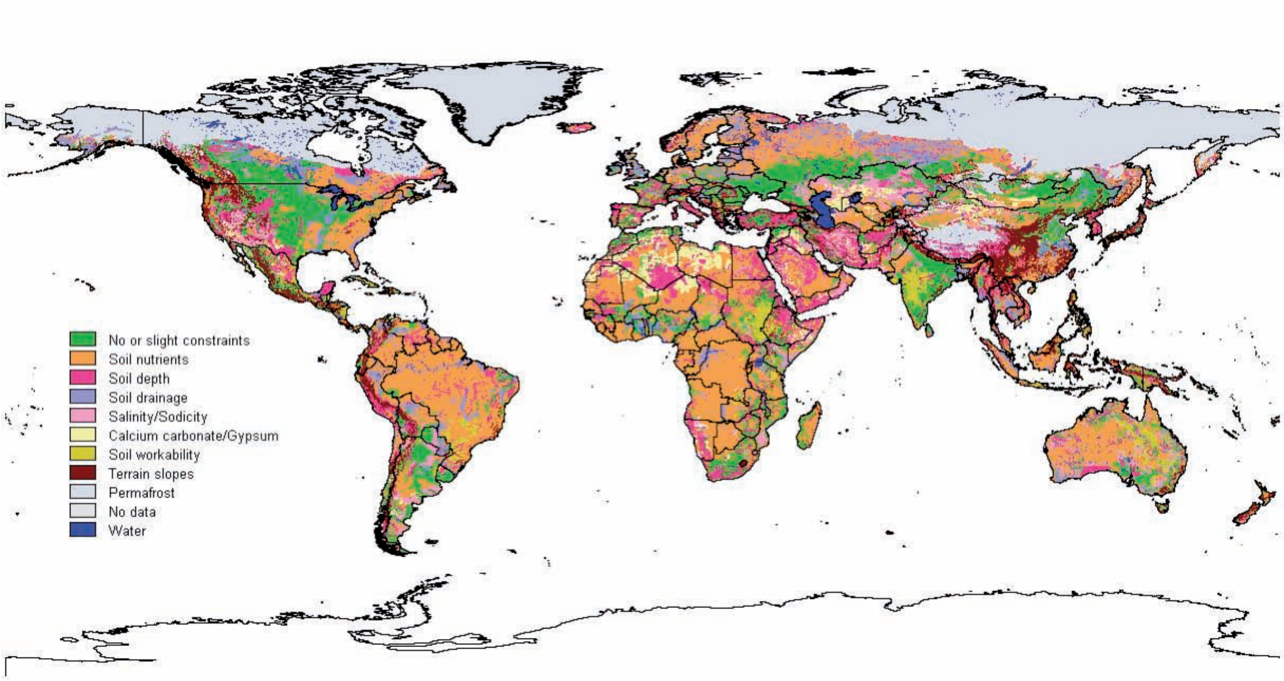
BOX 4: SOIL AND TERRAIN CONSTRAINTS

Soil and terrain slope constraints affecting agricultural production include:

Nutrient availability: decisive for successful low level input farming when relying on natural soil fertility.
Nutrient retention capacity: capacity of the soil to retain added nutrients against losses caused by leaching.
Rooting conditions: effective soil depth and effective soil volume may affect rootability.
Oxygen availability: drainage characteristics of soils may affect oxygen availability to roots.
Excess salts: saline and sodic soil conditions. Salinity inhibiting crop–water uptake of the soil and affecting growth and reducing yields. Sodicity causing sodium toxicity and affecting soil structure causing low soil permeability.
Calcium carbonate and gypsum: excess calcium carbonate causes micronutrient deficiencies and excess gypsum limits available soil moisture.
Soil workability constraints: soil conditions may cause physical hindrance to cultivation.
Terrain slopes: topsoil erosion reduces soil depth, natural soil fertility and soil moisture.

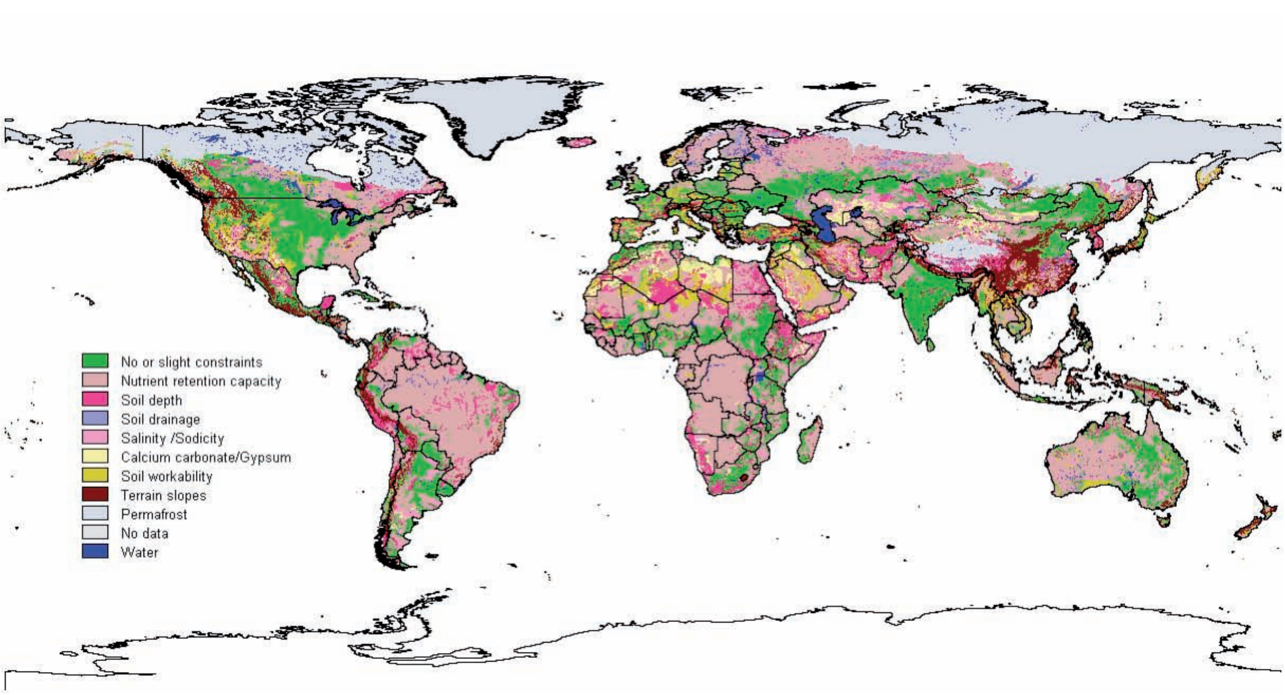
Figure 6 illustrates that soil nutrient availability is by far the most prevalent soil limitation in most regions, particularly in the tropics, especially in large parts of Central Africa and central South America. This is further detailed in Figure 8, which presents soil quality ratings computed in GAEZ–2009 for low input farming conditions.

FIGURE 6: DOMINANT SOIL AND TERRAIN CONSTRAINTS FOR LOW INPUT FARMING



Source: GAEZ 2009. Note: The class 'No or slight constraint' is used for grid cells where soil and terrain conditions result in constraint rating of 80 or more, for a possible range of 0 (absolutely not suitable) to 100 (perfectly suitable).

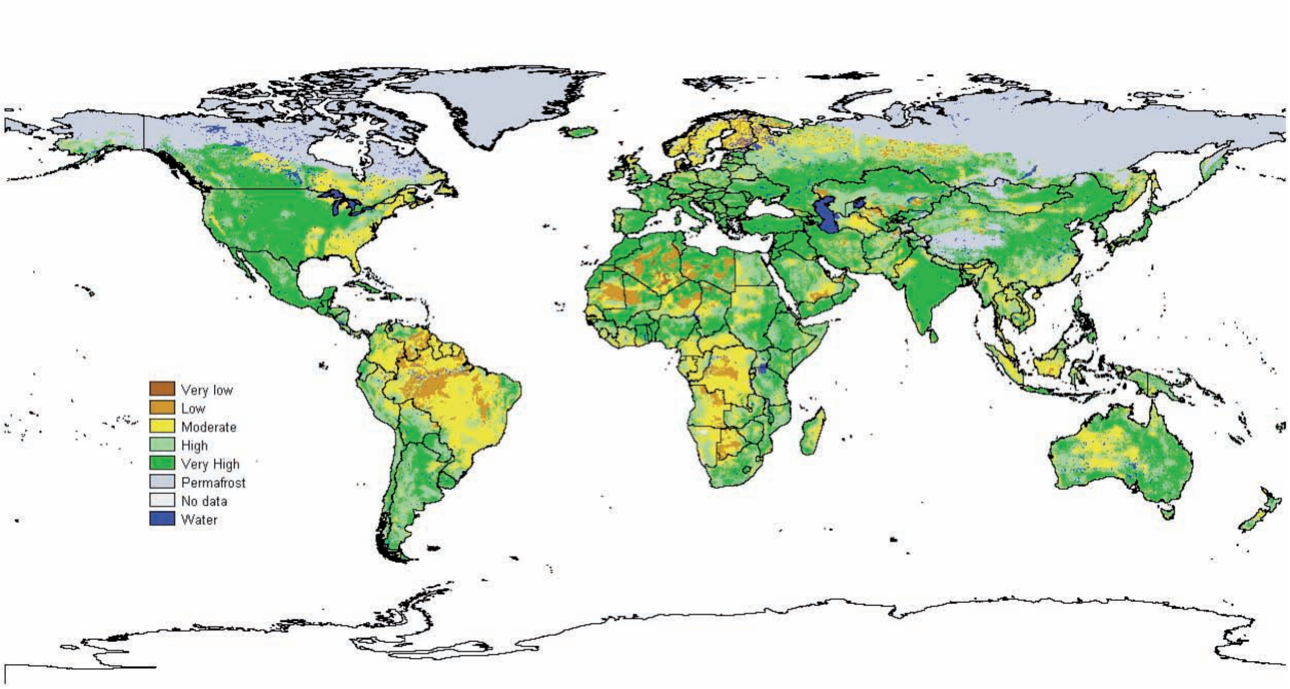
FIGURE 7: DOMINANT SOIL AND TERRAIN CONSTRAINTS FOR HIGH INPUT FARMING



Source: GAEZ 2009

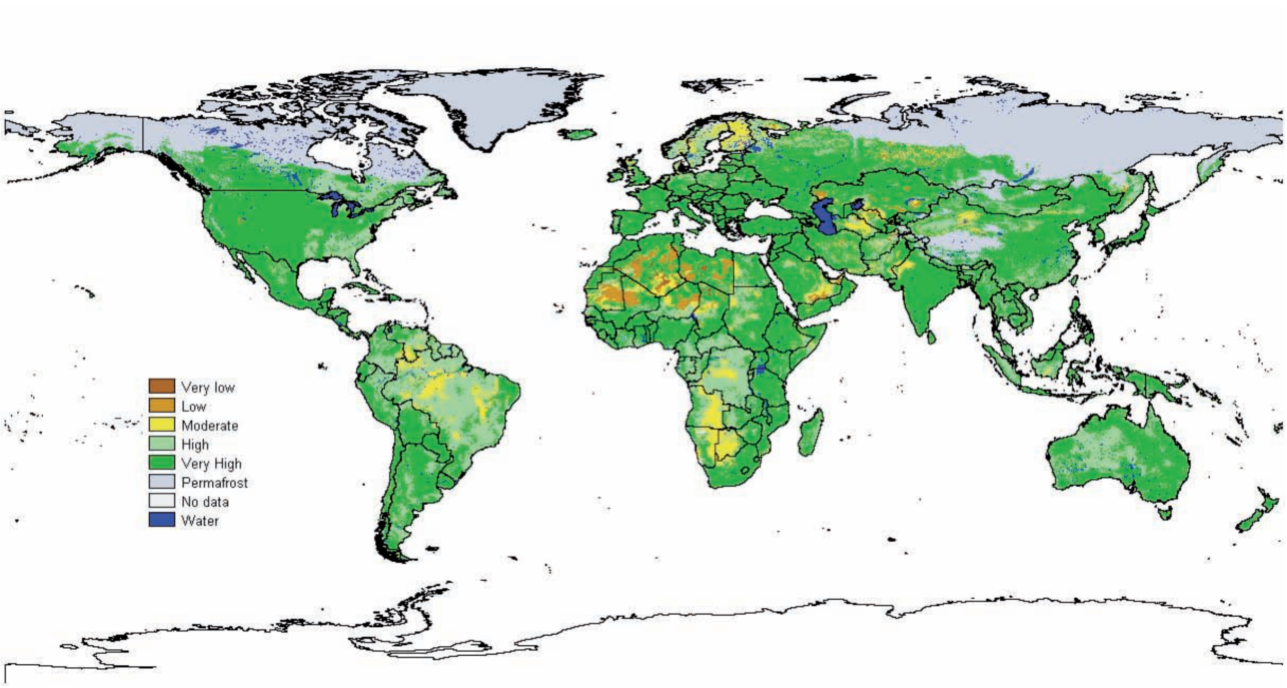
Natural fertility status of soils, as presented above, may have further deteriorated over time through 'nutrient mining'. Given proper soil management, with appropriate fallowing, the natural status may be restored over time.

FIGURE 8: NATURAL SOIL NUTRIENT AVAILABILITY



Source: GAEZ 2009

FIGURE 9: SOIL NUTRIENT RETENTION CAPACITY



Source: GAEZ 2009

Under high input farming conditions, a low natural nutrient availability can be alleviated by applying fertilizer provided the soil can adequately retain nutrients.

Low nutrient retention capacities are found in Southern Africa, the Amazon area, Central Asia and Northern Europe (see Figure 9). In these areas increased use of fertilizers alone may prove less effective for increasing crop yields.

