Photos: FAO Mediabase, Bartek Pogoda

Chapter 1

STATUS AND TRENDS IN LAND AND WATER RESOURCES

The world's land and water resources are finite and under pressure from a growing population. Global figures show a relatively low share of land and water actually used by agriculture, but these figures hide major regional variations and a series of locally important imbalances between demand and supply. Demand for land and water from non-agricultural sectors, and a growing recognition of the need to meet environmental requirements further intensifies competition. This chapter reviews current status and trends of land and water resources, their geographical distribution and their use in agriculture. It presents projections for future agricultural demands towards 2050, and analyses its implication both for rainfed and irrigated agriculture.

The present status of land and water

The world's net cultivated area has grown by 12 percent over the last 50 years, mostly at the expense of forest, wetland and grassland habitats. At the same time, the global irrigated area has doubled. The distribution of these land and water assets is unequal among countries. Although only a small proportion of the world's land and water is used for crop production, most of the easily accessible and (thus economic) resources are under cultivation or have other ecologically and economically valuable uses. Thus the scope for further expansion of cultivated land is limited. Only parts of South America and sub-Saharan Africa still offer scope for some expansion. At the same time, competition for water resources has also been growing to the extent that today more than 40 percent of the world's rural population is now living in water-scarce regions.

Land distribution, use and suitability

The global land area is 13.2 billion ha. Of this, 12 percent (1.6 billion ha) is currently in use for cultivation of agricultural crops, 28 percent (3.7 billion ha) is under forest, and 35 percent (4.6 billion ha) comprises grasslands and woodland ecosystems. Low-income countries cover about 22 percent of the land area (Table 1.1).

Land use varies with climatic and soil conditions and human influences (Map 1.1). Figure 1.1 further shows the dominant land use by region. Deserts prevail across much of the lower northern latitudes of Africa and Asia. Dense forests predominate in the heartlands of South America, along the seaboards of North America, and across Canada, Northern Europe and much of Russia, as well as in the tropical

TABLE 1.1: REGIONAL DISTRIBUTION OF MAIN LAND USE CATEGORIES (2000)

Country category			Cultivated land		Forest land		Grassland and woodland ecosystems		Sparsely vegetated and barren land		Settlement and Infrastructure		Inland water bodies	
	Global share of land, %	Share of global population, %	Mha	%	Mha	%	Mha	%	Mha	%	Mha	%	Mha	%
Low-income	22	38	441	15	564	20	1 020	36	744	26	52	1.8	41	1.4
Middle-income	53	47	735	11	2 285	33	2 266	33	1 422	21	69	1	79	1
High-income	25	15	380	12	880	27	1 299	39	592	18	31	1	123	4

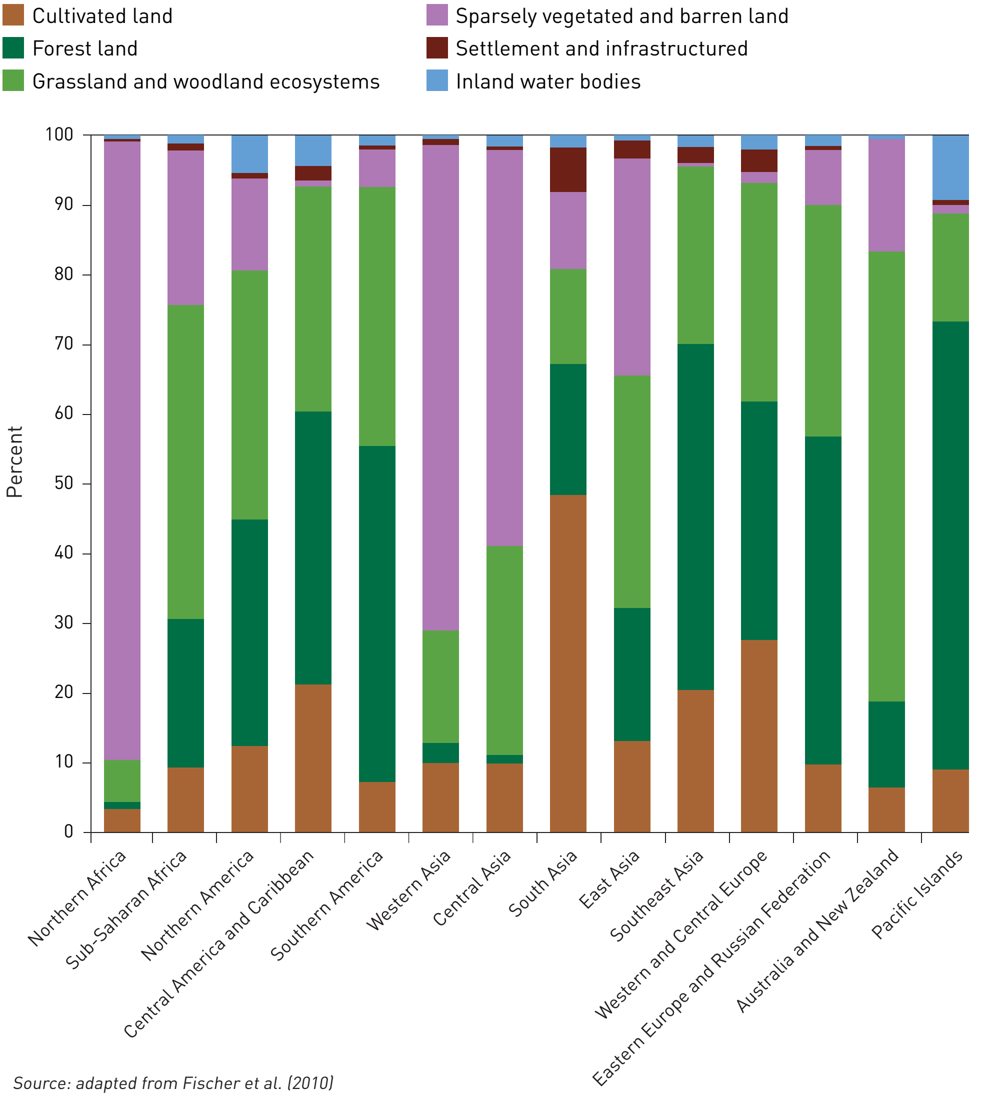
Source: adapted from Fischer et al. (2010)
Note: The extents of land cover classes were extracted from a dataset used for global agro-ecological modelling. Owing to different dates of data acquisitions, spatial resolutions, definitions and processing techniques, the estimates in this table may differ somewhat from those of other more recent sources. For example, the global extent of forest land is reported in FAO (2010d) as 4 billion ha versus approximately 3.7 billion ha reported here. See Annex A1 for the definition of regional and subregional country groupings.

belts of Central Africa and Southeast Asia. Cultivated land is 12 to 15 percent of total land in each category. Grasslands and woodlands (33 to 39 percent) and forest land (20 to 33 percent) dominate land use and cover in all three country income categories.

Cultivated land is a leading land use (a fifth or more of the land area) in South and Southeast Asia, Western and Central Europe, and Central America and the Caribbean, but is less important in sub-Saharan and Northern Africa, where cultivation covers less than a tenth of the area.

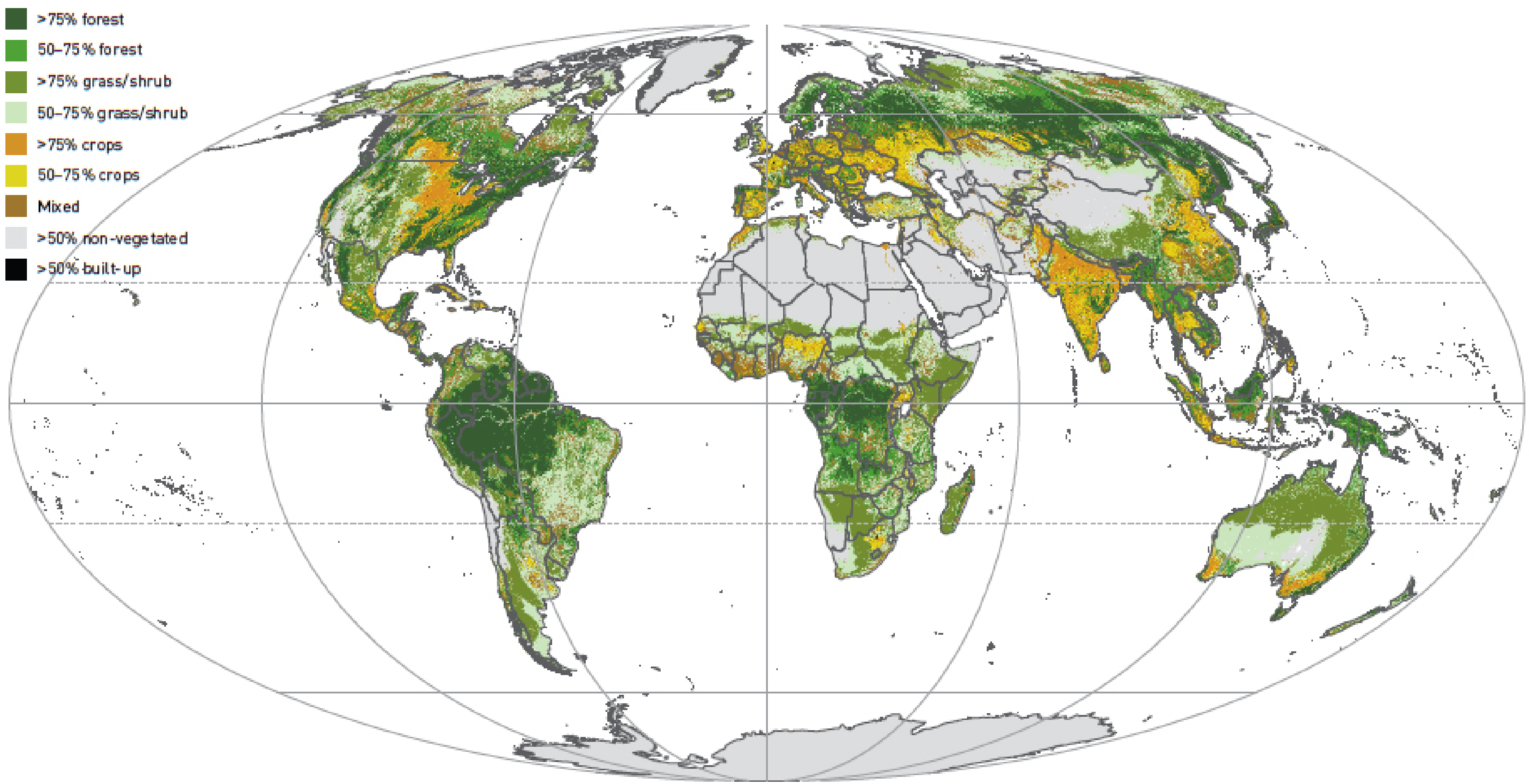
The global area of cultivated land has grown by a net 159 Mha since 1961 (Table 1.2 and Figure 1.2). This increase, however, includes a larger area of land newly brought