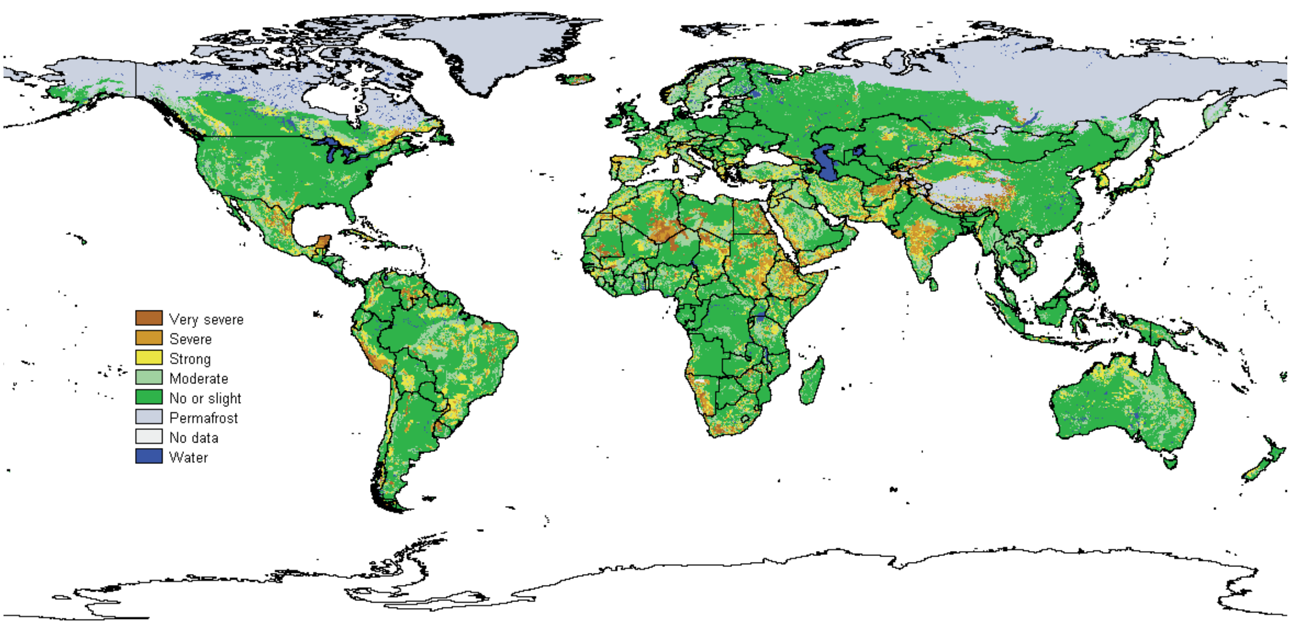
Another major obstacle to crop cultivation is the constraint related to soil workability. This is the main constraint in large parts of Ethiopia, Sudan and central India (Figure 10). Soil workability constraints may be reduced by high inputs and appropriate soil management. Often these areas are dominated by Vertisols, which are difficult to cultivate without mechanization.

Figure 11 summarizes the assessed most limiting soil constraints by region. It shows that in several regions soil quality constraints affect well over than half the cultivated land base, notably in Central Africa, South-eastern Asia, South America and Northern Europe.

About 60 percent of cultivated soils in developed countries, some 366 million ha, are assessed as having no or only minor soil and terrain constraints. Of the remainder, soil nutrient availability is the most limiting factor for about 40 percent. In less developed countries, overall 42 percent of cultivated soils, about 410 million ha, have no or only minor constraints. Nutrient availability dominates (about 45 percent of soils having constraints) the causes of soil limitations in the remaining 58 percent of developing countries' soils.

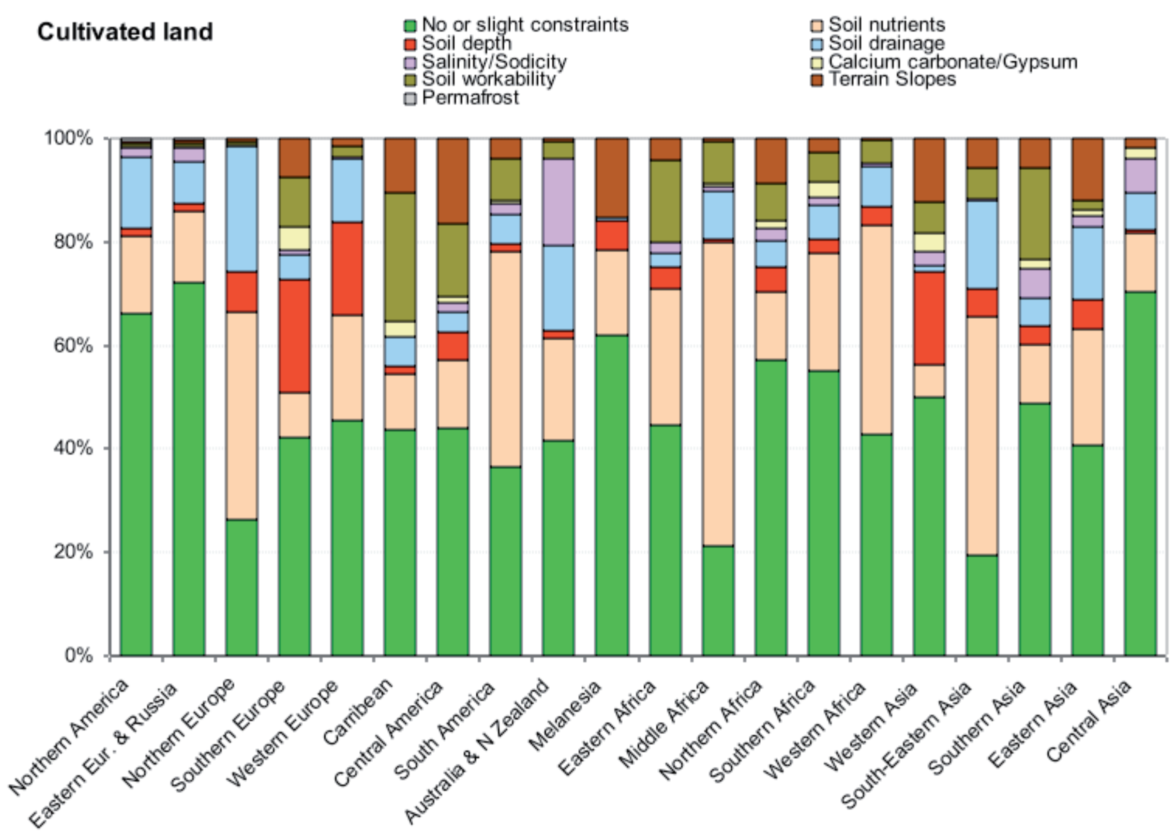
A distribution of soil evaluation results by broad classes of soil quality ratings for nutrient availability at low level of inputs is shown in Table 10. While nearly all cultivated soils exceed a rating of 40 (possible range 0 to 100), about 35 percent of soils in developing countries is rated in a range of 40–80 and 65 percent in the range 80–100. The share of soils in developed countries with no or low nutrient availability is 78 percent.

FIGURE 10: SOIL WORKABILITY CONSTRAINTS FOR LOW INPUT FARMING



Source: GAEZ 2009

FIGURE 11: MAIN SOIL AND TERRAIN CONSTRAINTS TO LOW INPUT FARMING OF CURRENT CULTIVATED LAND



Source: GAEZ 2009; data compilation by authors.

For comparison, Figure 12 and Figure 13 present summary statistics compiled for potentially available prime and good land (very suitable, suitable and moderately suitable in GAEZ 2009 terminology) located in current grassland/woodland and forest land ecosystems. Soil nutrient availability in prime and good quality unprotected grassland and woodland ecosystems is substantially lower than in cultivated land. In Central Africa, South America and South Eastern Asia – all in rather humid environments – the extent of relative land with constraints related to nutrient availability is widespread. Grassland and woodland in Northern Europe suffers from widespread soil drainage problems, which, if to be converted to cultivated land, may be reduced with investment in proper drainage systems.

In unprotected prime and good quality forest ecosystems natural soil nutrient availability is again lower, as compared to the unprotected prime and good quality grassland ecosystems. This is especially so in the forests of Northern Europe, South America, Central, South and Western Africa large areas with soil nutrient deficiencies exist over most of this land.

Water scarcity constraints of land

About one-quarter of the world's population live in areas categorized as physically water scarce and one-sixth in areas of economic water scarcity (United Nations, 2006). Two billion live without access to sanitation and one billion without access to improved sources of drinking water. Water demands continue to increase to provide the needs of growing populations and industries.

TABLE 10: DISTRIBUTION OF CULTIVATED LAND BY CLASS OF SOIL QUALITY RATING OF AVAILABILITY OF NATURAL NUTRIENTS

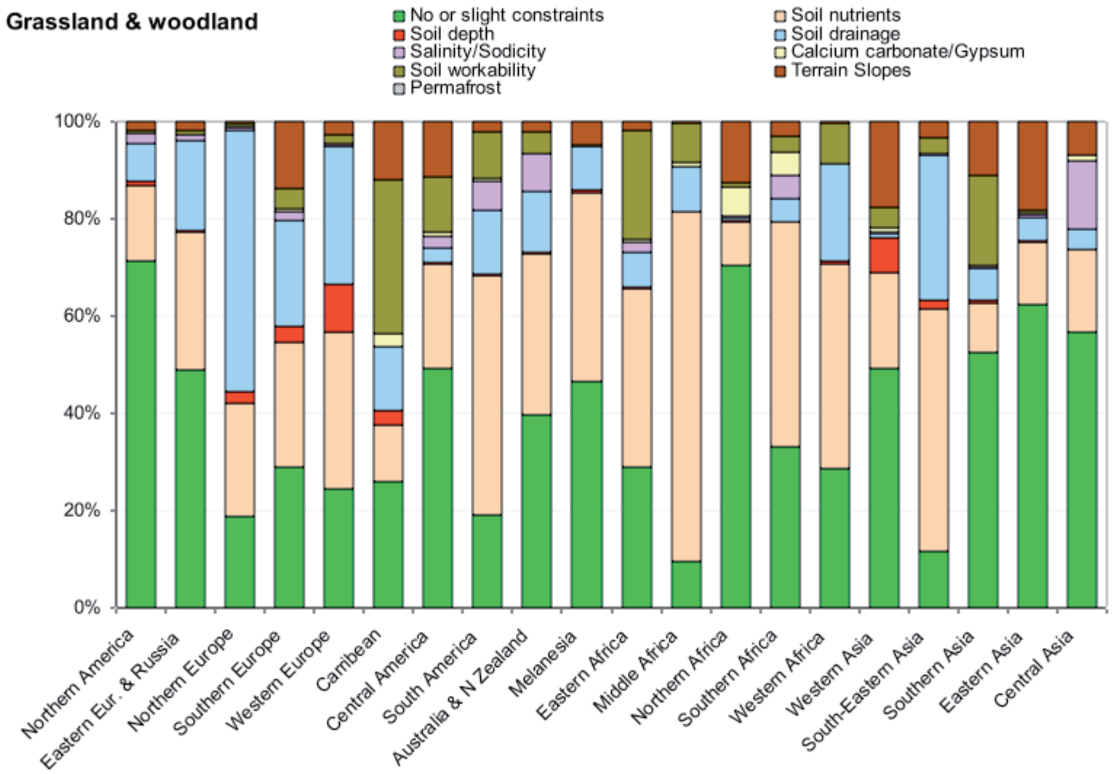
	Cultivated land	Area by class of soil natural nutrient availability rating (%)			
	Million ha	< 40	40–60	60–80	> 80
Northern America	232	1	10	8	80
Eastern Europe & Russia	207	1	3	14	82
Northern Europe	20	6	15	26	52
Southern Europe	44	0	5	10	84
Western Europe	35	1	8	15	76
Caribbean	7	0	3	17	81
Central America	36	0	5	16	79
South America	130	4	31	22	44
Australia & New Zealand	51	1	6	28	65
Melanesia	1	0	7	14	79
Eastern Africa	84	0	18	17	64
Central Africa	39	1	57	10	32
Northern Africa	19	1	1	14	83
Southern Africa	18	0	18	14	68
Western Africa	87	0	35	11	54
Western Asia	40	0	2	8	89
Southeastern Asia	97	0	49	16	35
Southern Asia	230	0	7	11	82
Eastern Asia	151	0	17	12	71
Central Asia	42	0	2	15	83
More developed	**593**	**1**	**7**	**13**	**78**
Less developed	**976**	**1**	**21**	**14**	**65**
World total	**1 569**	**1**	**16**	**14**	**70**

Source: GAEZ 2009; data compilation by authors.

Of all human activities, agriculture is the largest user of water. Irrigation water withdrawals are 70 percent of the total anthropogenic use of renewable water resources. Irrigated crops produce about 40 percent of total agricultural output, yields are typically twice those of rainfed crops. Irrigation has enabled farmers to increase crop yields by reducing their dependence on rainfall patterns, thus boosting average crop production while decreasing its inter-annual variability. Today, the irrigated area has expanded to over 270 million ha world-wide, about 18 percent of total cultivated land. With a doubling of food production necessary to supply the population in 2050, agricultural water demand may rise by a similar percentage, depending on how water is managed in agriculture.

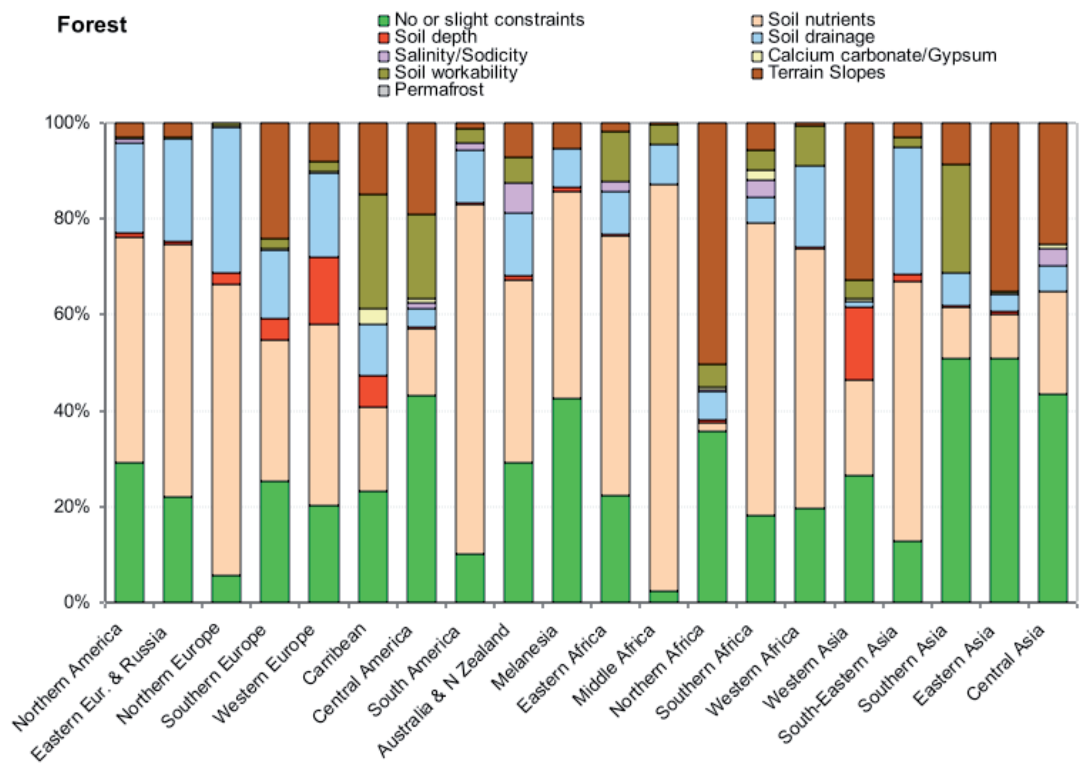
However, prospects to meet future food demands with further irrigation development are limited by the water demands of human settlements, industry and other uses, by the declining possibilities of tapping additional sources of irrigation water (owing to lowering of groundwater tables, melting of glaciers, the best reservoir sites already being developed and the silting of existing reservoirs), and widespread decreas-ing quality of water resources as a result of pollution and waste. Demand in other sectors is expected to

FIGURE 12: DOMINANT SOIL AND TERRAIN CONSTRAINTS FOR LOW INPUT FARMING OF AVAILABLE UNPROTECTED PRIME AND GOOD GRASSLAND/WOODLAND ECOSYSTEMS



Source: GAEZ 2009; data compilation by authors.