FIGURE 1.1: REGIONAL DISTRIBUTION OF LAND USE AND COVER



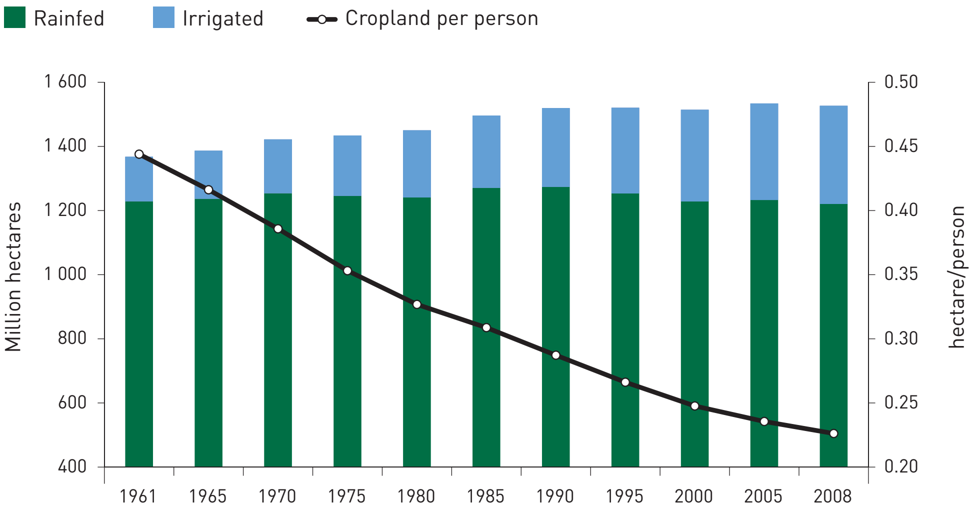
Source: adapted from Fischer et al. (2010)

MAP 1.1: DOMINANT LAND COVER AND USE



Source: *IIASA/FAO (2010)*

FIGURE 1.2: EVOLUTION OF LAND UNDER IRRIGATED AND RAINFED CROPPING (1961–2008)



Source: FAO (2010b)

TABLE 1.2: NET CHANGES IN MAJOR LAND USE (Mha)

	1961	2009	Net increase 1961–2009
Cultivated land	1 368	1 527	12%
• rainfed	1 229	1 226	–0.2%
• irrigated	139	301	117%

Sources: FAO (2010b,c)

into cultivation, while over the same period previously cultivated lands have come out of production. All of the net increase in cultivated area over the last 50 years is attributable to a net increase in irrigated cropping, with land under rainfed systems showing a very slight decline. Irrigated area more than doubled over the period, and the number of hectares needed to feed one person has reduced dramatically from 0.45 to 0.22 ha per person (FAO, 2010b).

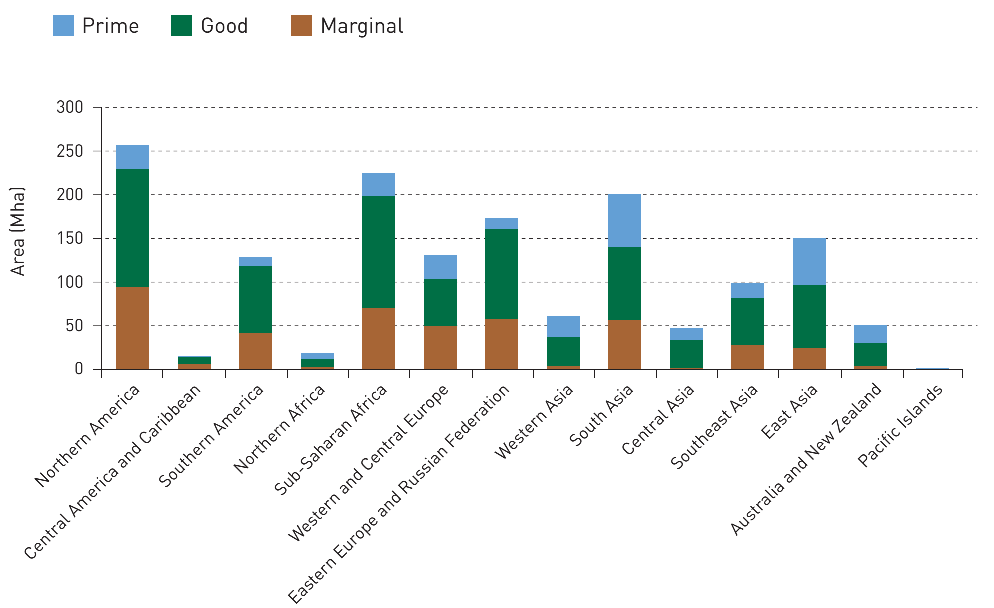
Methods for forest inventory, forest definitions and the geographical extents of assessments change over time, rendering comparisons difficult. Nonetheless, a decline of about 135 Mha (3.3 percent) in forested area between 1990 and 2010 suggests that the expansion in the cultivated area and the replacement of degraded arable land with new cultivated land have been partly achieved through conversion of previously forested areas (FAO, 2010d).

Globally, about 0.23 ha of land is cultivated per head of the world's population. High-income countries cultivate more than twice the area per capita (0.37 ha) than low-income (0.17 ha) countries, while middle-income countries cultivate 0.23 ha per capita (Table 1.3).

FAO defines land suitability for agriculture in terms of capacity to reach potentially attainable yields for a basket of crops (Box 1.1). Assuming well-adapted production systems are used, currently cultivated land is mostly of prime (28 percent of the total) or good quality (53 percent). The highest regional proportion of prime land currently cultivated is found in Central America and the Caribbean (42 percent), followed by Western and Central Europe (38 percent) and Northern America (37 percent). For high-income countries as a whole, the share of prime land in currently cultivated land is 32 percent (Table 1.3). In low-income countries, soils are often poorer and only 28 percent of total cultivated land is classed as prime (Figure 1.3).

CHAPTER 1

FIGURE 1.3: TOTAL EXTENT OF CULTIVATED LAND BY LAND SUITABILITY CATEGORY FOR EACH GEOGRAPHIC REGION



Source: Fischer et al. (2010)

TABLE 1.3: SHARE OF WORLD CULTIVATED LAND SUITABLE FOR CROPPING UNDER APPROPRIATE PRODUCTION SYSTEMS

Regions	Cultivated land (Mha)	Population (million)	Cultivated land per capita (ha)	Rainfed crops (%)		
				Prime Land	Good Land	Marginal Land
Low-income countries	441	2 651	0.17	28	50	22
Middle-income countries	735	3 223	0.23	27	55	18
High-income countries	380	1 031	0.37	32	50	19
Total	1 556	6 905	0.23	29	52	19

Source: adapted from Fischer et al. (2010)

BOX 1.1: HOW SUITABILITY OF LAND FOR CULTIVATION IS ASSESSED

This study considers three levels of suitability for cultivation: prime, good and marginal/unsuitable. Prime land is capable of producing 80 percent of potentially attainable yields for a basket of crops. Good land may produce 40–80 percent of potential. Marginal/unsuitable land produces less than 40 percent. Management influences yields everywhere. The figures shown in Table 1.3 assume appropriate production systems, where management and input levels are matched to soil suitability. On this assumption, the estimated extent of prime and good land worldwide varies between 70 percent at low input levels and 80 percent.

Source: Fischer et al. (2010)

Water use, withdrawals, scarcity and quality

Through the global hydrological cycle, renewable water resources amount to 42 000 km^3/yr. Of this, about 3 900 km^3 is withdrawn for human uses from rivers and aquifers: some 2 710 km^3 (70 percent) is for irrigation, 19 percent for industries and 11 percent for the municipal sector (Table 1.4). It is estimated that more than 60 percent of all water withdrawals flows back to local hydrological systems by return flows to rivers or groundwater. The remaining part is considered consumptive water use through evaporation and plant transpiration.

With the doubling of the global irrigated area over the last 50 years, withdrawals for agriculture have been rising. Globally, total water withdrawals still represent only a small share – about 9 percent of internal renewable water resources (IRWR) (Table 1.4), but this average masks large geographical discrepancies. The rate of withdrawal varies greatly by country or region. Europe withdraws only 6 percent of its internal resources and just 29 percent of this goes to agriculture. The intensive agricultural economies of Asia withdraw 20 percent of their internal renewable resources, of which more than 80 percent goes to irrigation. In many of the low rainfall regions of the Middle East, Northern Africa and Central Asia, most of the exploitable water is already withdrawn, with 80–90 percent of that going to agriculture, and thus rivers and aquifers are depleted beyond sustainable levels.

About 40 percent of the world's population lives in transboundary river basins, and more than 90 percent live in countries with basins that cross international borders (Sadoff and Grey, 2005). These 263 international water basins account for about 50 percent of global land area and 40 percent of freshwater resources (Giordano and Wolf, 2002). Many of these transboundary rivers are among the largest flows of water globally. The growth in water withdrawals, primarily by agriculture, has brought about the need for collaboration among countries, through treaties and agreements between riparian countries, the formulation of international agreements such as the 1997 UN Convention on the Law of the Non-navigational Uses of International Watercourses and regional initiatives such as the Southern African Development Community (SADC) Protocol on Shared Water Resources.

TABLE 1.4: **WATER WITHDRAWAL BY MAJOR WATER USE SECTOR (2003)**

Continent Regions	Total withdrawal by sector						Total water withdrawal *	Total freshwater withdrawal	Freshwater withdrawal as % of IRWR
	Municipal		Industrial		Agricultural				
	km³/yr	%	km³/yr	%	km³/yr	%	km³/yr	km³/yr	
Africa	**21**	**10**	**9**	**4**	**184**	**86**	**215**	**215**	**5**
Northern Africa	9	9	5	6	80	85	94	94	201
Sub-Saharan Africa	13	10	4	3	105	87	121	121	3
Americas	**126**	**16**	**280**	**35**	**385**	**49**	**791**	**790**	**4**
Northern America	88	15	256	43	258	43	603	602	10
Central America and Caribbean	6	26	2	11	15	64	24	24	3
Southern America	32	19	21	13	112	68	165	165	1
Asia	**217**	**9**	**227**	**9**	**2 012**	**82**	**2 456**	**2 451**	**20**
Western Asia	25	9	20	7	227	83	271	268	55
Central Asia	5	3	8	5	150	92	163	162	61
South Asia	70	7	20	2	914	91	1 004	1 004	57
East Asia	93	14	150	22	434	64	677	677	20
Southeast Asia	23	7	30	9	287	84	340	340	17
Europe	**61**	**16**	**204**	**55**	**109**	**29**	**374**	**374**	**6**
Western and Central Europe	42	16	149	56	75	28	265	265	13
Eastern Europe and Russian Federation	19	18	56	51	35	32	110	110	2
Oceania	**5**	**17**	**3**	**10**	**19**	**73**	**26**	**26**	**3**
Australia and New Zealand	5	17	3	10	19	73	26	26	3
Pacific Islands	0.01	14	0.01	14	0.05	71	0.1	0.1	0.1
World	**429**	**11**	**723**	**19**	**2 710**	**70**	**3 862**	**3 856**	**9**
High-income	145	16	392	43	383	42	920	916	10
Middle-income	195	12	287	18	1 136	70	1 618	1 616	6
Low-income	90	7	44	3	1 191	90	1 324	1 324	18
Low-income food deficit	**182**	**8**	**184**	**8**	**1 813**	**83**	**2 180**	**2 179**	**16**
Least-developed	**10**	**5**	**3**	**1**	**190**	**94**	**203**	**203**	**5**

* Includes use of desalinated water

Source: FAO (2010c)
Note: See Annex A1 for the definition of regional and subregional country groupings.

Water resources are very unevenly distributed, with some countries having an abundance of water while many manage conditions of extreme scarcity. In addition, even where water may appear abundant, much of it is not accessible or is very expensive to develop, or is not close to lands that can be developed for agriculture. Water scarcity has three dimensions: physical (when the available supply does not satisfy the demand), infrastructural (when the infrastructure in place does not allow for satisfaction of water demand by all users) and institutional (when institutions and legislations fail to ensure reliable, secure and equitable supply of water to users).

In terms of physical water scarcity, it is estimated that on average a withdrawal rate above 20 percent of renewable water resources represents substantial pressure on water resources – and more than 40 percent is 'critical'. In some regions, particularly in the Middle East, Northern Africa and Central Asia, countries are already withdrawing in excess of critical thresholds. The resultant stresses on the functions of ecosystems are increasingly apparent. It is now estimated that more than 40 percent of the world's rural population lives in river basins that are physically water scarce. Map 1.2 shows the global distribution of water scarcity by major river basin, based on consumptive use of water in irrigation.

Equally, countries have developed their water resources extensively through a combination of policies and investments to increase supply and stimulate demand. As a result, in many countries demand is outstripping supply, and this imbalance is creating new stresses on the agricultural sector. There remain few opportunities for easy and low-cost infrastructure, and thus the marginal cost of new water development projects is high.

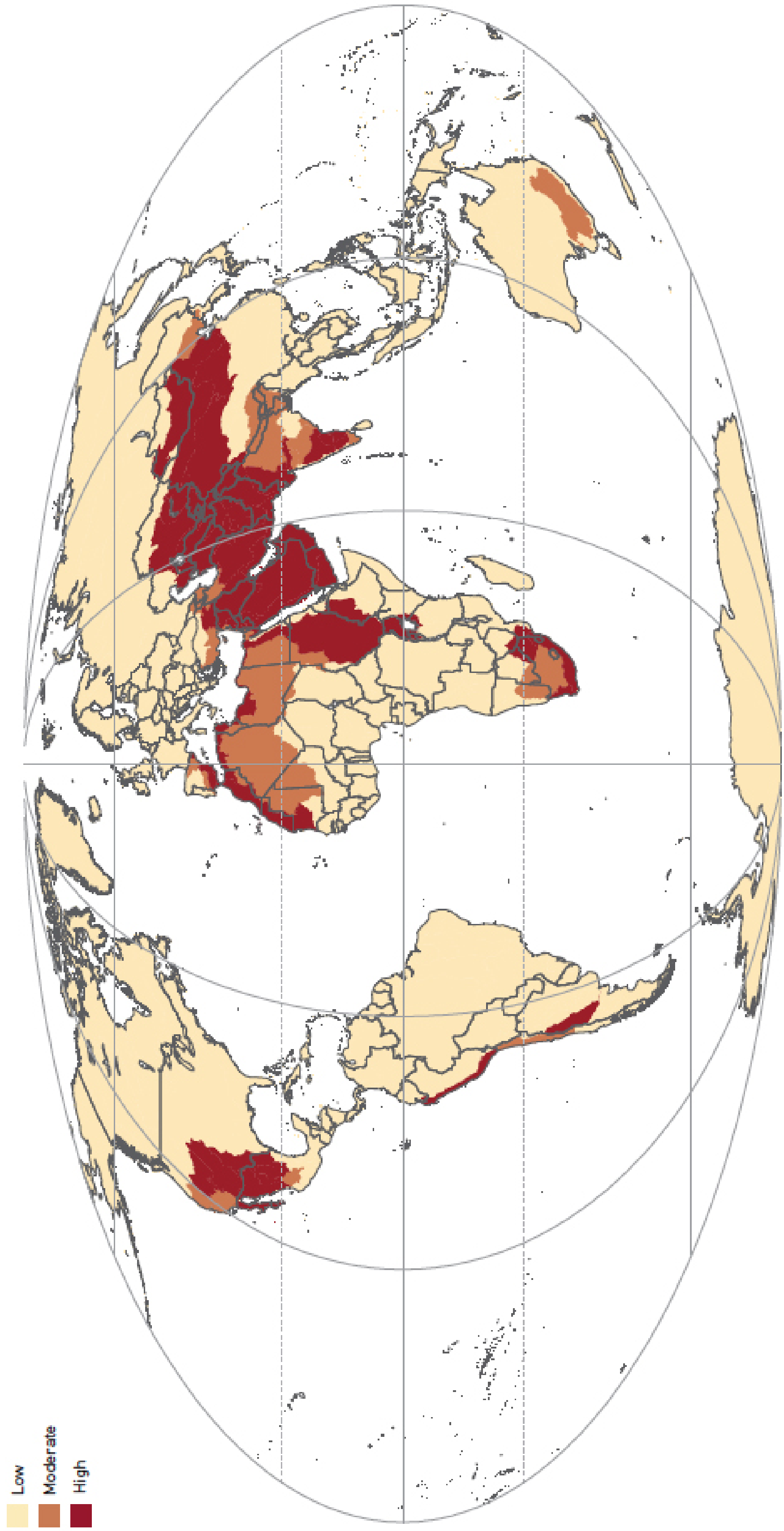
At the same time, demand from other sectors, particularly municipal and industrial demand, has been growing faster than agricultural demand. Whereas in less-developed countries agricultural use remains dominant, in Europe 55 percent of water is withdrawn by industry. Water stresses occur locally across the globe, but some entire regions are highly stressed, particularly the Middle East, the Indian subcontinent and northeastern China. Sub-Saharan Africa and the Americas generally experience lower levels of water stress.

When water is used in domestic and productive activities, and discharged again into the environment, water quality is changed. In general, increasing population and economic growth combined with little or no water treatment have led to more negative impacts on water quality. Agriculture, as the largest water user, is a major contributor. Key non-point source pollution includes nutrients and pesticides derived from crop and livestock management. A further problem arises from salinization: many soil and water salinity problems have been reported in large irrigation schemes in Pakistan, China, India, Argentina, Sudan and many countries in Central Asia, where more than 16 Mha of irrigated land are now salinized (FAO, 2010c).

Land and water resources in rainfed agriculture

Rainfed agriculture is the predominant agricultural production system worldwide. As practised in highland areas and in the dry and humid tropics, it is the system in which poorer smallholder farmers predominate and where the risks of resource degradation are highest. Soil nutrient availability in many rainfed lands tends to be

MAP 1.2: GLOBAL DISTRIBUTION OF PHYSICAL WATER SCARCITY BY MAJOR RIVER BASIN



Source: this study

low, and sloping terrain and patterns of rainfall and runoff contribute to erosion. High temperatures and low and erratic precipitation often make soil moisture availability inadequate, and techniques to improve water availability (such as water harvesting) are expensive. Higher levels of input and management can increase productivity, but many farmers cannot afford the costs or risks. All these factors affecting land and water for rainfed agriculture as practised by the poor contribute to their vulnerability and to their food insecurity.

Land and water resources distribution

Rainfed agriculture depends on rainfall for crop production, with no permanent source of irrigation. Of the current world cultivated area of 1 600 Mha, about 1 300 Mha (80 percent) are rainfed. Rainfed agriculture produces about 60 percent of global crop output in a wide variety of production systems (Table 1.5; Map 1.3). The most productive systems are concentrated in temperate zones of Europe, followed by Northern America, and rainfed systems in the subtropics and humid tropics. Rainfed cropping in highland areas and the dry tropics tends to be relatively low-yielding, and is often associated with subsistence farming systems. Evidence from farms worldwide shows that less than 30 percent of rainfall is used by plants in the process of biomass production. The rest evaporates into the atmosphere, percolates to groundwater or contributes to river runoff (Molden, 2007).

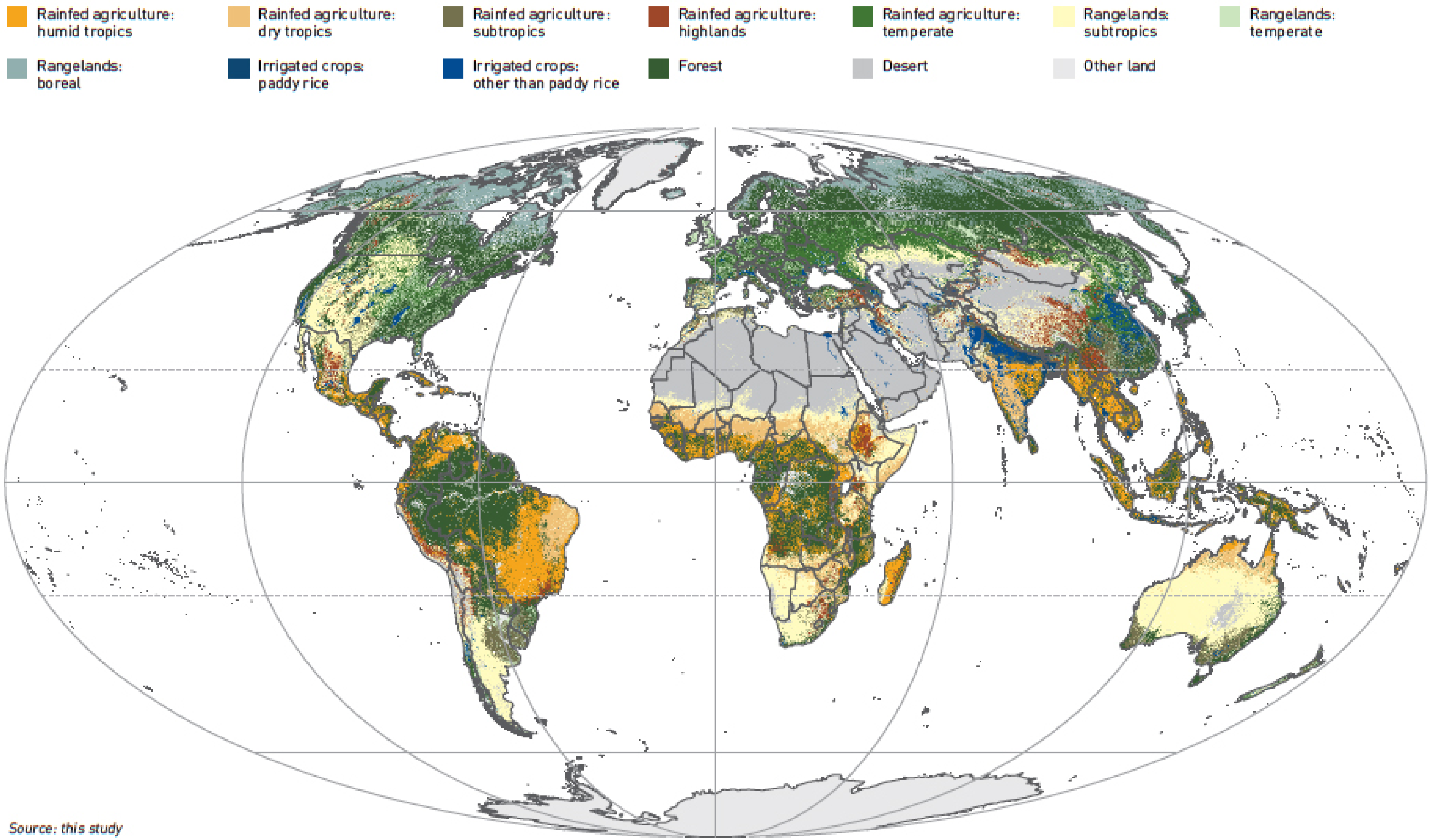
Depending on temperature and soil conditions, rainfed cropping of some kind is possible where annual rainfall exceeds 300 mm. The distribution of rainfall during