FIGURE 13: DOMINANT SOIL AND TERRAIN CONSTRAINTS FOR LOW INPUT FARMING OF AVAILABLE UNPROTECTED PRIME AND GOOD FOREST LAND



Source: GAEZ 2009; data compilation by authors.

increase by even greater amounts as the population continues to climb and developing countries industrialize. In many industrialized nations, domestic and industrial water withdrawals are greater than agricultural withdrawals.

While the world as a whole may have the required freshwater resources to satisfy the needs of the population, the resources are unevenly distributed. Some countries have an abundance of water, while many manage conditions of extreme scarcity. The extent of water scarcity can be measured in various ways. A commonly used, simple measure of scarcity is the ratio of water withdrawals[1] to the total renewable water resource. Water is considered scarce when the withdrawals exceed 40 percent of the renewable resource, which is true for many countries in North Africa, the Central East and Central Asia. According to statistics compiled by FAO (FAOSTAT), several countries including Libya, Egypt, Israel, Jordan, Saudi Arabia, Yemen, and Uzbekistan already withdraw more water than their total renewable resources.

Water withdrawals that exceed total renewable resources in a country are possible through water recycling, since not all the water withdrawn is consumptively used, and through water mining, where water is withdrawn from groundwater aquifers much faster than the aquifers can be recharged. Overdraft of groundwater is reported throughout Algeria, Djibouti, Egypt, Israel, Libya, Mauritania, Pakistan, Qatar, Saudi Arabia, Tunisia, Turkmenistan and the United Arab Emirates. It is also common in agricultural areas within other countries such as the North China Plain in China, around Mexico City, Mexico, the Indo-Gangetic plain in India and much of the Western United States of America. These overdrafts are unsustainable over the long term, and will place further pressure on available renewable freshwater resources in the future.

Figure 14 shows the spatial pattern of total annual water withdrawal and Figure 15 displays a spatial map of the ratio of total withdrawals to the available renewable water resource. Both water withdrawals and renewable water resources are downscaled to a five arc-minute grid. Domestic water withdrawals are downscaled by applying the per capita domestic water use to the population of each pixel. Industrial water withdrawals were downscaled by using the industrial water use per unit GDP and applying downscaled information on GDP. Water consumption is assumed to be 30 percent of domestic use and 10 percent of industrial use.

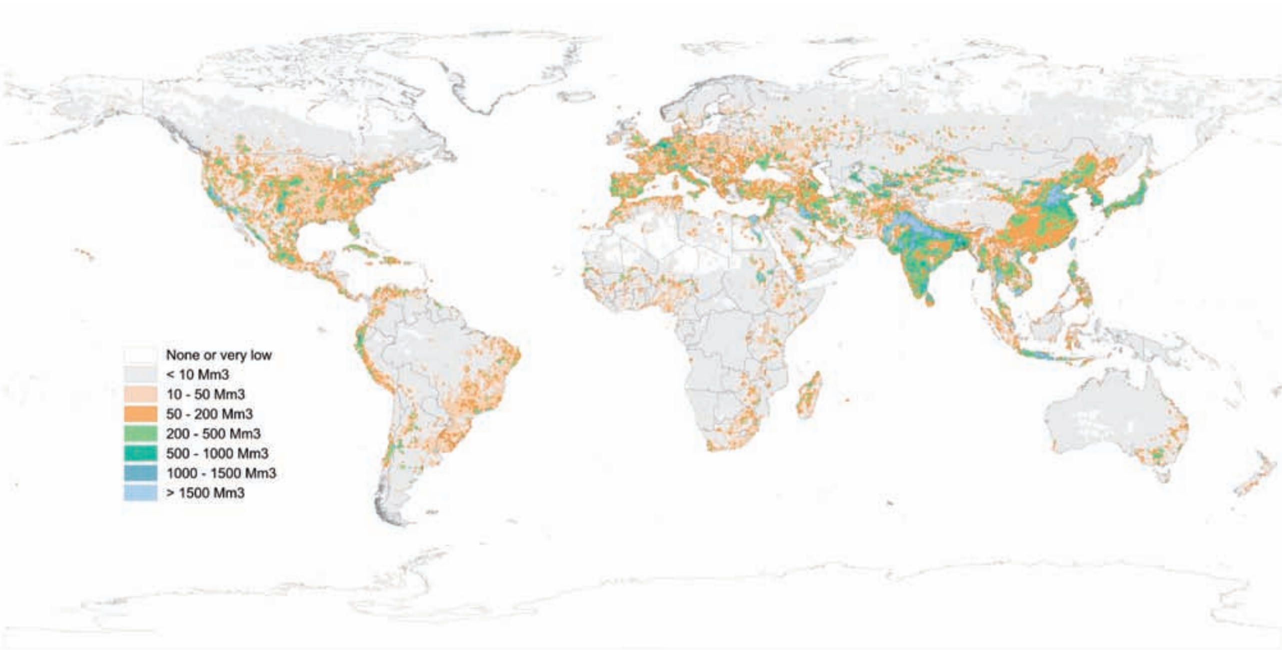
Finally, agricultural water consumption is assumed to be the sum of crop–water deficit in irrigated areas generated in the AEZ analysis and the water used for livestock consumption, applied to a global spatial data set of livestock distribution prepared by FAO. Water that is not consumed in one pixel flows to the next downstream pixel where it is considered part of the next pixel's available resource in addition to the runoff generated in that pixel. Data sets of water flow directions have been used in simulations both at 0.5°latitude/longitude (Vörösmarty, 2000) and for a grid of 5 arc-min (Graham, 1999).

Additional indications of water scarcity are provided by maps showing length of growing period (LGP) and crop–water deficits. AEZ analysis combines this information along with yield reductions caused by climatic conditions into climatic constraints, the calculation of which is described in detail in several reports (Fischer *et al*., 2002a; Fischer *et al*., 2000; FAO, 1978–1981). Figure 16 shows where the calculated annual growing period is constrained by moisture rather than by temperature.

A measure of the vulnerability of a country's renewable water resource is the dependency ratio, the amount

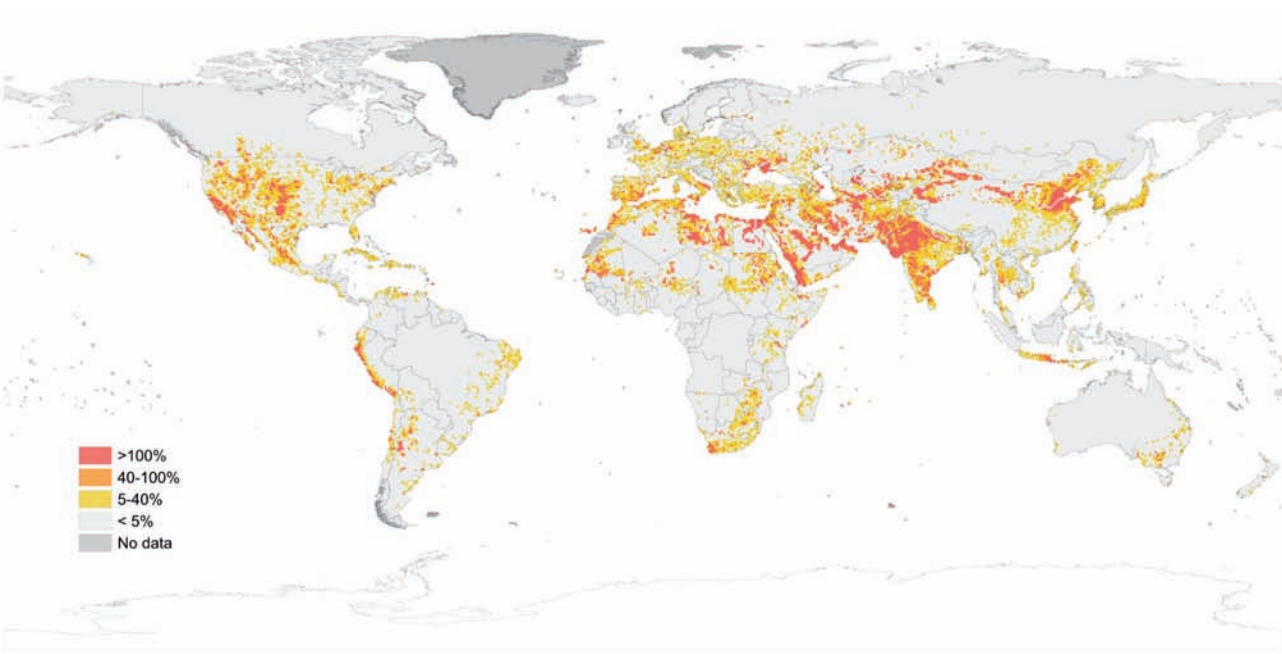
[1] Water withdrawal denotes the removal of water from a water source, such as groundwater, for use by humans. The water is subsequently returned some time later after it is used. The quality of the returned water may not be the same as when it was originally removed.

FIGURE 14: ESTIMATED ANNUAL WATER WITHDRAWAL (MILLION M3/YEAR BY GRID CELL (0.5° LAT./0.5° LONG.)



Source: GAEZ 2009 and AQUASTAT; downscaling simulations by authors.

FIGURE 15: RATIO OF ANNUAL WATER WITHDRAWAL TO AVAILABLE RENEWABLE WATER RESOURCE

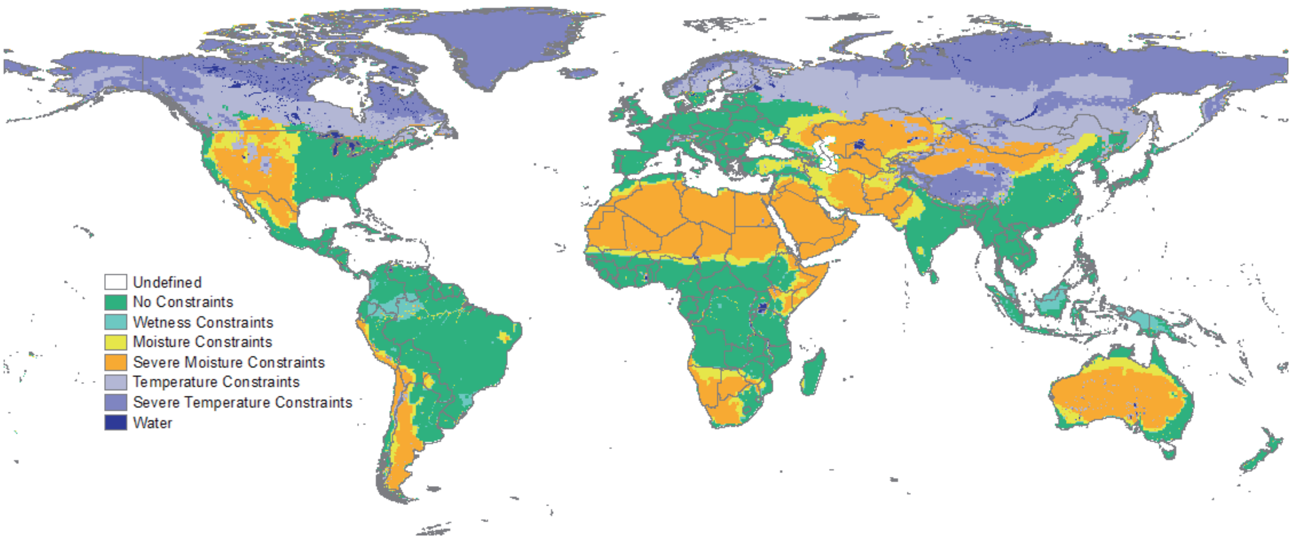


Source: GAEZ 2009 and AQUASTAT; simulations and data compilation by authors.

of the country's total renewable water resources that flows in from other countries. The dependency ratio by country is depicted in Figure 17.