TABLE 1.5: TYPES OF RAINFED SYSTEMS

System	Characteristics and selected examples
Rainfed agriculture: **highlands**	Low productivity, small-scale subsistence (low-input) agriculture; a variety of crops on small plots plus few animals.
Rainfed agriculture: **dry tropics**	Drought-resistant cereals such as maize, sorghum and millet. Livestock consists often of goats and sheep, especially in the Sudano-Sahelian zone of Africa, and in India. Cattle are more widespread in southern Africa and in Latin America.
Rainfed agriculture: **humid tropics**	Mainly root crops, bananas, sugar cane and notably soybean in Latin America and Asia. Maize is the most important cereal. Sheep and goats are often raised by poorer farmers while cattle are held by wealthier ones.
Rainfed agriculture: **subtropics**	Wheat (the most important cereal), fruits (e.g. grapes and citrus) and oil crops (e.g. olives). Cattle are the most dominant livestock. Goats are also important in the southern Mediterranean, while pigs are dominant in China and sheep in Australia.
Rainfed agriculture: **temperate**	Main crops include wheat, maize, barley, rapeseed, sugar beet and potatoes. In the industrialized countries of Western Europe, the United States and Canada, this agricultural system is highly productive and often combined with intensive, penned livestock (mainly pigs, chickens and cattle).

Source: this study

MAP 1.3: MAJOR AGRICULTURAL SYSTEMS



Source: this study

the growing season is also a key factor: ample annual averages may conceal poor spacing in relation to the growing season and, combined with uncertainties such as rainfall variability between years, this increases risks and reduces the chances of rainfed agriculture being highly productive.

The extent of rainfed area has not grown in recent years, but this masks the replacement of some land too degraded for further cropping and consequently abandoned, and their replacement by lands newly converted from forests and grasslands to arable farming. This process of land degradation and abandonment, and the development of new lands in replacement, is particularly characteristic of low-input, low-management farming systems such as 'slash-and-burn' in the humid tropics, or cultivation on steep slopes. Because data on these farming systems are sparse, and because some of these lands may not be permanently degraded but may be brought back into cultivation after long fallow, it is difficult to estimate the areas involved.

Trends in rainfed areas differ by region. Sub-Saharan Africa, where 97 percent of staple production is rainfed, has doubled cultivated cereals area since 1960. In Latin America and the Caribbean, rainfed cultivation has expanded by 25 percent in the last 40 years (FAO, 2010b).

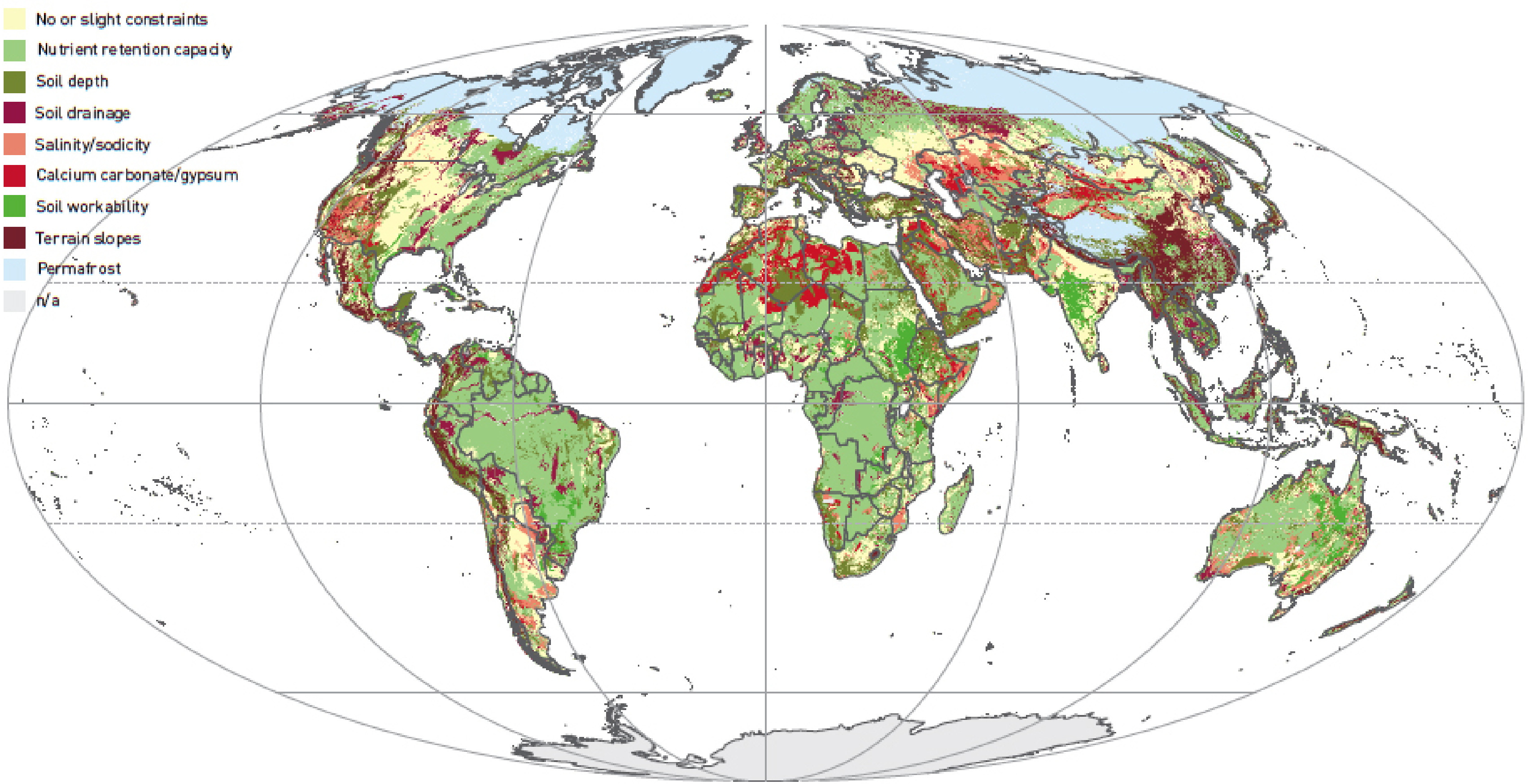
Soil and terrain constraints

Provided that adequate moisture is available in the soil, the broad potential of rainfed lands is determined largely by soil quality (Map 1.4). The most important factor is nutrient availability and related nutrient retention capacity of the soil. In addition, soil depth affects plant rooting, and drainage characteristics affect the availability of oxygen as roots grow. Soil structure is important for ease of cultivation, and is linked to soil chemistry and cultivation practices. Finally, the slope of the land can affect soil quality as sloping terrain erodes as a result of runoff and mass wasting.

Soil nutrient availability is the prevalent soil limitation in current cultivated land in most regions, particularly in tropical developing countries. This is due in part to lower availability of natural nutrients than in temperate lands. Sub-Saharan Africa, Southern America, East Asia, Southeast Asia, and Australia and New Zealand have particularly low levels of natural soil nutrient availability. The share of soils with no or minor nutrient availability constraints is highest in high-income countries (76 percent), compared with 68 percent in low-income countries (Table 1.6). In addition, the natural fertility status of some soils has deteriorated over time through 'nutrient mining'.

In several regions, soil quality constraints affect more than half the cultivated land base, notably in sub-Saharan Africa, Southern America, Southeast Asia and

MAP 1.4: DOMINANT SOIL AND TERRAIN CONSTRAINTS FOR LOW INPUT FARMING



Source: IIASA/FAO (2010)

TABLE 1.6: DISTRIBUTION OF CULTIVATED LAND BY CLASSES OF SOIL QUALITY RATING OF NATURAL NUTRIENT AVAILABILITY

Country category	Cultivated land (Mha)	Area by class of soil nutrient availability rating (%)			
		< 40	40–60	60–80	> 80
Low-income countries	443	0	20	12	68
Middle-income countries	740	1	16	15	67
High-income countries	382	1	9	13	76

Source: adapted from Fischer et al. (2010)

Northern Europe. In low-income countries, only 44 percent of cultivated soils (about 196 Mha), have no or only minor constraints. The main constraint on the remaining 247 Mha is poor nutrient availability, affecting about 24 percent of the soils with varying levels of constraints from light to very severe.

But with good soil management, quality can be improved. Under high-input farming conditions, a low natural nutrient availability can be alleviated by fertilizer application, provided the soil has adequate nutrient retention capacity. However, low nutrient retention capacities are found in Southern Africa, the Amazon area, Central Asia and Northern Europe. In those areas increased use of fertilizers alone may prove ineffective for increasing crop yields, and thus additional forms of soil enhancement are necessary. Another major obstacle to crop cultivation is poor soil structure and 'workability', which is, for example, prevalent in large parts of Ethiopia, Sudan and central India. Such constraints may again be reduced with the use of high input and appropriate soil management. Often these are areas dominated by vertisols, which ideally should be cultivated with zero-tillage techniques.

Rainfed productivity and production gaps

The productivity of rainfed cropping is measured by yields (production per unit of area). Productivity varies enormously, and is highly sensitive to factors other than soil and water – for example, the availability and affordability of technologies and inputs, access to markets, and the local financial returns. At one extreme, dry farming systems produce sorghum or millet yields of a few hundred kilograms per hectare. At the other extreme, farmers in Europe achieve yields as high as 7–10 t/ha for wheat (FAO, 2010b; Molden, 2007).

In sub-Saharan Africa, yields have changed little since the 1960s, and increases in production have come almost entirely from land expansion. Rainfed maize yields, for example, have remained constant at around 1t/ha. In Latin America and the Caribbean, by contrast, yields for rainfed maize tripled over the same period, from little more than 1t/ha to over 3t/ha. Average wheat yields across

Europe more than doubled (2t / ha to over 5t / ha). FAO has calculated a 'yield gap' by comparing current productivity with what is potentially achievable assuming that inputs and management are optimized in relation to local soil and water conditions (Map 1.5; Table 1.7).

These results show that the yield gap is greatest in sub-Saharan Africa (where yields are only 24 percent of what could be produced under higher levels of management). The gap is lowest in East Asia (11 percent). This implies that if all current land and water were managed optimally, output could double in the regions where the yield gap is less than 50 percent: Northern Africa, sub-Saharan Africa, Central America and the Caribbean, Southern America, Western Asia, Central Asia, South Asia, Eastern Europe and Russian Federation, and the Pacific Islands. By contrast, much of Asian farming is already using advanced management, with Eastern Asia in particular rivalling the most productive systems in the developed world, at 89 percent of potential.

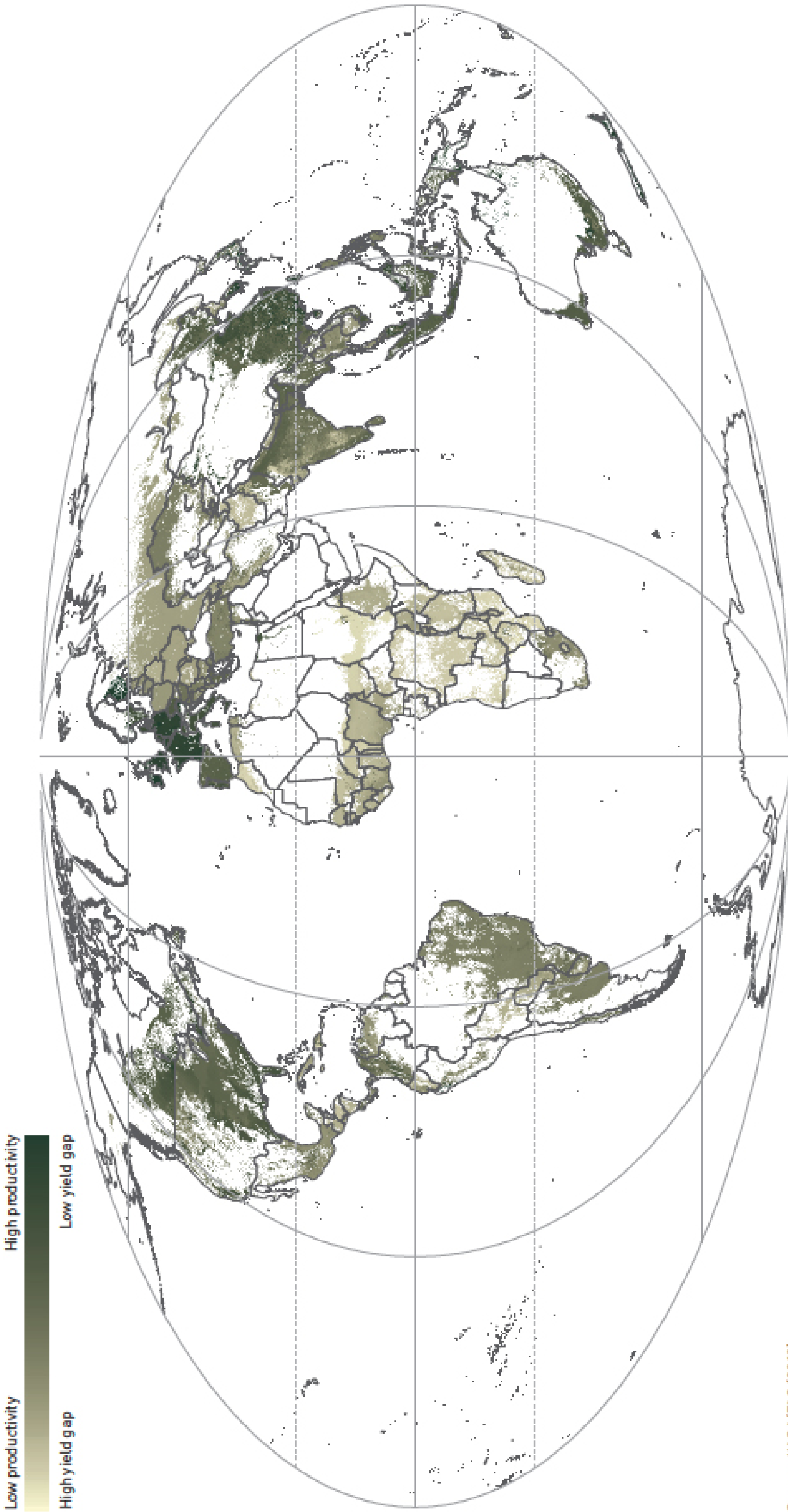
Land and water resources in irrigated agriculture

Irrigated systems have expanded in recent years to bring water control, which, together with rapid increases in water productivity, has greatly boosted agricultural production and incomes. However, most irrigated farming systems are performing well below their potential, and there is considerable scope for improving land and water productivity. Groundwater abstraction has provided an invaluable source of ready irrigation water, but has proved almost impossible to regulate. As a result, agriculture withdrawals of groundwater are intensifying and some key aquifers are being depleted. Water quality is deteriorating, with impacts from irrigation on both surface and groundwater, and the salinization of irrigated lands is a growing problem. Competition for water from domestic and industrial users is growing fast, and many countries and basins face water scarcity with reduced quantities available to irrigation. New impoundments and diversions have higher marginal costs and pose increasing environmental challenges. Recycled water can increase supply, but it is a limited and costly resource and it needs careful management.

Extent of land use and water resources control

In 2006, the global area equipped for irrigation stood at 301 Mha (Table 1.8). Irrigation has developed rapidly in recent decades, particularly in developing countries, in response to the need to ensure controlled water sources for optimal crop productivity (Figure 1.4). As the global population grew, the area equipped for irrigation more than doubled – from 139 Mha to 301 Mha – and water withdrawals for irrigation almost doubled – from about 1 540 km^3 to 2 710 km^3. Over the same period the proportion of total cultivated land that is irrigated grew from 10 to 20 percent.

MAP 1.5: YIELD GAP FOR A COMBINATION OF MAJOR CROPS



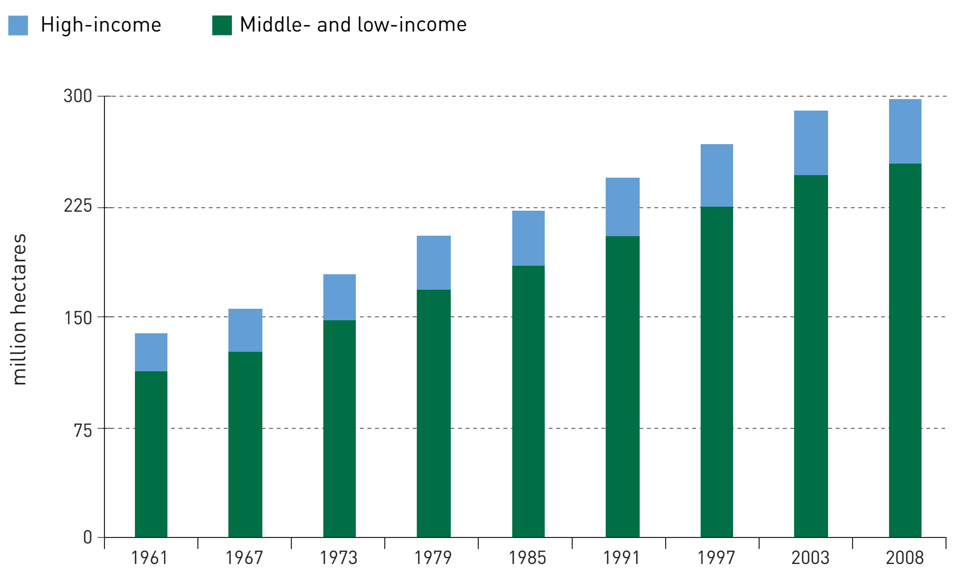
Source: IIASA/FAO (2010)

TABLE 1.7: ESTIMATED YIELD GAPS (PERCENTAGE OF POTENTIAL) FOR CEREALS, ROOTS AND TUBERS, PULSES, SUGAR CROPS, OIL CROPS AND VEGETABLES COMBINED

Region	Actual yields in 2005 compared with potential yield (%)	Yield gap (%)
	Year 2005	
Northern Africa	40	60
Sub-Saharan Africa	24	76
Northern America	67	33
Central America and Caribbean	35	65
Southern America	48	52
Western Asia	51	49
Central Asia	36	64
South Asia	45	55
East Asia	89	11
Southeast Asia	68	32
Western and Central Europe	64	36
Eastern Europe and Russian Federation	37	63
Australia and New Zealand	60	40
Pacific Islands	43	57

Source: adapted from Fischer et al. (2010)

FIGURE 1.4: AREA EQUIPPED FOR IRRIGATION



Source: FAO (2010b)

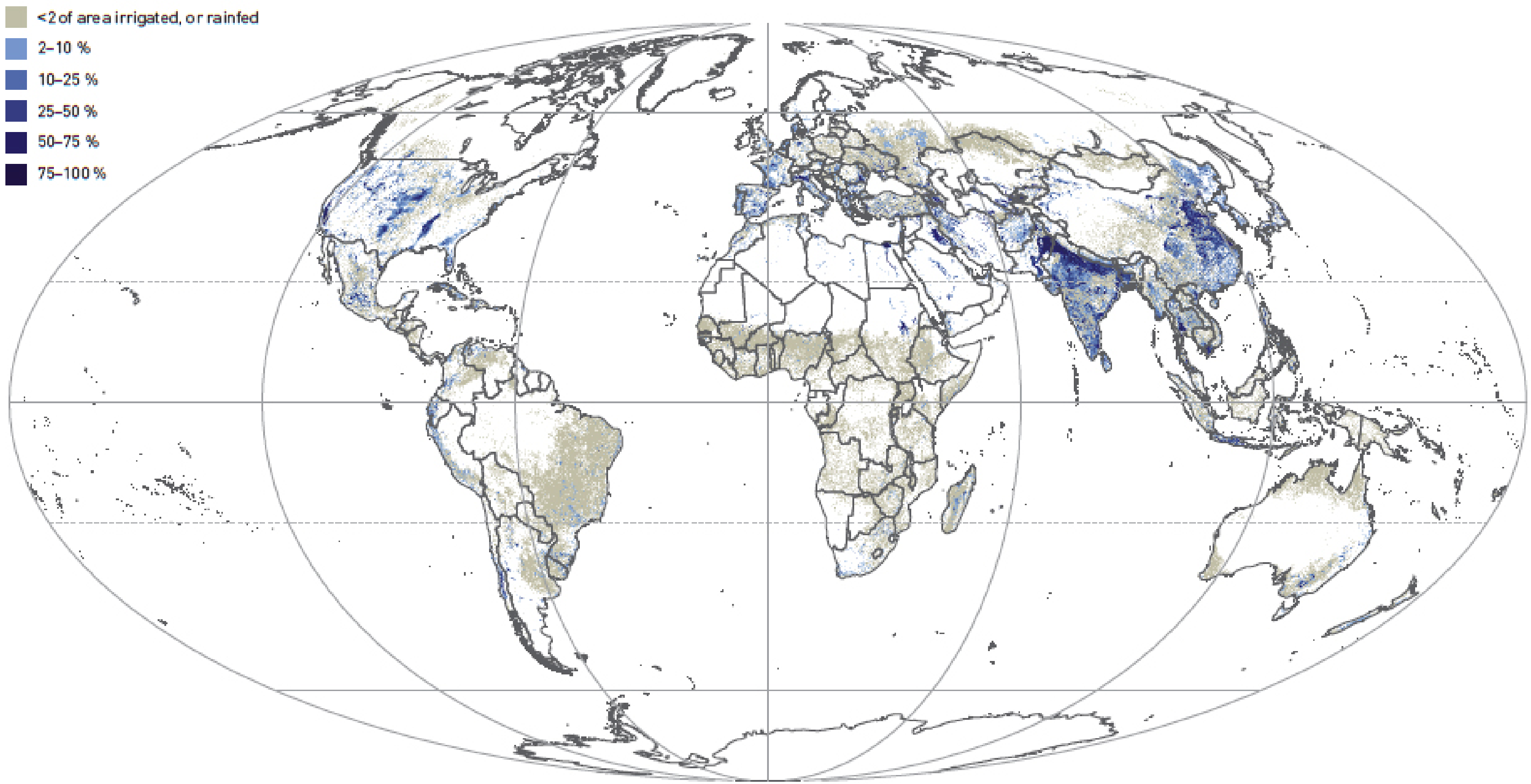
TABLE 1.8: AREA EQUIPPED FOR IRRIGATION (PERCENTAGE OF CULTIVATED LAND AND PART IRRIGATED GROUNDWATER)