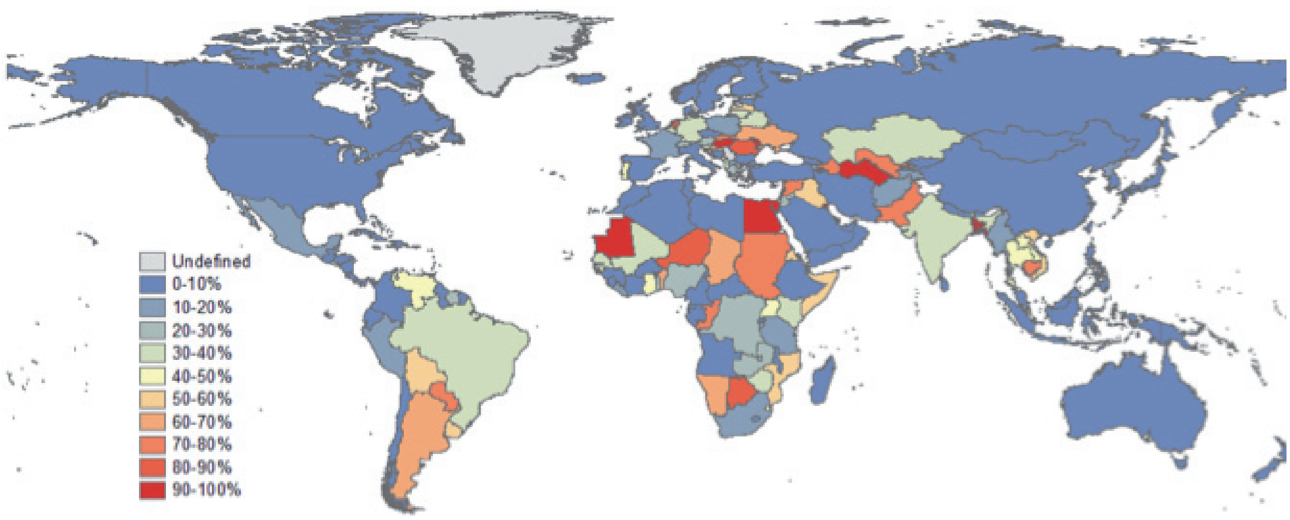
In Figure 18, a combined indicator is plotted, integrating the ratio of water withdrawals to availability, the LGP groups and the dependency ratio to provide a more complete picture of water scarcity.

FIGURE 16: **GLOBAL DISTRIBUTION OF MOISTURE AND TEMPERATURE CONSTRAINTS**



Source: Fischer et al. (2002).

FIGURE 17: **WATER RESOURCES DEPENDENCY RATIO**

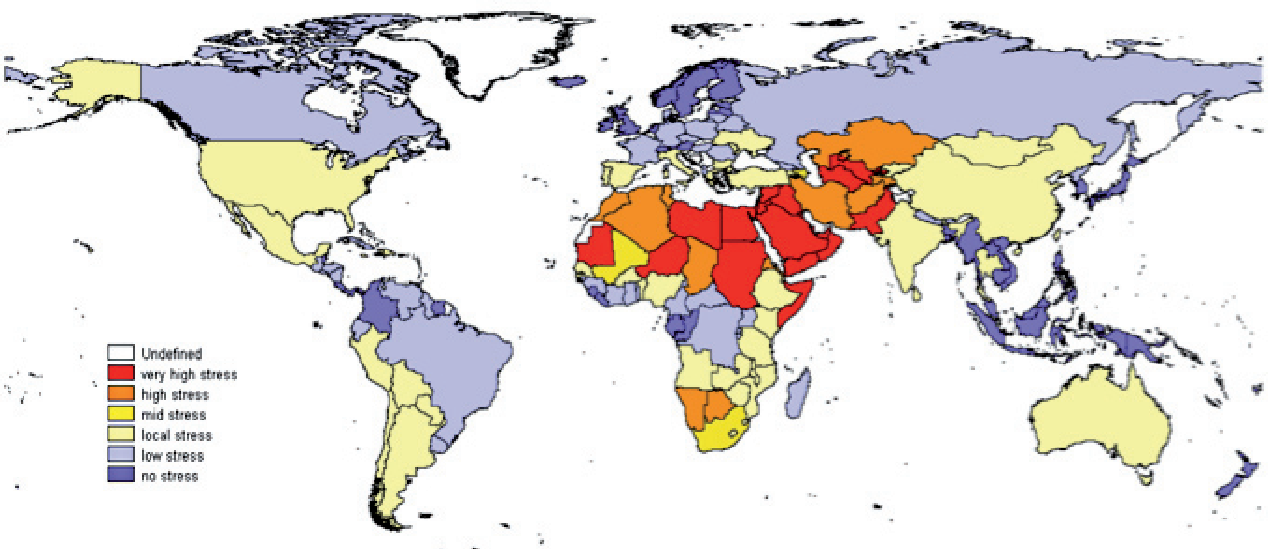


Source: AQUASTAT

In addition to, and because of, increasing freshwater scarcity, water resources are being degraded, ecosystems are being lost at alarming rates, and climate change is expected to have the most negative impacts in areas that are already struggling.

On the other hand, the world has the water resources required to supply the world's population now and in the future, since more than 70 percent of the Earth's surface area is water. The economic feasibility of using resources of varying quality is the problem, but there is reason to believe that despite regions of serious concern and despite the increasing scarcity of water, water issues can be solved through optimal management,

FIGURE 18: GLOBAL DISTRIBUTION OF WATER SCARCITY FOR AGRICULTURE



Source: GAEZ 2009 and AQUASTAT; data compiled by the authors.

cooperation, and trade. Currently, much of Africa is achieving 20 percent of agricultural potential that can be achieved without adding additional water. Relatively simple soil–water management practices and water-harvesting techniques can improve calculated potential yields by an additional 80 percent, while decreasing the variability of yields and frequency of failure years (Fischer *et al.*, 2009).

New crop cultivars are constantly being developed to increase the water productivity of plants and enable them to handle more saline water. Irrigation techniques and technology are evolving to apply water only during crop growth phases when it is necessary, eliminating excessive evaporation. Water-saving technology is available and being implemented in other economic sectors, increasing the economic water productivity. Gains can be made quickly by improving institutions such as agricultural extension services to educate and disseminate knowledge, technology, and resources. In dry coastal areas, desalination has become a viable option as the cost has declined to that of developing other sources of supply in the driest areas.

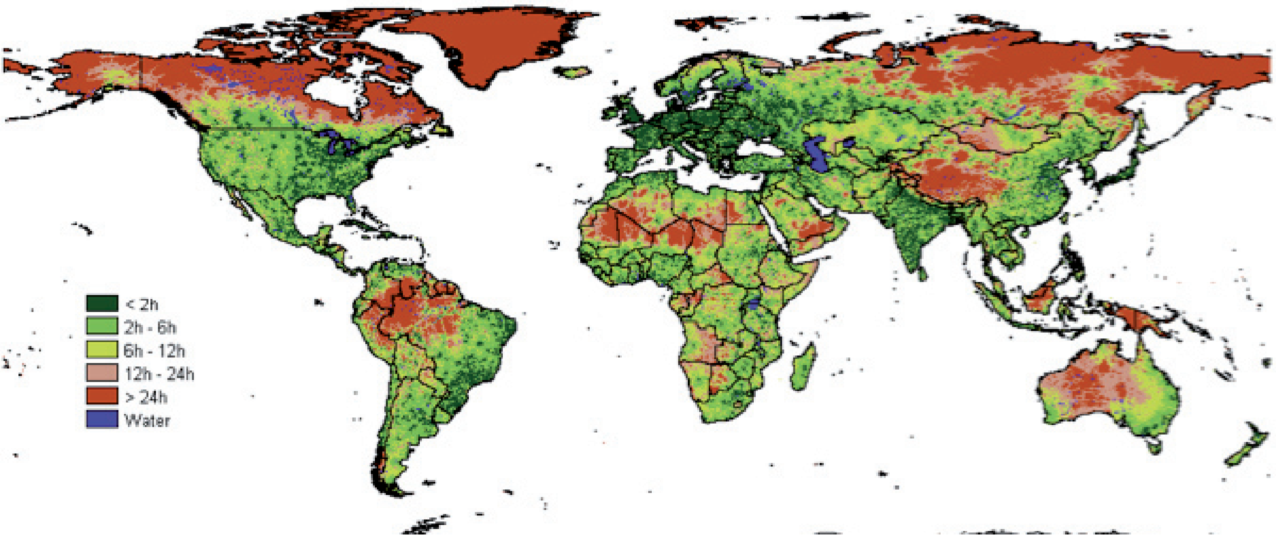
Constraints to land accessibility

A data set of 'Travel time to major cities' (Nelson, 2008) was used to quantify accessibility of land resources. Accessibility is defined as the travel time to the nearest city of 50 000 or more people in 2000 using land (road/off road) or water (navigable river, lake and ocean) based travel (Figure 19).

Table 11 shows accessibility of current cultivated land in terms of four broad classes. According to the spatial analysis, about half the cultivated land in developed countries is accessible within 2 hours. The most accessible land, 85 percent, is found for farmland in Western Europe. About one-third of less developed countries are within 2 hours travel time of accessible cultivated land. Accessibility is lowest in sub-Saharan Africa, notably in Central and Eastern Africa where only 7 to 13 percent fall into the accessible category. Only one-fifth of the African continent's 244 million ha of cultivated land is within 2 hours travel time and one-quarter is over 6 hours.

Table 12 and 13 show the distribution of assessed prime or good quality land for cultivation in respec-

FIGURE 19: TRAVEL TIME TO NEAREST MARKET (IN HOURS)



Source: Nelson (2008)

tively grassland/woodland and forestland ecosystems. While significant extents of such areas appear to exist, it is apparent that accessibility for commercially viable agricultural use would require major investment in infrastructure for much of these resources. For example, of current global grassland/woodland ecosystems with prime and good land quality, equivalent to 251 million ha, about one-fifth is accessibly within 2 hours travel time.

3. Opportunities and risks

3.1 Land resources; needs for food and feed towards 2050

Improving the use and access to the world's land, water and ecosystems is critically important. Each affects demand for the others and use of all affects climate and biodiversity. Available long-term outlooks assume that increased agricultural productivity per unit area will contribute on the order of 90 percent of the required doubling of production in developing countries to 2050. In the context of climate change, an enormous effort is required to achieve this growth of nearly 1.4 percent per year, because of regional land and water scarcities, growing competition from non-food uses and increasing environmental impacts.

Currently, 15 percent of the global population is at risk of hunger. Over the next 40 years food and water demand in the developing world will more than double. How does this relate to areas with expected high population growth and limited suitable land resources available for conversion to agricultural land?

For an estimated population of about 9 billion people in 2050 agricultural production has to increase over 2000 levels by 70 percent globally and 100 percent in developing countries, i.e. by more than a billion tonnes of cereal grains and 200 million tonnes livestock products. About 45 percent of the cereal demand increase is for direct food consumption, and an estimated 40 percent for livestock feeding and the remainder for other use including industrial, seeds and waste (Fischer 2009).

TABLE 11: ACCESSIBILITY OF CURRENT CULTIVATED LAND (TRAVEL TIME TO NEAREST MARKET; HOURS)					
	Current Cultivated land	Area by accessibility class (%)			
	Million ha	< 2 hours	2–6 hours	6–12 hours	>12 hours
Northern America	230	43	50	5	3
Eastern Europe & Russia	205	53	43	3	1
Northern Europe	20	68	30	2	0
Southern Europe	44	64	34	2	0
Western Europe	35	85	14	0	0
Caribbean	7	68	30	2	0
Central America	36	41	47	9	3
South America	129	32	53	11	4
Australia & New Zealand	51	16	67	14	3
Melanesia	1	5	21	19	55
Eastern Africa	83	13	53	24	10
Central Africa	38	7	46	34	13
Northern Africa	19	62	34	3	0
Southern Africa	18	28	54	14	5
Western Africa	86	19	64	16	1
Western Asia	40	44	51	5	0
Southeastern Asia	97	31	43	15	11
Southern Asia	229	53	40	5	1
Eastern Asia	151	41	47	10	2
Central Asia	41	20	50	29	1
More developed	**590**	**49**	**44**	**5**	**2**
Less developed	**970**	**35**	**48**	**13**	**4**
World total	**1 559**	**41**	**47**	**10**	**3**

Source: GAEZ 2009 using Nelson (2008)

In developing countries output must be doubled, implying an increase of almost 1.4 percent per year, which may seem little but means an enormous effort for farmers, agricultural researchers, extension workers, irrigation development, the fertilizer industry and infrastructure for input transport and market accessibility. Note that in the more developed countries historical increases over the last 50 years have been on average around 2 percent per year. Much of the concern about feeding the world in 2050 relates to the slowing of yield growth in major cereals over the past three decades (World Bank, 2007). In the group of least developed countries cereal yields increased on average by only 1 percent annually (FAOSTAT, accessed online in June 2010). The average annual growth of cereal yields was even lower for the group of land-locked developing countries. It is therefore uncertain whether an average annual growth in output of 1.4 percent per unit of land can be achieved and sustained over a period of 50 years.

Projected global use of cultivated land in IIASA's baseline scenario of the world food system (Fischer, 2009) increases by about 118 million ha from 2000 to 2030. While aggregate arable land use in developed countries

TABLE 12: ACCESSIBILITY OF PRIME AND GOOD UNPROTECTED LAND IN GRASSLAND/WOODLAND ECOSYSTEMS					
	Prime and good grass/wood land	Area by accessibility class (%)			
	Million ha	< 2 hours	2–6 hours	6–12 hours	>12 hours
Northern America	137	23	59	14	4
Eastern Europe & Russia	104	40	46	9	5
Northern Europe	8	69	31	0	0
Southern Europe	6	58	40	2	0
Western Europe	12	82	18	0	0
Caribbean	4	63	31	6	0
Central America	26	31	54	12	2
South America	311	23	51	16	10
Australia & New Zealand	72	7	29	28	36
Melanesia	5	1	6	8	85
Eastern Africa	209	9	50	27	14
Central Africa	136	3	33	34	30
Northern Africa	11	50	46	4	0
Southern Africa	39	14	49	21	16
Western Africa	67	13	65	21	2
Western Asia	13	45	53	2	0
Southeastern Asia	29	12	32	22	34
Southern Asia	15	36	52	10	2
Eastern Asia	61	15	46	30	9
Central Asia	53	10	57	31	2
More developed	**339**	**29**	**46**	**14**	**11**
Less developed	**980**	**16**	**48**	**23**	**13**
World total	**1 319**	**19**	**48**	**21**	**13**

Source: GAEZ 2009 using Nelson (2008)

remains fairly stable, decreasing in Europe and Japan and increasing somewhat in Northern America and Australia, all of the net increases occur in developing countries. Africa and South America together account for 85 percent of the expansion of cultivated land. To meet the 2050 food requirements some land conversion will still be required. For the productivity growth and demand assumptions in the IIASA baseline scenario this would equate to additional cultivated land of 165 million ha between 2000 and 2050 (Fischer, 2009).