Continent / Regions	Equipped area (million ha)		As % of cultivated land		of which groundwater irrigation (2006)	
Year	1961	2006	1961	2006	Area equipped (million ha)	As % of total irrigated area
Africa	**7.4**	**13.6**	**4.4**	**5.4**	**2.5**	**18.5**
Northern Africa	3.9	6.4	17.1	22.7	2.1	32.8
Sub-Saharan Africa	3.5	7.2	2.4	3.2	0.4	5.8
Americas	**22.6**	**48.9**	**6.7**	**12.4**	**21.6**	**44.1**
Northern America	17.4	35.5	6.7	14.0	19.1	54.0
Central America and Caribbean	0.6	1.9	5.5	12.5	0.7	36.3
Southern America	4.7	11.6	6.8	9.1	1.7	14.9
Asia	**95.6**	**211.8**	**19.6**	**39.1**	**80.6**	**38.0**
Western Asia	9.6	23.6	16.2	36.6	10.8	46.0
Central Asia	7.2	14.7	13.4	37.2	1.1	7.8
South Asia	36.3	85.1	19.1	41.7	48.3	56.7
East Asia	34.5	67.6	29.7	51.0	19.3	28.6
Southeast Asia	8.0	20.8	11.7	22.5	1.0	4.7
Europe	**12.3**	**22.7**	**3.6**	**7.7**	**7.3**	**32.4**
Western and Central Europe	8.7	17.8	5.8	14.2	6.9	38.6
Eastern Europe and Russian Federation	3.6	4.9	1.9	2.9	0.5	10.1
Oceania	**1.1**	**4.0**	**3.2**	**8.7**	**0.9**	**23.9**
Australia and New Zealand	1.1	4.0	3.2	8.8	0.9	24.0
Pacific Islands	0.001	0.004	0.2	0.6	0.0	18.7
World	**139.0**	**300.9**	**10.2**	**19.7**	**112.9**	**37.5**
High-income	26.7	54.0	6.9	14.7	26.5	49.1
Middle-income	66.6	137.9	10.5	19.3	36.1	26.1
Low-income	45.8	108.9	13.1	24.5	50.3	46.2
Low-income food deficit	**82.5**	**187.6**	**16.6**	**29.2**	**71.9**	**38.3**
Least-developed	**6.1**	**17.5**	**5.2**	**10.1**	**5.0**	**28.8**

Data sources: FAO (2010b,c)

About 70 percent of the world area equipped for irrigation is in Asia, where it accounts for 39 percent of the cultivated area (Map 1.6). South and East Asia account for over half of the world's area equipped for irrigation, and India and China alone (each with about 62 Mha equipped for irrigation), account for 40 percent. Most of this irrigation is large-scale development within major basins, primarily for paddy rice production. Irrigation is also very important in Western Asia, where it accounts for 37 percent of the cultivated area, and in Northern Africa (23 percent of cultivated area). The region with the least irrigation is sub-Saharan Africa, where only 3 percent is irrigated.

MAP 1.6: AREA EQUIPPED FOR IRRIGATION AS A PERCENTAGE OF LAND AREA



Source: Siebert et al. (2007)

Rate of expansion

The rate of expansion of irrigation, over 2 percent a year in the 1960s and 1970s, has decreased substantially. The reasons are many, and include a long period of stable food supply and declining food prices (until 2007), declining population growth rate, and the rising importance of investment in other sectors (Faurès *et al.*, 2007). In addition, rising investment and maintenance costs (and associated low economic return of irrigation schemes), and concerns over negative social and environmental impacts, have led to reduction in government and donor interest.

Most irrigation expansion has taken place by conversion from rainfed agriculture. Part of irrigation, however, takes place on arid and hyper-arid (desert) land that is not suitable for rainfed agriculture. It is estimated that of the 219 Mha irrigated at present in developing countries, some 40 Mha are on arid and hyper-arid land, which could increase to 43 Mha in 2050. In some regions and countries, irrigated arid and hyper-arid land forms an important part of the total irrigated land presently in use: 19 out of 28 Mha in the Near East and Northern Africa, and 15 of 85 Mha in South Asia.

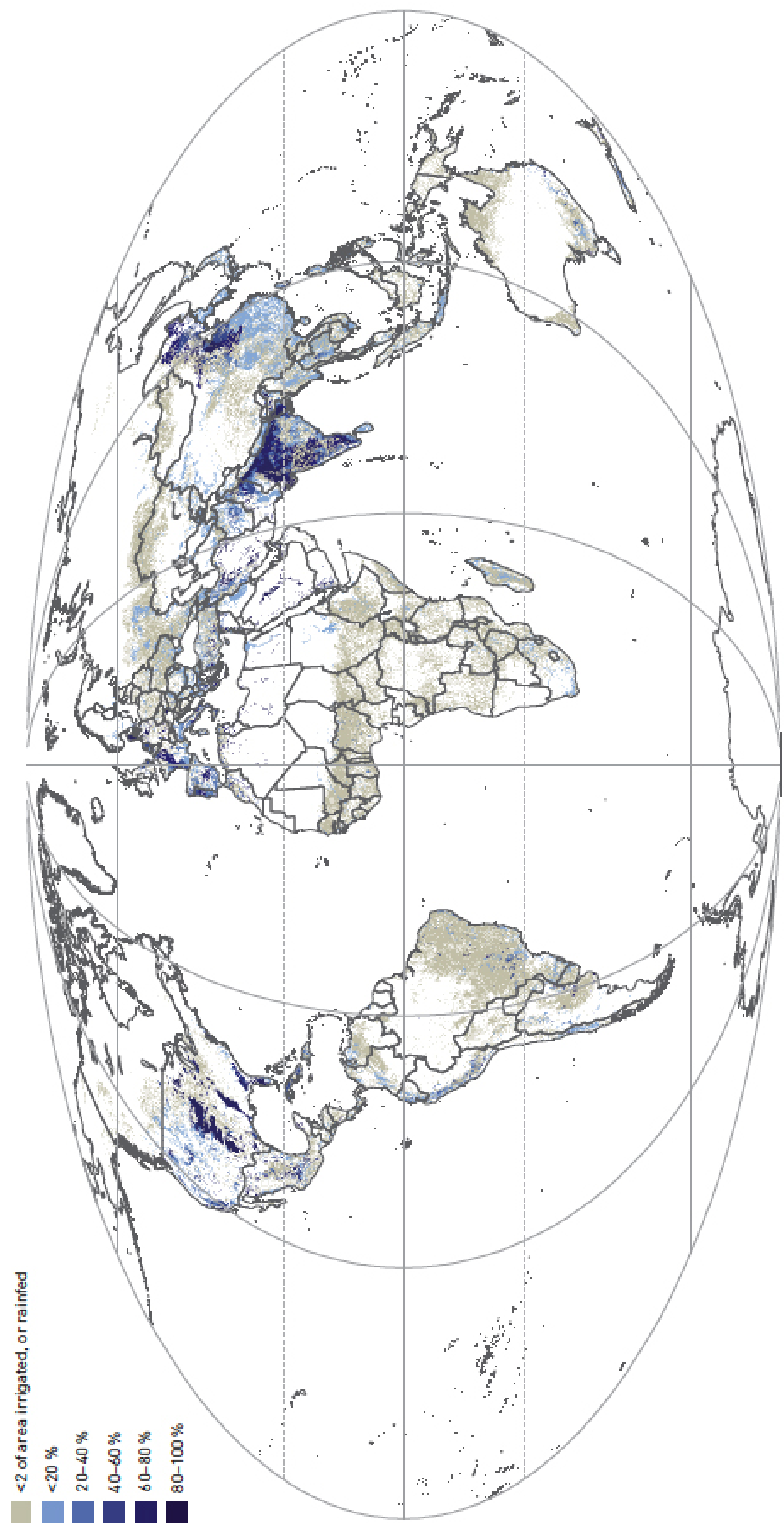
Some regionally specific factors also played a part. In Asia, almost all sites had been developed. Eastern Europe and the countries of Central Asia, which developed irrigation rapidly in the 1960s and 1970s, entered a period of economic crisis and reorganization after the break-up of the former Soviet Union. Some parts of Eastern Europe and the Russian Federation have seen large areas equipped for irrigation abandoned in the last two decades.

Sources of irrigation water

Irrigation extracts water from rivers, lakes and aquifers. About 188 million ha (62 percent of the irrigated area), is supplied from surface water, and 113 Mha (38 percent) from groundwater (Map 1.7). Following the introduction of tubewell technology, and driven by low energy prices, groundwater use has grown rapidly in recent years, particularly in Asia, Northern Africa and the Middle East. From agricultural census data for India, the irrigated areas equipped with groundwater structures rose from approximately 10 Mha in 1960 (Mukherji and Shah, 2005) to almost 40 Mha by 2010 (Seibert *et al.* 2010). In South Asia, groundwater now accounts for 57 percent of the total irrigated area, and in the Arabian Peninsula for 88 percent.

Non-conventional sources of water such as treated wastewater and desalinated water provide a minor source of irrigation water (about 1 percent). Use of treated wastewater is on the increase as urban areas invest in treatment, and its use is popular for peri-urban cropping. Desalinated water is used for irrigation where high-value crops are grown and no alternative sources of water are available, but these tend to be exceptional cases.

MAP 1.7: PERCENTAGE OF IRRIGATED AREA SERVICED BY GROUNDWATER



Source: *Siebert et al. (2010)*

Water resources constraints

In some regions, the competition for water and the growing water scarcity are constraining both current availability of water for irrigation and further expansion of the irrigated area. There are already very severe water shortages, in particular in Western, Central and South Asia, which use half or more of their water resources in irrigation (Table 1.9), and in Northern Africa, where withdrawals for irrigation exceed renewable resources due to groundwater overdraft and recycling. By contrast, Southern America barely uses 1 percent of its resources. In many parts of the Middle East, North Africa, China and elsewhere, water tables are declining as farmers abstract over and above rates of replenishment from recharge and aquifer leakage.