Quality of cultivated land and possibilities for expansion of the current cultivated land vary widely geographically. The per capita availability of cultivated land varies from less than 0.1 ha in East Asia to more than 2 ha in Australia. Some regions hold abundant unprotected land resources of high quality such as in Eastern Europe, North and South America and Eastern and Central Africa. However, in Africa only a relatively small fraction of this land is easily accessible. Other regions, including some of the Sahelian countries, which will be experiencing the largest population growth, have relatively poor quality cultivated land and are lacking possibilities for cultivated land expansion and are void of renewable water resources. Finally, the possibility of potential expansion onto cultivated land or unprotected grassland/woodland

TABLE 13: ACCESSIBILITY OF UNPROTECTED PRIME AND GOOD LAND IN FORESTLAND ECOSYSTEMS

	Prime and good forest land	Area by accessibility class (%)			
	Million ha	< 2 hours	2–6 hours	6–12 hours	>12 hours
Northern America	214	32	47	14	6
Eastern Europe & Russia	206	23	48	18	11
Northern Europe	6	61	39	1	0
Southern Europe	5	41	52	6	0
Western Europe	8	74	25	1	0
Caribbean	2	57	32	10	0
Central America	26	26	49	20	6
South America	440	7	20	16	56
Australia & New Zealand	35	11	39	25	24
Melanesia	13	0	3	8	89
Eastern Africa	71	8	47	30	15
Central Africa	215	2	26	37	35
Northern Africa	2	39	52	8	1
Southern Africa	6	12	52	24	11
Western Africa	23	13	60	23	4
Western Asia	2	37	58	4	0
Southeastern Asia	57	6	25	23	45
Southern Asia	21	33	56	10	1
Eastern Asia	45	16	44	27	14
Central Asia	3	15	60	23	2
More developed	**480**	**28**	**47**	**16**	**9**
Less developed	**922**	**7**	**28**	**23**	**41**
World total	**1 402**	**14**	**34**	**21**	**30**

Source: GAEZ 2009 using Nelson (2008)

ecosystems is limited in most Asian countries, the exception being Central Asia.

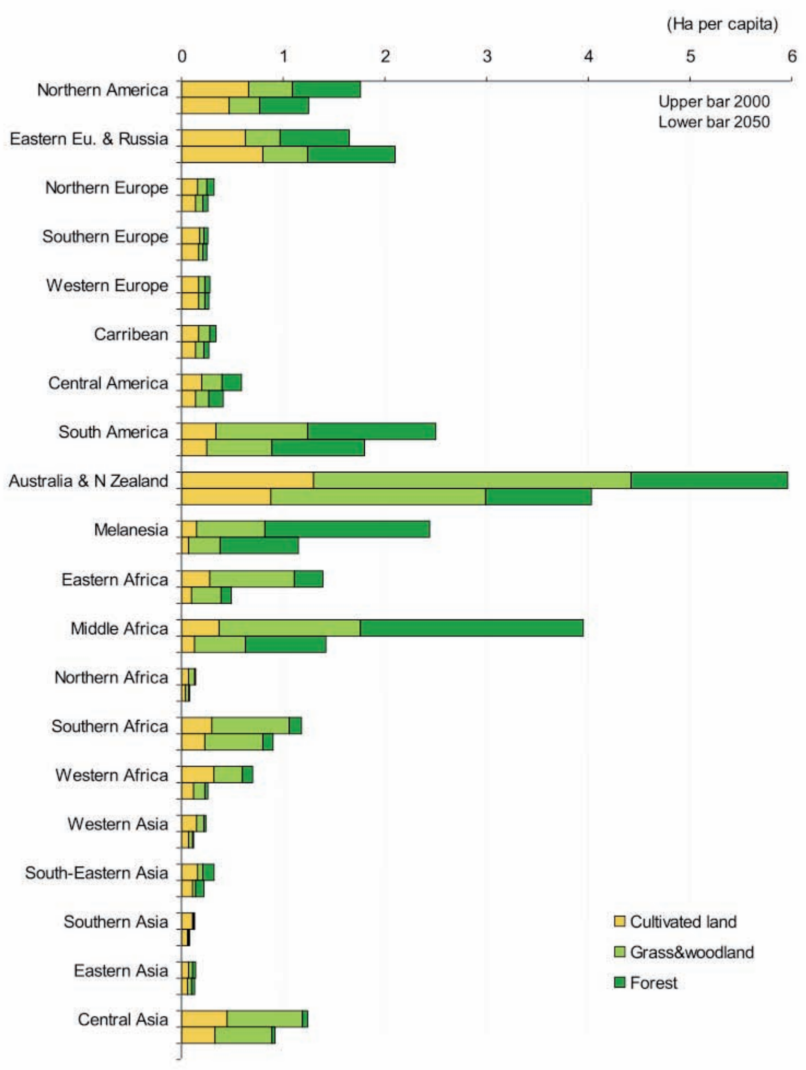
Because of these local differences, location-specific analysis on availability and quality of land resources is required. "Agriculture is an intensely local activity. Crop and livestock productivity, market access, and the effects of climate are all location-specific. Yet national and global efforts to collect and disseminate data on the spatial nature of agriculture, especially over time, are poorly developed." (*Agriculture and climate change: an agenda for negotiation in Copenhagen*, IFPRI, May 2009).

Based on analysis using the global agro-ecological zones (GAEZ) modelling framework and databases, Figure 20 shows the availability of land in different regions on a per capita basis for both 2000 populations and projected populations in 2050 (United Nations, 2009). It is striking to realize that prime and good resources for agriculture on a per capita basis are plentiful in only a few regions, foremost Australia, South America, North America, and Eastern Europe and Russia. The diagram also indicates substantial resources are available for development in Eastern and Central Africa; although these include a large fraction of good land in current forestland ecosystems.

There is little to very little land per capita available in Northern Africa and Asia and these countries will have to achieve their utmost to overcome resource scarcities with technological improvements and gains in efficiency achieved by way of improved management of land and water resources. Under such conditions the further decline in per capita availability caused by population growth will likely exacerbate development challenges in these countries.

A substantial decline of per capita resources available in 2050 is apparent for regions in sub-Saharan Africa where population growth is largest. By implication, unless these countries are able to successfully improve the performance of their agricultural systems, a currently seemingly abundant situation, as far as land availability is concerned, could become a serious development constraint.

FIGURE 20: **PER CAPITA AVAILABILITY OF CULTIVATED LAND AND PRIME OR GOOD LAND FOR CROP PRODUCTION IN CURRENT GRASSLAND/WOODLAND AND FORESTLAND ECOSYSTEMS**



Source: GAEZ, 2009; data compilation by authors.

3.2 Competition with other uses

Urbanization

Currently urbanized areas and areas used for rural settlements and infrastructure occupy an estimated 150 million ha or 1.1 percent of the global land mass (excluding Antarctica). The expansion of urban areas and land required for infrastructure and other non-agricultural purposes is expected to at least keep pace with population growth. As has happened historically, urbanization and expansion of infrastructure will disproportionately affect availability of prime quality, and easily accessible cultivated land concentrated near current and expanding urban areas.

Projections, using the IIASA world food system model (Fischer, 2009; Fischer *et al.*, 2009), indicate that conversion of land for residential, industrial and infrastructure use during the period 2000 to 2050 are significant, respectively estimated at 54 million ha for the period 2000 to 2030 and 27 million ha for 2030 to 2050. More than 90 percent of the additional urban/built-up land is required in developing countries.

Fodder production versus food production

In comparison, about 5 to 10 times more cultivated land is required for livestock products relative to food crops in terms of food energy content. Further expansion of livestock production in response to increasing demand, in particular in rapidly developing large economies in Asia, will enhance competition for current cultivated land or cause land conversion. According to available FAO data, the harvested area of fodder crops in 2000 amounted to 170 million ha, i.e. more than 12 percent of total harvested area.

In the simulations of the world food system with IIASA's global food system model (Fischer, 2009; Fischer *et al.*, 2009), cereal production increases by about 60 percent by 2050. In comparison, the simulated increases are 65 percent for ruminant-based livestock production and 80 percent for the commodity group of poultry meat, eggs and pork. The simulations indicate that crop and land demand for feeding animals will continue at a rapid pace. As a result of better output-input ratios for poultry and pigs, the gradual shift in composition between ruminants and non-ruminant livestock will help improve feeding efficiencies over and above technological improvements that are possible for each individual livestock category.

A global account of the balance of the land currently classified as grassland and woodland that may be used for feed and for ligno-cellulosic biofuel feedstock production is shown in Figure 21. Excluding all current cultivated land, forests, built-up land, water and non-vegetated land (desert, rocks, etc.) from a total global land area of 13.2 billion ha (excluding Antarctica and Greenland) resulted in 4.6 billion ha remaining land area (about 35 percent of total). Excluding unproductive, very low productive (e.g. tundra, arid land) or steeply sloped land as well as the protected areas from these areas, a remaining area of 1.75 billion ha (Fischer *et al.*, 2009) was estimated, comprised of grassland and woodland. Part of these resources might become available for bio-energy feedstock production (see pie chart on the right in Figure 21). Over two-thirds of this grassland and woodland is located in developing countries, foremost in Africa and South America. These estimates are to be understood as indicative and are subject to the limitations and accuracy of global land cover, soil and terrain data.

Currently, an important use of these land resources is for grazing livestock. Using available United Nations FAOSTAT data on feed use of crops and processed crop products (e.g. oilseed cakes and meals), production of fodder crops, national livestock numbers and livestock production, we estimated the feed energy provided by these recorded sources in each country to determine the energy gap to be filled by grassland and pastures.

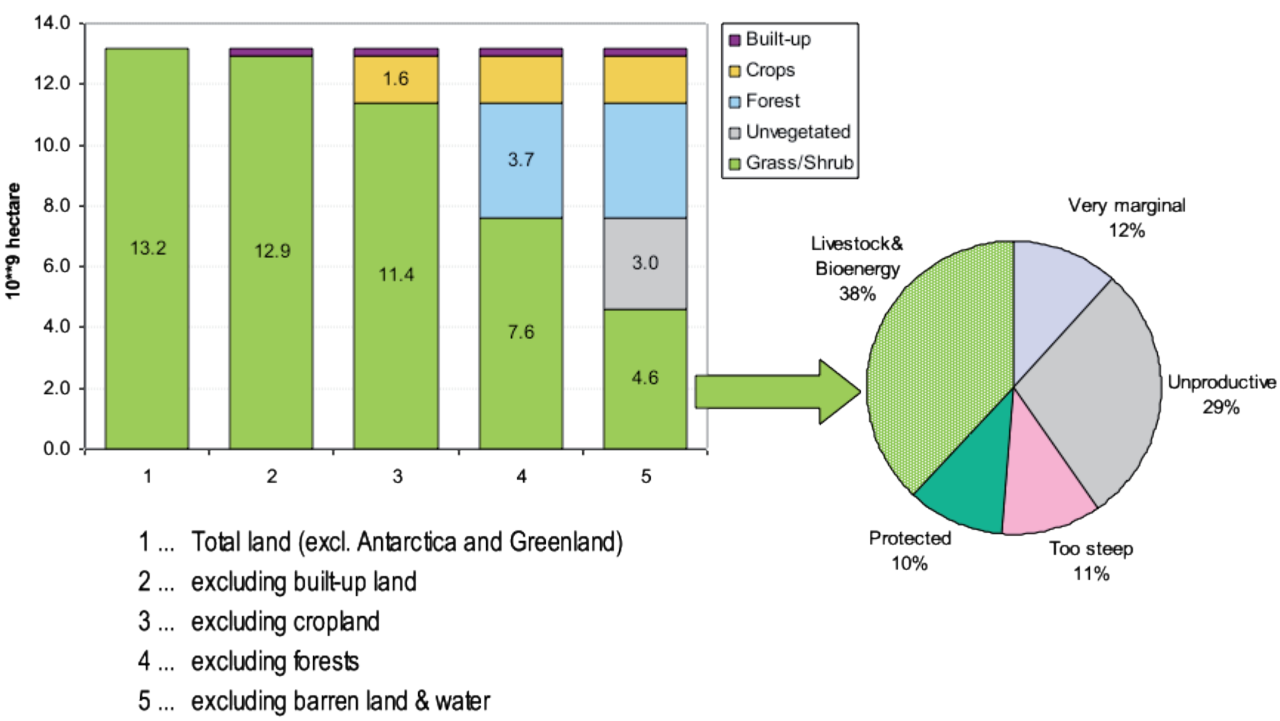
The results of detailed livestock feed energy balances suggest that in 2000 about 55–60 percent of the above-ground grassland biomass (excluding biomass of protected, too steep, very marginal and unproductive land) was required to feed animals. This share is about 40 percent in developed countries. In developing countries this amounts to an average of 65 percent. Values for Asian regions are greater than 80 percent and about 50 percent in sub-Saharan Africa.

Besides demand for livestock feeding and potential bio-energy production, it should be noted that grassland and woodland ecosystems may have other social or environmental functions, such as for a feed source for wildlife or resource base for indigenous people. Estimates are subject to uncertainty regarding grass and pasture yields, which owing to scarcity of measured data was estimated in model simulations using the GAEZ 2009 model.

Biofuels

A shift away from current economies based primarily on fossil petrochemicals towards bio-based economies, relying mostly on renewable energy sources, may be inevitable in the mid-term. It is widely agreed that there is an urgent need for better understanding and management of competing uses of land, water and ecosystem services, including (i) robust expansion of food and energy production, (ii) sustaining regulating ecosystem functions (cleaning, buffering, climate regulation), (iii) protecting and preserving global gene pools, and (iv) enhancing terrestrial carbon pools. While many potential areas are already being exploited for agricultural production and forestry or contain a large portion of terrestrial carbon and global gene pools, many areas of so-called marginal and/or degraded land. Meeting growing population demands for food and energy will imply the need for greater reliability and better management of these areas.

FIGURE 21: BALANCE OF LAND CLASSIFIED AS UNPROTECTED GRASSLAND AND WOODLAND THAT CAN POTENTIALLY BE USED FOR RAINFED FODDER AND BIOFUEL FEEDSTOCK PRODUCTION



Source: Fischer et al. (2009).

In 2007 an estimated 1.6 percent of the global cultivated land or 25.1 million ha, was devoted to the production of biofuel feedstocks, mainly sugarcane, maize, cassava, oil palm, rape and soybean (FAO, 2008). According to projections based on targets set by individual countries (Fischer *et al.,* 2009), cultivated land used for first generation biofuel feedstocks may increase from current 25 million ha to between 45 and 70 million ha by 2030 or between 3 percent and 4.5 percent of current cultivated land. There is no projection beyond 2030 for substantial further expansion of first generation biofuel feedstocks grown on cultivated land. More efficient second generation ligno-cellulosic feedstocks are expected to dominate (IEA, 2009). These feedstocks do not necessarily rely on cultivated land but could be grown sustainably on non-cultivated land.