TABLE 1.9: ANNUAL LONG-TERM AVERAGE RENEWABLE WATER RESOURCES AND IRRIGATION WATER WITHDRAWAL

Continent Regions	Precipitation (mm)	Renewable water resources* (km³)	Water-use efficiency ratio (%)	Irrigation water withdrawal (km³)	Pressure on water resources due to irrigation (%)
Africa	**678**	**3 931**	**48**	**184**	**5**
Northern Africa	96	47	69	80	170
Sub-Saharan Africa	815	3 884	30	105	3
Americas	**1 091**	**19 238**	**41**	**385**	**2**
Northern America	636	6 077	46	258	4
Central America and Caribbean	2 011	781	30	15	2
Southern America	1 604	12 380	28	112	1
Asia	**827**	**12 413**	**45**	**2 012**	**16**
Western Asia	217	484	47	227	47
Central Asia	273	263	48	150	57
South Asia	1 602	1 766	55	914	52
East Asia	634	3 410	37	434	13
Southeast Asia	2 400	6 490	19	287	4
Europe	**540**	**6 548**	**48**	**109**	**2**
Western and Central Europe	811	2 098	43	75	4
Eastern Europe and Russian Federation	467	4 449	67	35	1
Oceania	**586**	**892**	**41**	**19**	**2**
Australia and New Zealand	574	819	41	19	2.3
Pacific Islands	2 062	73	-	0.05	0.1
World	**809**	**43 022**	**44**	**2 710**	**6**
High-income	622	9 009	45	383	4
Middle-income	872	26 680	39	1 136	4
Low-income	876	7 332	50	1 191	16
Low-income food deficit	**881**	**13 985**	**48**	**1 813**	**13**
Least-developed	**856**	**4 493**	**28**	**190**	**4**

* Refers to internal renewable water resources; it excludes 'incoming flows' at the regional level.

Source: FAO (2010c)

At the country level, variations are even higher. In 2005–7, four countries (Libyan Arab Jamahiriya, Saudi Arabia, Yemen and Egypt) used volumes of water for irrigation that were larger than their annual renewable water resources. Overall, eleven countries used more than 40 percent of their water resources for irrigation, the threshold that is considered critical. An additional eight countries withdrew more than 20 percent of their water resources, indicating substantial pressure and impending water scarcity.

For several countries, relatively low overall figures may give an overly optimistic impression of the level of water stress: China, for instance, is facing severe water shortage in the north while the south still has abundant water resources. Groundwater mining also occurs in certain parts of some other countries of the Near East, and in South and East Asia, Central America and in the Caribbean, even if at the national level the water balance may still be positive.

Irrigation and land productivity

Irrigation has contributed greatly to the improvements in global agricultural productivity and output in recent decades. India and China tripled production in the 25 years from 1964–6 to 1997–9, mainly through investment in irrigation and widespread adoption of measures to enhance land and water productivity. At present in developing countries, irrigated agriculture covers about a fifth of all arable land, but accounts for nearly half (47 percent) of all crop production and almost 60 percent of cereal production. In the least-developed countries, irrigation accounts for less than one-fifth (17 percent) of the harvested cereals area but almost two-fifths (38 percent) of cereal production (Table 1.10).

Irrigated agriculture is highly diverse. The irrigation unit may range from an individual farm up to massive integrated schemes such as the Rohri canal system in Pakistan, which covers 1.04 Mha.

The predominant models are: large-scale public systems (either paddy fields for rice production in humid areas or for staples and cash crops in dry areas); small- and medium-scale community-managed systems; commercial private systems for cash crops; and farm-scale individually managed systems producing for the local market (Molden, 2007: 359). Water conveyance and distribution may be by gravity or under pressure, and management and institutional set-up public, user-run, private, community-based, or a combination.

Water productivity and productivity gaps

In water-scarce countries such as Mexico, the challenge is to optimize water productivity in the face of competition from municipal and industrial demand. In much of China and India, the very high agricultural use of water is prompting improvements

TABLE 1.10: SHARES OF IRRIGATED LAND AND SHARE OF IRRIGATED CEREAL PRODUCTION IN TOTAL CEREAL PRODUCTION (2006)

	All irrigated crops		Irrigated cereals		
Continent Regions	Actually irrigated land as % of cultivated land	Harvested irrigated land as % of total harvested land	Harvested irrigated cereal land as % of total harvested irrigated land	Harvested irrigated cereal land as % of total harvested cereal land	Harvested irrigated cereal production as % of total cereal production
Africa	**5**	**7**	**48**	**7**	**24**
Northern Africa	21	43	48	33	75
Sub-Saharan Africa	2	3	48	3	9
Americas	**10**	**15**	**44**	**14**	**22**
Northern America	11	20	43	15	22
Central America and Caribbean	7	18	32	17	32
Southern America	8	8	47	13	22
Asia	**34**	**43**	**68**	**51**	**67**
Western Asia	28	49	52	32	48
Central Asia	30	43	45	27	45
South Asia	38	41	70	52	70
East Asia	44	58	69	68	78
Southeast Asia	19	21	84	35	49
Europe	**5**	**9**	**28**	**4**	**8**
Western and Central Europe	9	12	30	5	10
Eastern Europe and Russian Federation	1	5	23	2	4
Oceania	**7**	**12**	**14**	**2**	**7**
Australia and New Zealand	7	12	14	2	7
Pacific Islands	1				
World	**17**	**25**	**62**	**29**	**42**
High-income	11	19	39	13	20
Middle-income	26	28	63	32	49
Low-income	14	26	69	33	55
Low-income food deficit	**26**	**34**	**68**	**42**	**64**
Least-developed	**8**	**10**	**83**	**17**	**38**

Sources: FAO (2010b,c)

in water productivity, but environmental issues of pollution and groundwater overdraft are threatening the resource base. In Pakistan, drainage problems and resultant salinization dominate the irrigation agenda, while flood control is a preoccupation in the coastal deltas of Bangladesh and Vietnam.

Irrigation systems typically have yields at least twice those of nearby rainfed crops. Globally, rainfed cereals yields in the developing world average 1.5t/ha, but irrigated yields are 3.3t/ha. Irrigated cropping intensities are typically higher too, with two crops per year in most of Asia (Faurès *et al.*, 2007). Water productivity has also been increasing: over the last 40 years, both rice and wheat have more than doubled their yield per unit of water. But as demand grows, more production will be needed from these same equipped areas.

Over the last 50 years, the rate of increase in production for globally important crop groups exceeds the rate of increase of the extent of arable land and permanent crops. Cereals are by far the most important crop group (on the basis of total harvested area) and have registered relatively large average increases in yields (Figure 1.5). More than two-thirds of the increase in production has come from yield increases, especially under irrigated conditions. Bruinsma (2003) estimated that 77 percent of production increases in developing countries came from 'intensification' arising from increases in both yield and cropping intensities. South and East Asia, where the share of irrigation in the cultivated area is highest, produced the most rapid growth in productivity, with 94 percent of increased production attributable to intensification.

Two main factors have driven up irrigated yields: the widespread adoption of new varieties, inputs and husbandry practices; and breakthroughs in irrigation technology, such as tubewell and pressurized irrigation.

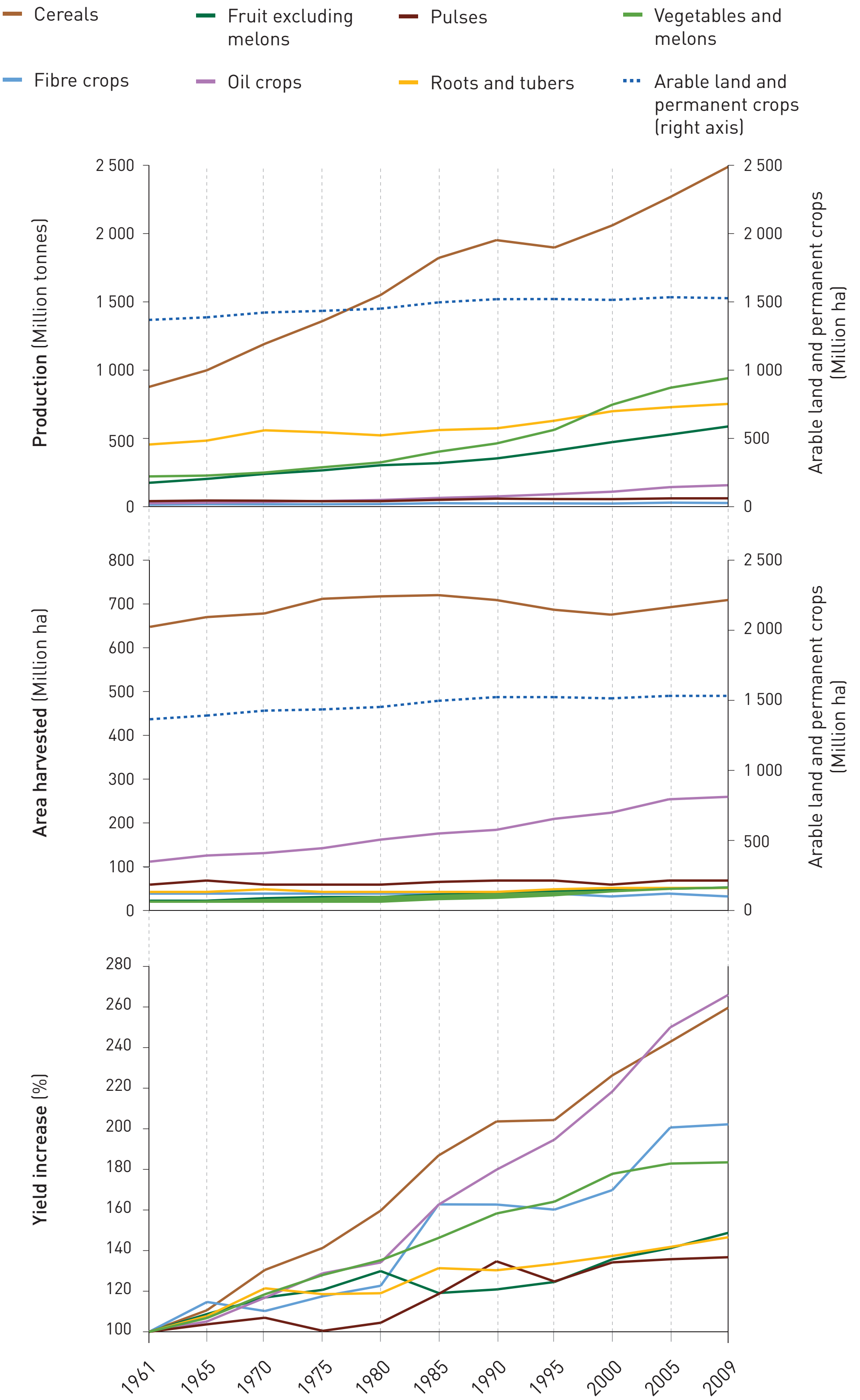
Forests, rangelands, inland fisheries and aquaculture

Forests

FAO's *Global forest resources assessment* provides regular estimates of the state of the world's forests, their extent and health, and the status of their socio-economic and environmental functions (FAO, 2010d). In 2010, forests covered approximately 4 billion ha. Deforestation arising mainly from the conversion of tropical forests to agricultural land has recently shown signs of decreasing, but still continues at an alarming rate. Around 13 Mha of forest were converted to other uses or lost through natural causes each year in the last decade, compared with 16 Mha per year in the 1990s. However, during the last decade, the net reduction in forest areas has been significantly limited by large-scale planting of trees, estimated at 5.2 Mha per year during the first decade of the 21st century. Net losses of forested land were concentrated in South America, sub-Saharan Africa, Southeast Asia and Oceania, while the US, India, China, Russia and several European countries showed net gains in forested land. Primary forests account for 36 percent of forest area, but have decreased by more than 40 Mha since 2000. Reduction in primary forests may have important impacts on forest biodiversity.