Potential future land conversions

The land suitability analysis shows that 80 percent of the current 1.6 B ha cultivated land is located on the world's best land resources (prime and good land). In addition, substantial extents of unprotected forests and grassland/woodland ecosystems were assessed as prime or good land for rainfed crop production.

Converting forests to cultivated land implies substantial risks of adverse greenhouse gas impacts and loss of biodiversity. This is recognized by the United Nations in the efforts to implement mechanisms for reducing emissions from deforestation and degradation (REDD). Especially tropical forests hold the world's richest areas of high biodiversity. Some 675 million ha forests of prime and good land for rainfed crop production are accessible in less than 6 hours travel time; about half of it is located in less developed countries.

As discussed in the section Land resources needs for food and feed towards 2050. Cultivated land may well expand by at least 150 million ha by 2050 (Fischer, 2009) to satisfy the food and feed demand of a growing and more affluent population. If forests are safeguarded for reasons of climate and biodiversity, the world's grassland/woodland ecosystems will have to provide all the land resources needed for future cultivated land expansion.

A total of 1.3 billion ha of grassland/woodland ecosystems are of prime or good quality for rainfed crop production. Of this prime and good quality land about two-thirds requires less than 6 hours travel time to access the nearest market. However, there is a large regional disparity in land availability, with nearly half of the easily accessible, unprotected and good quality grass/woodland ecosystems being located in South America and Eastern and Central Africa.

As in the past, urbanization and infrastructure development is expected to occur largely on accessible land of prime or good quality. An additional 100 million ha of land is estimated to be required for residential, industrial and infrastructure purposes until 2050, more than 90 percent of it in less developed countries.

To summarize, prime and good quality land of current grass/woodland ecosystems could provide significant land resources for cultivated land expansion to satisfy future food and feed demand. However there are very large regional differences in potentials for cultivated land expansion.

The use of modern bio-energy is expected to increase in the future in an effort to reduce fossil fuel dependency in energy demand. Grassland/woodland ecosystems could be a considerable source of land resources for cultivating biomass. In the short term growth of certain species on current grassland/woodlands could provide additional greenhouse gas sinks.

3.3 Land rush

The recent surge in food and fuel prices has prompted investors to rush into biofuels and has driven countries with high dependence on food imports to seek assured food supplies through agricultural investment in other countries. There is agreement on the potential of such investment in agriculture as a catalyst for access to technology, skills, capital and employment. However, such investment carries considerable risks, including the use of good agricultural land resources for other purposes than food production for local populations and may therefore increase expansion of cultivated land into available grassland, woodland and forest ecosystems In countries where available land balances are already tight, in proportion to what is required for a growing population, this may cause increasing dependence on food imports (and aid) and may further increase risks of food insecurity and undernourishment.

During the last few years, major food importing countries, for example, the Gulf Cooperation Council Countries, China, India, South Africa and South Korea have been buying and leasing farmland. The issue is of concern as often the investor-targeted countries are food insecure, especially in sub-Saharan Africa. Here the danger is that the food insecurity of the wealthy investing country will end up being exported to the food insecure host country. In addition, land rights and policy frameworks are often only poorly developed, which has recently created several examples where investments have threatened local resources and marginalized local producers without creating a win-win situation as seems theoretically possible through such investments (Cotula, 2010).

In many of the above-mentioned cases Government finance, often channeled through publicly funded companies, has been the foremost investment. There has been an increase in the number of recently established large investment equity funds in Europe and the United States that are scrambling to invest in farmland.

While multilateral institutions are developing principles of international agricultural investments to ensure social, environmental and economic sustainability, they are also establishing a code of conduct and legal instruments. However, the most critical need is that for credible and scientific information that quantifies the sustainable agro-ecological potential of important food security crops on current cultivated and any additional land. This information should include the costs of inputs, transport, etc. to facilitate estimates of net revenue, which in turn would enable estimation of fair rental or value of land for sale.

Agricultural investment priority should be given to the current cultivated land areas, as this approach has good potential for a win–win partnership for the investor as well as the local community and would help avoid adverse environmental impacts from land conversions such as deforestation. Although contract farming has been demonstrated as a means to generate cash income for farmers in developing countries, this mainly works in areas with well-functioning markets. In many countries in sub-Saharan Africa, agricultural markets and distribution channels are lacking. This inhibits the timely purchase of inputs for the farmers' local production, which in turn would result in food-supply shortfalls in the domestic market, thereby driving up food prices.

A shared-benefits model that would best meet the needs of the investor and the local community in currently cultivated land areas, where the yield gaps are large, could provide the basis for responsible and sustainable agricultural development partnerships.

3.4 Climate change impacts on land resources

Global warming can potentially boost food production in parts of the world, e.g. Canada and Russia and limit it in others, e.g. Southern Africa through its effects on climate, soil and water resources.

Climate change and variability affect thermal and hydrological regimes. In turn, this influences the structure and functionality of ecosystems and human livelihoods.

Climate change scenarios were developed to estimate their effects on crop yields, the extent of land having cultivation potential, and the number and type of crop combinations that can be cultivated. A climate change scenario is defined as a physically consistent set of changes in meteorological variables, based on generally accepted projections of $CO_{2,}$ and other trace gas, levels.

To provide the spatial assessment of the agronomic impact of climate change on crop yields using the FAO/IIASA AEZ family of crop models, climate change parameters are computed at each grid point of the resource inventory by comparing the GCM monthly-mean prediction for the given decade to those corresponding to the GCM 'baseline' climate of 1960–1990. Such changes, i.e. differences in temperature; ratios for precipitation, etc. are then applied to the observed climate of 1960–1990 (New *et al*., 2002), used in AEZ, to generate future climate data; a plausible range of outcomes in terms of likely future temperatures, rainfall, incoming sun light, etc. for the nominal years 2025 (termed the 2020s), 2055 (i.e. the 2050s) and 2085 (termed the 2080s) (Fischer *et al*., 2002b; Fischer *et al*., 2005).

Table 14 illustrates results from the UK HadCM3 model for the 2050s for an emission pathway of the IPCC SRES A2 scenario. The chosen climate projection is from the United Kingdom Hadley Centre (GCM results from the UK HadCM3 model for the 2050s for an emission pathway of the IPCC SRES A2 scenario (Nakicenovic *et al*., 2000). An increase is shown of the percentage of current cultivated land falling into arid (LGP 0-60 days) and semi-arid (LGP 60-120 days) climatic zones in Africa[2], a change that is most pronounced and severe in the subregions of northern and southern Africa. In Asia, this indicator shows a modest improvement in all subregions owing to climate change.

Results for land currently with grassland/woodland ecosystem and with forests (see Table 15 and Table 16) highlight improvements in the respective distribution over broad LGP zones in high latitude developed regions and in Asia. Results show deterioration for all subregions in Africa as well as in Central and South America. As LGP is highly correlated with net primary production, the results suggest an overall negative impact of climate change on land productivity in these regions.

Calculations compiled in Table 17 and shown in Figure 22 look at all cereal types represented in GAEZ 2009 (some 118 cereal LUTs covering wheat, rice, maize, barley, sorghum, millet, rye, oats and buckwheat). The computations separately determine, for current and future climate conditions, the most productive cereal type in each grid-cell of the spatial resource inventory to define overall cereal productivity, i.e. assuming a high level of crop adaptation. Results indicate a somewhat increasing global rainfed production potential by 2050, provided CO_2 fertilization is effective and full adaptation of crop types is achieved. However, climate change may result in reduced global production by 5 percent if these two aspects are not achieved. In the latter case,

[2] LGP denotes the number of days in a year when both temperature and soil moisture conditions are conducive to crop growth. As low temperature is not a limiting factor in most of the tropics and subtropics, LGP impacts in Africa are mostly influenced by changing precipitation patterns/amounts and increasing evaporative demand of crops owing to warming.

TABLE 14: **DISTRIBUTION OF CURRENT CULTIVATED LAND BY LGP ZONE, CURRENT AND FUTURE CLIMATE**

	Cultivated land	Percentage of total by LGP zone, Reference climate 1961-1990					Percentage of total by LGP zone, Hadley Centre A2, 2050s				
	Million ha	0-60	60-120	120-180	180-270	> 270	0-60	60-120	120-180	180-270	> 270
Northern America	230	2	30	17	37	13	1	35	21	31	12
Eastern Europe	205	0	39	36	25	0	0	32	53	15	0
Northern Europe	20	0	0	27	65	8	0	0	22	59	19
Southern Europe	44	0	1	22	65	12	0	2	16	73	9
Western Europe	35	0	0	7	78	15	0	0	6	71	23
Caribbean	7	0	0	2	69	29	0	4	35	54	8
Central America	36	3	5	27	40	24	5	7	28	44	16
South America	129	1	3	10	44	43	1	6	15	47	31
Australia & New Zealand	51	2	30	33	26	8	3	32	36	21	7
Melanesia	1	0	0	0	13	87	0	0	0	14	86
Eastern Africa	83	2	17	31	36	14	3	19	37	29	13
Central Africa	38	0	19	21	28	32	0	22	18	30	30
Northern Africa	19	23	10	24	42	0	27	20	20	33	0
Southern Africa	18	3	52	29	14	3	7	59	24	8	2
Western Africa	86	1	24	33	28	13	3	25	30	27	15
Western Asia	40	13	34	36	17	0	13	25	42	19	0
Southeastern Asia	97	0	0	1	41	58	0	0	2	45	54
Southern Asia	229	7	22	43	25	4	5	22	47	22	4
Eastern Asia	151	3	5	25	24	43	3	4	17	30	46
Central Asia	41	6	83	7	3	1	6	75	13	6	1
More developed	**590**	**1**	**28**	**25**	**38**	**8**	**1**	**28**	**32**	**31**	**9**
Less developed	**970**	**4**	**17**	**25**	**30**	**24**	**4**	**17**	**27**	**30**	**22**
World total	**1 559**	**3**	**21**	**25**	**33**	**18**	**3**	**21**	**29**	**31**	**17**

Source: GAEZ 2009 simulations, May 2009.

most regions would experience a reduction. At the regional level, results for Southern Africa, North Africa and Central America show the largest negative climate change impacts on the potential for rainfed cereal production.

Looking at the global level, the research showed that on balance the positive and negative climate change effects combined would not have a large impact on food production in the period up to 2050, provided the carbon dioxide (CO_2) fertilization effect materializes in farmers' fields. The beneficial effect is expected to occur with increased concentrations of CO_2 in the atmosphere. While CO_2 contributes to climate change, it also enhances plant photosynthesis and the efficiency of water us. The broadly balanced global picture of the impact of climate change on food production until 2050 assumes agronomic adaptation by farmers. It does not account for changes in climate variability, which is expected to increase over the coming decades and may be an important destabilizing factor in the short to medium term. It also hides a far more worrying outlook beyond 2050. After the middle of the century, negative impacts of projected warming dominate and cause a

TABLE 15: DISTRIBUTION OF CURRENT GRASS/WOODLAND ECOSYSTEMS BY LGP ZONE, CURRENT AND FUTURE CLIMATE	Grass/wood land	Percentage of total by LGP zone, Reference climate 1961-1990					Percentage of total by LGP zone, Hadley Centre A2, 2050s				
	Million ha	0-60	60-120	120-180	180-270	> 270	0-60	60-120	120-180	180-270	> 270
Northern America	673	21	54	19	4	2	12	54	26	6	2
Eastern Europe	604	5	63	26	6	0	1	53	42	5	0
Northern Europe	61	0	34	29	28	10	0	6	53	25	16
Southern Europe	37	0	2	25	66	6	0	2	21	72	4
Western Europe	34	0	3	11	75	11	0	2	11	69	19
Caribbean	7	0	0	3	73	23	0	6	40	49	5
Central America	99	35	22	16	16	12	41	20	14	17	9
South America	657	7	13	12	34	34	7	17	16	36	24
Australia & New Zealand	510	64	20	11	3	2	68	19	8	2	2
Melanesia	15	0	0	0	12	88	0	0	0	12	88
Eastern Africa	478	13	18	29	34	6	13	20	36	26	5
Central Africa	229	3	12	23	35	27	3	20	18	32	26
Northern Africa	33	30	27	22	21	0	43	24	21	12	0
Southern Africa	176	45	41	9	4	0	59	31	7	2	0
Western Africa	202	19	23	25	26	7	21	23	23	26	7
Western Asia	56	13	43	33	11	0	13	34	40	13	0
Southeastern Asia	111	0	0	1	36	63	0	0	2	41	58
Southern Asia	118	32	39	19	9	1	25	40	23	10	2
Eastern Asia	386	16	37	20	10	17	6	33	29	13	18
Central Asia	125	10	81	6	2	0	8	79	10	3	0
More developed	1 923	26	45	19	8	2	23	41	27	8	2
Less developed	2 689	15	25	18	24	18	14	25	22	24	15
World total	4612	19	33	19	17	11	18	32	24	17	10

Source: GAEZ 2009 simulations, May 2009.

rapid decrease in the crop production potential in most regions and for the global aggregate by damaging arable land, water and biodiversity resources.

This impact will be of global significance on hunger if imposed on an already high level of undernourishment. In the socio-economic development scenario underlying FAO's projections of *How to feed the world in 2050* (Bruinsma, 2009; Fischer, 2009; FAO, 2006a), there is fairly solid economic growth and transition to stable or declining population levels after 2050, declining poverty and with it hunger; although negatively affected by climate change, is shown to be far less ubiquitous phenomenon than it is today.

Research indicates that both socio-economic development and climate change in this century will significantly impact irrigation water requirements (Fischer *et al.*, 2007). Simulation results suggest that globally the impacts of climate change on increasing irrigation water requirements could be nearly as large as the changes projected in response to socio-economic development alone. A projected growth of water withdrawals in the

TABLE 16: DISTRIBUTION OF CURRENT FORESTLAND BY LGP ZONE, CURRENT AND FUTURE CLIMATE

	Forest land	Percentage of total by LGP zone, Reference climate 1961-1990					Percentage of total by LGP zone, Hadley Centre A2, 2050s				
	Million ha	0-60	60-120	120-180	180-270	> 270	0-60	60-120	120-180	180-270	> 270
Northern America	609	3	24	41	20	12	2	19	39	28	12
Eastern Europe	850	0	31	61	8	0	0	17	74	9	0
Northern Europe	70	0	8	72	18	1	0	0	76	22	2
Southern Europe	43	0	2	24	59	14	0	2	21	64	13
Western Europe	32	0	1	12	78	9	0	1	12	73	14
Caribbean	5	0	0	2	55	42	0	3	28	56	13
Central America	89	6	8	31	30	25	7	9	31	33	20
South America	851	0	1	4	18	76	0	3	8	49	40
Australia & New Zealand	98	5	23	25	25	22	9	23	25	25	17
Melanesia	34	0	0	0	6	94	0	0	0	6	94
Eastern Africa	138	1	4	26	57	12	1	7	39	41	12
Central Africa	305	0	1	6	32	61	0	4	8	29	59
Northern Africa	5	2	10	23	65	0	5	17	19	59	0
Southern Africa	15	7	39	27	24	3	9	50	24	15	2
Western Africa	56	0	2	18	47	34	0	2	18	44	36
Western Asia	11	2	23	44	28	3	2	13	44	36	4
Southeastern Asia	210	0	0	0	27	73	0	0	1	31	69
Southern Asia	83	1	6	37	44	12	0	6	41	41	12
Eastern Asia	224	1	5	27	30	38	1	3	20	34	43
Central Asia	9	2	52	19	23	5	1	49	24	20	6
More developed	1 726	1	25	50	17	6	1	17	55	20	7
Less developed	2 009	1	3	11	27	58	1	4	14	40	42
World total	3 736	1	13	29	22	34	1	10	33	31	26

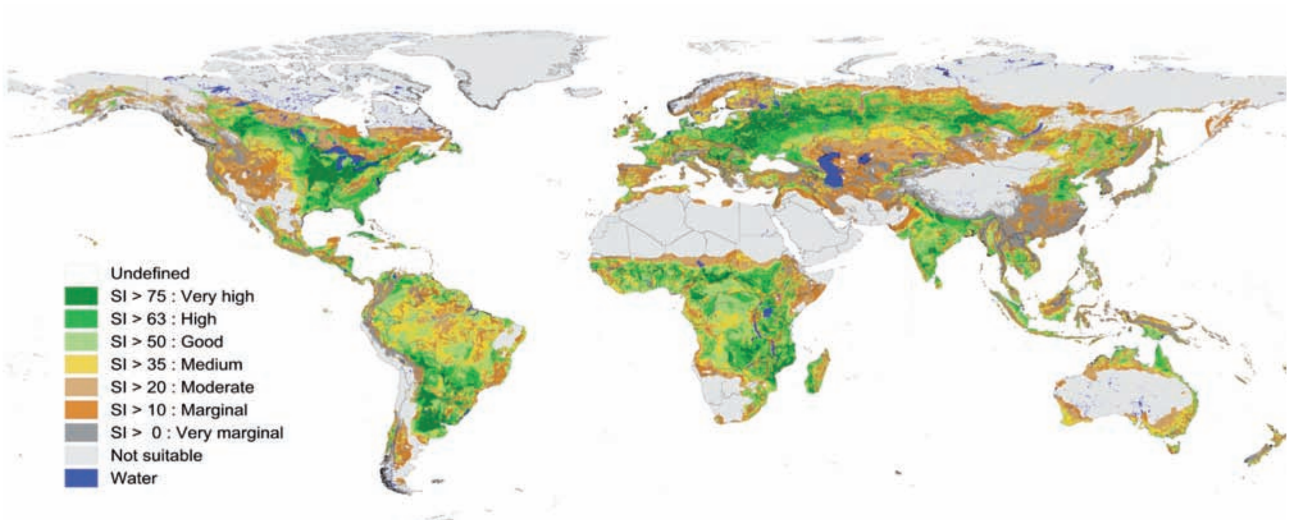
Source: GAEZ 2009 simulations, May 2009.

order of 25 percent due to socio-economic development as compared to an increase of about 20 percent in global irrigation water needs as a result of global warming (results assume technological progress in water use efficiency with time).

The results of the AEZ analysis suggest some main conclusions:

- While the global balance of crop production potential of the current cultivated land is not much affected by climate change in the next decades, there are a number of regions where climate change poses a significant threat for food production.
- The capacity to adapt to climate change impacts is strongly linked to future development paths. The socio-economic and, even more so, the technological characteristics of different development futures strongly affect the capability of societies to adapt to and mitigate climate change.
- Assumptions regarding yield increases because of increased atmospheric CO2 concentrations (the CO2

FIGURE 22: GLOBAL SUITABILITY FOR RAINFED CEREAL PRODUCTION (BASED ON WHEAT, BARLEY, RYE, RICE, MAIZE, SORGHUM, MILLET, AND BUCKWHEAT) FOR HADLEY A2 2050



Source: GAEZ 2009; simulations May 2009.

fertilization effect) play an important role in scenario outcomes. When disregarding the CO2 fertilization effect, negative climate change impacts on crop yields and world food system indicators are already noticeable in the short term and are substantial in the medium and long-term.

- Scenario results confirm that, with and without CO2 fertilization, the impacts of projected climate change on crop yields and production could be severe in the second half of this century.

In the short-term, policy-makers need to strengthen farmers' adaptation capacity and must support strategies to cope with climate variability and extreme events, which may severely affect the welfare of the most vulnerable populations. In the long run, climate change, if not halted, will result in irreparable damage to arable land, water and biodiversity resources, with eventually serious consequences for food production and food security.

3.5 Opportunities through yield gap reduction of current rainfed cultivated land

The potential for intensification of agricultural production is dependent on various socio-economic factors including availability and affordability of technologies. Distance to markets and cost of transport are important determinants for the provision of inputs and for selling agricultural products. The potential impact of technological progress has been assessed by estimating location and agricultural activity specific yield and production gaps between actual achieved and potentially achievable yield and production. The analysis employs downscaled agricultural statistics for 23 major commodities and compares these with respective potentials. The actual production for 2000 and 2005 have been compared with potentials for traditional low input level farming and advanced farming, assuming that required agricultural inputs are available and that appropriate management is applied as appropriate for land conditions; this is referred to as mixed input level potentials.

TABLE 17: IMPACTS OF CLIMATE CHANGE ON THE PRODUCTION POTENTIAL OF RAINFED CEREALS IN CURRENT CULTIVATED LAND (PERCENTAGE CHANGES WITH RESPECT TO POTENTIAL UNDER CURRENT CLIMATE)

		Hadley A2, 2050s versus Reference Climate			
Region	Cultivated land	Without CO_2 fertilization; current crop types	Without CO_2 fertilization; adapted crop types	With CO_2 fertilization; current crop types	With CO_2 fertilization; adapted crop types
North America	230	-7	-6	-1	0
Europe	179	-4	-4	3	3
Russian Federation	126	3	3	9	9
Central America & Caribbean	43	-10	-6	-6	-2
South America	129	-8	-3	-4	1
Oceania & Polynesia	53	2	4	6	8
North Africa & West Asia	59	-8	-7	-2	-1
North Africa	19	-15	-13	-10	-8
West Asia	40	-4	-4	1	1
Sub-Saharan Africa	225	-7	-3	-3	1
Eastern Africa	83	-3	2	2	6
Central Africa	38	-7	-2	-3	3
Southern Africa	17	-32	-31	-29	-28
Western Africa	86	-7	-4	-3	1
Asia	519	-3	1	2	5
Southeast Asia	98	-5	-1	-1	4
South Asia	229	-6	-2	-2	2
East Asia & Japan	151	2	6	7	10
Central Asia	41	14	14	19	19
Developed	**591**	**-3**	**-3**	**2**	**3**
Developing	**972**	**-5**	**-2**	**-1**	**3**
World	**1 563**	**-5**	**-2**	**0**	**3**

Source: Fischer, 2009.

Results of the analysis show that at the global level the achieved crop yields are just over 50 percent of potentially achievable yields, assuming mixed levels of input and about 140 percent as compared to traditional low level input farming. Even on broad regional levels these gaps vary strongly. In particular, in sub-Saharan Africa yield gaps are large; as compared to mixed input potentials, the actually obtained yields are lower by a factor of 4, and sometimes even below potentials of traditional low-input farming (see Table 18). Figure 23 presents yield gap ratios as compared to potentials attainable with advanced farming (mixed inputs). In particular in Africa and Eastern Europe and the countries in Central Asia large yield gaps prevail. In Northern and Western Europe, as well as in Northern America, East Asia and Oceania yield gaps are smallest.

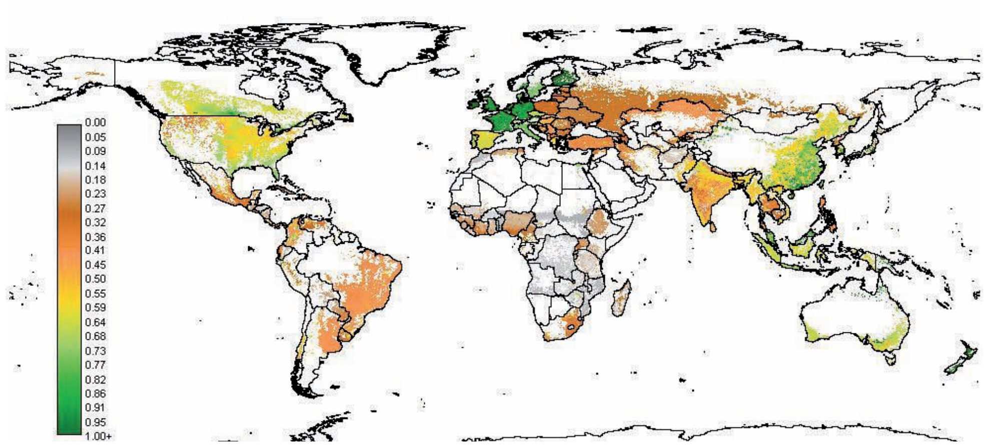
TABLE 18: ESTIMATED YIELD GAPS (PERCENTAGE OF POTENTIAL) FOR CEREALS, ROOTS AND TUBERS, PULSES, SUGAR CROPS, OIL CROPS AND VEGETABLES COMBINED

Region	Actual yields for 2000 and 2005 compared to potential yield (percentage) for advanced farming (mixed inputs) and traditional farming (low inputs)			
	2000		2005	
	Mixed	Low	Mixed	Low
Northern America	62	184	69	204
Eastern Europe & Russia	32	97	38	114
Northern Europe	85	319	91	343
Southern Europe	51	124	54	132
Western Europe	90	288	93	303
Caribbean	30	82	31	78
Central America	45	115	48	124
South America	46	142	48	154
Australia & New Zealand	71	158	60	132
Melanesia	46	146	46	148
Eastern Africa	19	66	19	66
Central Africa	23	83	23	82
Northern Africa	36	103	40	114
Southern Africa	37	99	41	108
Western Africa	25	86	28	94
Western Asia	49	108	53	119
Southeastern Asia	60	198	68	227
Southern Asia	44	118	45	120
Eastern Asia	84	177	89	181
Central Asia	31	79	35	88
More developed	**54**	**158**	**59**	**172**
Less developed	**50**	**136**	**53**	**143**
World total	**52**	**142**	**55**	**151**

Source: Data compilation by authors based on FAOSTAT and GAEZ 2009.

The yield gaps presented in Figure 23 are based on comparisons between cereals, roots and tubers, pulses, oil crops, sugar crops and vegetables. Yield calculations assume the harvested parts and its moisture content as used in FAOSTAT. The GAEZ (dry weight) potentials have been adjusted accordingly to allow comparison. A general conclusion from regional data suggests that across commodity groups yield gap ratios are similar; as shown for cereals in Figure 24 and Table 19.

FIGURE 23: YIELD GAP RATIOS COMPARING ACTUAL CROP PRODUCTION FOR 2000 WITH ACHIEVABLE POTENTIAL IN CURRENT CULTIVATED LAND WITH ADVANCED FARMING



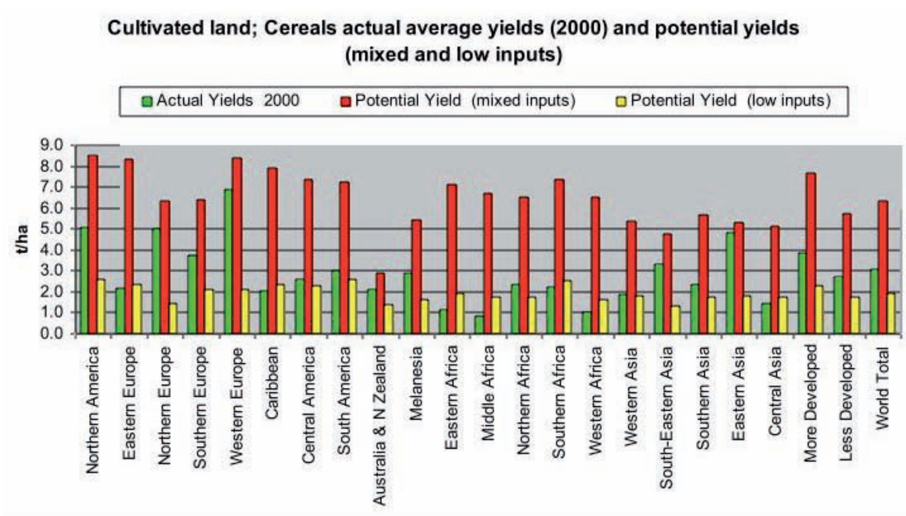
Source: GAEZ 2009 and data compilation by authors.

TABLE 19: ESTIMATED YIELD GAPS IN 2000 AND 2005 FOR CEREALS

Region	Actual yield		Potential yield		Actual yields compared to potential (%)			
	2000	2005	Mixed	Low	2000		2005	
	tonnes/ha	tonnes/ha	tonnes/ha	tonnes/ha	Mixed	Low	Mixed	Low
Northern America	5.1	5.7	8.5	2.6	60	194	67	218
Eastern Europe & Russia	2.2	2.5	8.3	2.4	26	93	31	108
Northern Europe	5.0	5.3	6.3	1.5	79	341	84	361
Southern Europe	3.7	4.0	6.4	2.1	58	177	63	191
Western Europe	6.9	7.1	8.4	2.1	82	326	84	334
Caribbean	2.1	2.0	7.9	2.4	26	87	26	86
Central America	2.6	2.9	7.4	2.3	36	113	39	124
South America	3.0	3.3	7.3	2.6	42	116	46	130
Australia & New Zealand	2.1	1.6	2.9	1.4	73	156	56	119
Melanesia	2.9	2.7	5.4	1.6	54	176	50	164
Eastern Africa	1.1	1.1	7.1	1.9	16	59	16	59
Central Africa	0.8	0.8	6.7	1.7	12	48	12	48
Northern Africa	2.3	2.8	6.5	1.7	36	135	42	155
Southern Africa	2.2	2.7	7.4	2.5	30	88	37	108
Western Africa	1.0	1.1	6.5	1.7	15	61	17	68
Western Asia	1.9	2.3	5.4	1.8	35	103	42	126
Southeastern Asia	3.3	3.7	4.8	1.3	69	248	77	277
Southern Asia	2.4	2.5	5.7	1.8	42	135	44	142
Eastern Asia	4.8	5.2	5.3	1.8	91	265	97	282
Central Asia	1.5	1.6	5.1	1.7	29	85	30	90
More developed	3.9	4.2	7.7	2.3	50	169	54	183
Less developed	2.7	2.9	5.7	1.8	48	155	51	164
World total	3.1	3.3	6.4	1.9	49	160	52	170

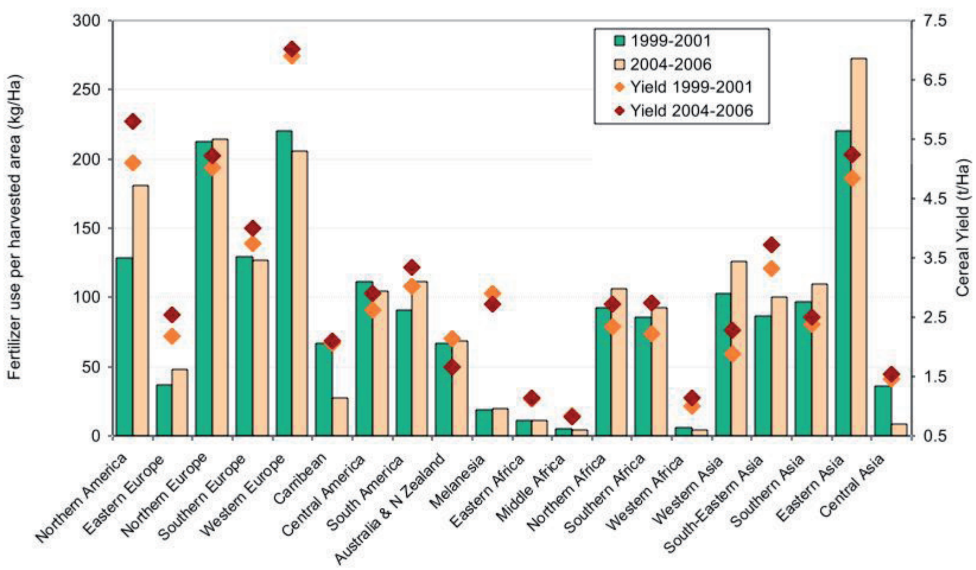
Source: Data compilation by authors based on FAOSTAT and GAEZ 2009.

FIGURE 24: ACTUAL YIELDS OF CEREALS ACHIEVED IN 2000 AND COMPARISON TO POTENTIAL YIELDS AT LOW AND HIGH INPUT LEVEL.



Source: Data compilation by authors based on FAOSTAT and GAEZ 2009.

TABLE 25: REGIONAL DIFFERENCES IN FERTILIZER USE AND CEREAL YIELDS



Source: Data compilation by authors based on FAOSTAT

Figure 25 shows average fertilizer application by region and indicates the reported average cereal yields of 2000 and 2005 (FAOSTAT, accessed July 2010). It is noticeable that actual average yields in the 20 main world regions shown clearly correlate with respective fertilizer consumption. It can be concluded that in sub-Saharan Africa, where crop yields are lowest and in those areas where soil nutrient retention capacity of soils is favorable, increased fertilizer use is likely to boost crop yield levels substantially. Creating an enabling and economically attractive environment for improved nutrient management and use therefore appears to be a prerequisite for effective yield gap reduction in these areas.

4. Regional land development constraints and needs

By 2050 the world will need to feed about 50 percent more people than in 2000. At the same time the world population will, on the whole, be wealthier and therefore will demand and be able to afford more agricultural products, particularly more meat. The key to ensuring sufficient food in 2050 is the sustainable intensification of agriculture, both in terms of yield increases and multiple uses of the land, to deliver the necessary increase in food production of some 70 percent. Increased investment and research to sustain such productivity growth is clearly essential.

A key message is that it should be possible to produce enough food in 2050 at a global level to feed a world population that has increased to more than nine billion. But this assumes that intensification (yield increases and multiple use of land) would account for about 90 percent of production increases. Considerable uncertainties are recognized, including those related to the impact of climate change and the demand for biofuels on global food supply.

To address food security, it is essential not simply to focus on supply issues, but also on the demand side, and the question of access of the world's poor and hungry to the food they need to live active and healthy lives. Furthermore, it would be insufficient and dangerous to focus only on the aggregate and to ignore disparities across and within regions.

Food, water, and health are recognized as fundamental human rights and yet today, a billion people are undernourished, over 1.2 billion have no access to safe water, and half the worlds population is at risk of infectious diseases. The tragic situation will be further exacerbated in the twenty-first century by global change, including climate change, ecological degradation, economic inequities and the momentum of demographic processes.

The year 2008 will be remembered as the defining moment when the reality of the interlinkages and interdependencies between food and energy were recognized. A number of factors, including the adoption of mandatory biofuels targets, the high volatility of crude oil prices, increasing demand for food imports from major developing countries, below-average harvests in some countries and market speculation, together with the low level of world food stocks, resulted in sudden increases in world food prices. This caused the domestic prices of staple foods in a number of countries to increase by over 50 percent in a matter of weeks. The poorest were, of course, the hardest hit.

Poverty and hunger eradication is a much more complex process, involving far greater risks and uncertainty, than was imagined in 2000 when the Millennium Development Goal (MDG) of halving, between 1990 and 2015, the proportion of people who suffer from hunger and debilitating poverty, seemed feasible. For a number of reasons, eradicating extreme poverty and hunger, numerically and ethically the first of the MDGs, is now, paradoxically, the least likely to be achieved.

4.1 Trends aggravating food insecurity

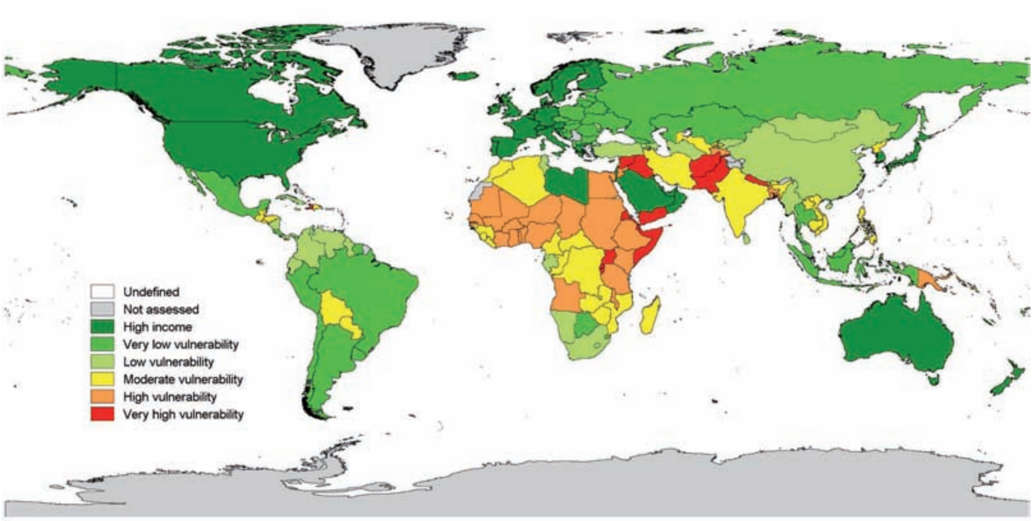
Demographic pressures: growing population numbers in developing countries stretch the food and water supply more thinly. The developing-country population is projected to increase by some 60 percent to about 8 billion by 2050, clearly indicating that there will be more mouths to feed, which is reflected in land-use changes. The amount of new land brought under cultivation over the last 30 years has been around 5 million ha annually. Some 1.6 billion ha of land are currently used for crop production, with about 1 billion under cultivation in developing countries. As people strive to get the most out of land already in production or exploit virgin territory to develop more agricultural land to grow food, the damage inflicted on the environment grows. Arable lands are lost to erosion, salinity, desertification and urban spread; forests disappear and biodiversity is lost. About 40 percent of the world's arable land is degraded to some degree and will be further impacted by climate change, expected extreme weather events and climate variability.

Climate change makes a serious situation worse: an already difficult food insecurity situation is being exacerbated by the overarching effects of climate change. This is caused by the atmospheric accumulation of greenhouse gas emissions, particularly carbon dioxide (CO_2). While current research confirms that crops would respond positively to elevated CO_2 in the absence of climate change, human activities — primarily the burning of fossil fuels and deforestation — are causing massive atmospheric concentrations of greenhouse gas emissions, leading to higher temperatures, altered precipitation patterns and increased frequency of extreme events, such as drought and floods. This combination of factors will likely depress agricultural yields and increase food production risks in many world regions in the future, particularly in many of the current food-insecure countries.

Water scarcity exacerbates food insecurity: compounding food insecurity is water scarcity in the locations that need it most. Note that water supply does not coincide with regional distribution of the world's population. Water-stressed and water-scarce countries are defined as those with less than 1 700 and 1 000 m^3, respectively, of available water per capita. Some 30 countries already face water shortages, and by 2050 this number could increase to over 50 countries; most in the developing world. As around 70 percent of the world's fresh water use goes to agriculture, even 90 percent in countries that rely extensively on irrigation, water scarcity is often a very serious obstacle to achieving food security.

Biofuels add to the competition for land and water: about 80 percent of current global carbon dioxide emissions originate from the burning of fossil fuels, making the development of cleaner fuels, the improvement of energy efficiency measures and adaptation of conservation practices vital. Several developed and developing countries have embraced the apparent win–win opportunity of fostering the development of biofuels to respond to the threats of climate change, reduce oil dependency, and contribute to agriculture and rural development. The reality, however, is complex, as biofuel development has social, environmental and economic impacts well beyond the national and regional setting of domestic biofuels targets. When important food and animal feed crops, including maize, wheat and soybean, are redirected toward the production of biofuels, there is competition for land — with serious implications for food security, especially, as demonstrated in 2007/2008, when the speed of biofuels development outpaced annual production increases of agriculture.

FIGURE 26: COUNTRIES VULNERABLE TO FOOD INSECURITY



Source: Data compiled by authors from various sources (United Nations, World Bank, FAO, GAEZ, 2009).

The map identifies those countries that are most vulnerable to food insecurity. A country's vulnerability is estimated according to:

- population growth in 2000 to 2050 projected by the United Nations;
- wealth expressed in GDP per capita in 2005;
- land potential for rainfed cereal production per capita of 2050 population;
- total renewable water resources per capita of 2050 population; and
- impact of climate change projected in 2050 on crop production potential.

It is assumed that high income countries with 2005 GDP per capita exceeding US$7 500 (in 1990 US dollars) will not be vulnerable to food insecurity.

4.2 Ways forward

Commitment to sustainable agricultural development

Agriculture is the dominant user of the environment and natural resources; it has the greatest impact on the sustainability of ecosystems and their services and accounts directly and indirectly for a major share of employment and livelihoods in rural areas in developing countries. The reality for many developing countries is that no progress on reducing rural poverty and hunger can be achieved without political and resource commitment to sustainable agricultural development. Given that 70 percent of the world's food insecure population live in rural areas, food security cannot be tackled unless the issues of sustainable agriculture and rural development are tackled first. These obviously require the highest policy and resource commitment.

However, trends over the last 30 years show a reduced allocation of national development budgets to agriculture in many developing countries, a setback that has coincided with declining multilateral lending and bilateral aid for the sector. Agriculture, it seems, has been regarded as 'backward' and thus of low priority by national governments and their international partners. The agricultural sector faces a complex challenge: to produce more food of better quality while using less water per unit of output; to provide rural people with resources and opportunities to live a healthy and productive life; to apply clean technologies that ensure environmental sustainability; and to contribute productively to local and national social and economic development.

Think globally and act locally

The paradox of food insecurity and hunger is that at the global level there is sufficient production to provide food for everyone at a level of nutrition considered satisfactory; yet one in seven people in the world face daily hunger. Notwithstanding the global adequacy of food supplies, at the local level people in countries with persistent food insecurity problems may not be able to access the actual or potential global plenty. In many countries food security depends fully on the performance of local agricultural production. Investing in the development of agriculture will be particularly effective in countries with high population growth. However, the natural resource base of some of these countries may not be sufficient to make significant progress. Therefore, serious thought needs to be given to the option that efforts to develop agriculture be supplemented with interventions in other sectors that are not dependent on agricultural resources.

Focus research and development on the needs of the poor

The challenge facing biological sciences is to combine the best of conventional breeding with safe and ethical molecular and cellular genetics research to develop nutritionally enhanced and productive germplasm. In developing countries there is a risk that modern biotechnology and technological development may bypass poor farmers. The rapidly increasing privatization and patenting of agricultural research findings is of concern as the priority of creating a profit means that it is unlikely that the needs and crops of the poor will be focused upon. Targeted research may overcome many environmental constraints such as infertile soils; limitations related to water, pests and diseases, etc. as well as increase the nutritional content of crops.

In many countries, agricultural extension and marketing services have declined owing to budgetary constraints and low priority of political support for agriculture. Yet, agricultural extension services, combined with adequate basic education, will be an essential link to inform and train farmers in the agricultural adaptation to climate change. Poor farmers often cannot benefit from access to markets because of the lack of infrastructure. Development of adequate infrastructure for both transport and communication helps farmers to access required inputs such as fertilizers as well as targeted production for local markets.

Land rights and tenure are indispensable

Providing adequate rights of access to land and other natural resources and secure tenure of those rights are essential to fostering sustainable and progressive agricultural development. Secure land tenure empowers and enables development and provides a valuable safety net. This is because land is a source of shelter, food and income, especially in times of hardship and leads to greater environmental security. Farmers are quite naturally more inclined to invest in improving their land through soil protection measures, planting trees, and improving pastures if they have secure tenure and can benefit from their investments. Without a land title, the alternative is for farmers to exploit marginal land, abandon it when it becomes unproductive, and then move on to clearing forests and other fragile land.

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