Forests play a crucial role in the hydrological cycle, which is why they must be taken into consideration when analysing water issues at landscape level. They capture and store water, prevent soil erosion, and serve as natural water purifica-

FIGURE 1.5: INCREASES IN WORLD PRODUCTION, AREA HARVESTED AND CROPLAND EXTENT, 1961–2009



Source: FAO (2010a)

tion systems. Forests influence the amount of water available, regulate surface and groundwater flows, and ensure high water quality. Moreover, forests and trees contribute to the reduction of water-related risks such as landslides, local floods and droughts, and help prevent desertification and salinization. Forested watersheds and wetlands supply three-quarters of the world's accessible fresh water to satisfy domestic, agricultural, industrial and ecological needs (FAO, 2008c).

Rangelands

Rangelands extend over all latitudes, and are usually characterized by low biomass production due to constraints related to soil, temperature and water availability. They cover some 25 percent of the global land area, and include the drylands of Africa (66 percent of the total continental land area) and the Arabian Peninsula, the steppes of Central Asia and the highlands of Latin America (Nori and Neely, 2009). Vegetation is mostly dominated by natural plant communities of perennial and annual species, including grasses, shrubs and trees. By their nature, rangelands are fragile ecosystems and when mismanaged readily result in degradation, loss of biodiversity and water retention capacity, carbon emissions and reduced productivity.

The extent and trends in rangelands are hard to assess. Global statistics indicate that the total area of rangelands was 3.43 billion ha in 2000, and decreased slightly to 3.36 billion ha by 2008. The reasons for these minor changes cannot be easily identified, though may include poor data, desertification and encroachment of agriculture. Large-scale conversion of drier grasslands to crops and inappropriate management has had unfortunate consequences, such as the 'dust bowl' of the Great Plains of the USA in the 1920s and 1930s. In the mid 20th century, drylands were widely cultivated in the USSR, but crop production was also unsustainable in that region (Boonman and Mikhalev, 2005) and these lands are now reverting to rangelands.

The contribution that rangelands make to the maintenance of ecosystem functions and biodiversity is important. In addition to providing feed for livestock, they play an important role as a habitat for wildlife, for water retention and for the conservation of plant genetic resources. The flora of rangelands is rich: about 750 genera and 12 000 grass species. These ecosystems are also important for the maintenance of fauna; for example, grasslands contain 11 percent of the world's endemic bird areas (White *et al.*, 2000: 40), and contribute to the maintenance of pollinators and other insects that have important regulating functions. Ecosystem benefits, especially regulating services such as water infiltration and purification, climate regulation (e.g. carbon sequestration) and pollination, have begun to be assigned an economic value, and systematic data-gathering in rangelands of both developed and developing countries should be a global priority.

Over 600 million people depend on rangelands for their livelihoods. Pastoral societies have developed strategies that continuously adapt to limited, highly variable and unpredictable resource endowments (e.g. by migratory livestock rearing), but both the rangelands and their users are also vulnerable to the changes brought by demographic pressure, conversion of cropland (Box 1.2) and climate change. Fluctuations in rainfall and drought are recurring problems in rangelands – for example, 70 million people in the Horn of Africa, many of whom are pastoralists, suffer from long-term chronic food insecurity (FAO, 2000). Table 1.11 lists major pastoral systems and illustrates how they evolve with time.

Significant amounts of carbon are lost from drylands due to poor management, driven largely by increasing human and livestock pressures. Due to degradation, dryland soils are now far from being saturated in carbon and their potential to sequester carbon may be very high. It has been estimated that improved range-

BOX 1.2: CONVERSION OF PASTURE TO CULTIVATION IN NORTH AFRICA, THE NEAR EAST AND THE MEDITERRANEAN

Degraded pastureland in Morocco

Escalating human and livestock populations combined with loss of traditional grazing rights have led to serious overstocking and degradation of pastures around the Mediterranean littoral. Much semi-arid land has been ploughed for annual cropping, which is unsustainable under current practices. Livestock production systems are changing through intensification, the gradual control of animal diseases and commercialization of livestock products, particularly in peri-urban areas. Drought and desertification processes are being exacerbated by climate change.

Photo: G. Schwilch

TABLE 1.11: REGIONAL ZONATION OF PASTORAL SYSTEMS

Zone	Main Species	Current Status
Sub-Saharan Africa	Cattle, camel, sheep, goats	Declining due to advancing agriculture
Mediterranean	Small ruminants	Declining due to enclosure and advancing agriculture
Near East and South-Central Asia	Small ruminants	Declining in some areas due to enclosure and advancing agriculture
India	Camel, cattle, sheep, goats	Declining due to advancing agriculture but peri-urban livestock production expanding
Central Asia	Yak, camel, horse, sheep, goats	Expanding following de-collectivization
Circumpolar	Reindeer	Expanding following de-collectivization in Siberia, but under pressure in Scandinavia
North America	Sheep, cattle	Declining with increased enclosure of land and alternative economic opportunities
Andes	Llama, alpaca	Contracting llama production due to expansion of road systems and European-model livestock production but expansion of alpaca wool production

Source: Bleach (1999)

land management has the biophysical potential to sequester 1 300–2 000 Mt CO_2eq worldwide to 2030 (Tennigkeit and Wilkes, 2008). Strategies to increase the stock of carbon in rangelands include restoring soil organic matter and root biomass, thereby enhancing soil biota (e.g. rehabilitation with improved legumes and grasses; manure cycling and agroforestry; erosion control; afforestation and forest restoration; optimal livestock densities; water conservation and harvesting; land-use change, such as from crops to grass/trees; set-aside). However, there are still significant gaps in knowledge about dryland carbon sequestration potential, acceptable methodologies and cost–benefit analysis of carbon-sequestering practices for small-scale rural farmers and pastoralists.

Fodder and grasslands

Grasslands (including rangelands, shrubland, pasture land, and cropland sown with pasture trees and fodder crops) occupy almost 30 percent of the emerged ice-free land areas. Fodders and pastures cover over 60 percent of the world's agricultural land (FAO, 2010b). Fodder and grasslands are multipurpose: they provide essential ecosystem services and support livelihoods in a number of ways (e.g. as a genetic resource for food production and sustainable production intensification; as a resource for energy production; as a raw material in industrial production; and for carbon sequestration). Many permanent fodder and grassland areas are used for watershed protection, polluted-land rehabilitation and bio-energy production. The sustainable intensification of crop–livestock systems based on improved management of fodders, grasslands and rangelands could therefore contribute significantly to the enhancement of sustainable development on a wide scale (Box 1.3). Globally, grassland soils have the potential to sequester 0.2–0.8 Gt CO_2 per year by 2030, depending on grazing and other management practices applied. Grassland cover can capture 50–80 percent more water, reducing risks of droughts and floods. These attributes taken together are critical for climate change mitigation and adaptation.

The crop–livestock sector provides livelihoods to the majority of smallholders around the world, and rapidly increasing demand for livestock products implies that means must be found to decrease the production footprint of livestock systems. This is an urgent rationale for integrated crop–livestock systems, for which crop residues provide feed for livestock, which in turn produce manure to fertilize crops, in on-site or within-landscape nutrient cycling. Although they have been a feature of traditional agriculture for centuries, integrated crop–livestock systems are now benefiting from synergistic components provided by the modern crop, livestock and agroforestry sectors.

Grasslands are important to the livelihoods of almost a billion people, including some 200 million pastoralist households. Improving crop intensification and diversification practices through the introduction of fodders, forage legumes and mixed grass–forage species, efficient use of manure and nutrient management, and diversification of crop and livestock production at farm level, will assist these people to increase the stability of their incomes and the efficient use of their soil and water resources, and to improve the mitigation and adaptation potential of their agricultural practice.

Inland fisheries and aquaculture

Globally, lakes, reservoirs and wetlands important for inland fisheries cover an area of about 7.8 million km^2. Relatively high proportions of land are covered with surface

BOX 1.3: FODDER GRASSES FOR FEED AND FUEL FOR ENERGY

Today we utilize large amount of plant produce for animal feed, and we need to rethink our systems by improving the use of flexible fodders that can provide feed, fuel, carbon sequestration, increase biodiversity of the ecosystem and improved soil fertility, according to the economic and sustainability priorities of the farmer. Among such fodders are *Pennisetum purpureum* (elephant grass), *Miscanthus giganteus* (switchgrass) and *Setaria* spp. They produce high biomass yields, can be converted to biofuels in biorefineries and leave a surplus of fodder for livestock production. They also contain material that can be utilized as raw material in industry.

waters in Southeast Asia, North America, east and central West Africa, the northern part of Asia, Europe and South America (FAO 2010a). Inland fisheries represent an extremely diverse activity that includes large-scale industrial fishing, as well as small-scale and subsistence fishing that require little or no financial investment in order to participate. As such, inland fisheries provide quality nutrition, livelihood opportunities and a safety net for the poor when other food production sectors may fail.

About 90 percent of inland fish is caught in developing countries and 65 percent is caught in low-income, food-deficit countries. Asia and Africa regularly account for about 90 percent of reported landings. The reported harvest from the world's inland fisheries has grown from 2 million tonnes in 1950 to over 10 million tonnes in 2008. However, the production is believed to be much higher, as much of the small-scale and subsistence fishing is not registered. Large-scale and industrial inland fisheries, for example on the Great Lakes of Africa, can produce hundreds of millions of US dollars' worth of fish, which are often exported (FAO, 2010a).

Globally, aquaculture has increased from less than 1 million tonnes of annual production in 1950 to 52.5 million tonnes in 2008, and accounts for 45.7 percent of the world's food fish production for human consumption (FAO, 2010a). Integrated approaches to land and water use have been successfully applied in many parts of the world (FAO/ICLARM/IIRR, 2001; Halwart and Van Dam, 2006). Rice–fish culture, often operating at family scale with renovated paddy fields, has expanded rapidly among rice farmers in China in recent decades, and the total area of rice fields used for aquaculture was 1.47 Mha in 2008. Cage aquaculture in both freshwater lakes and rivers has flourished in many countries, as a very efficient non-consumptive use of freshwaters.

Asia (and especially China) has the greatest freshwater aquaculture production in relation to land area and water surface area, although some European and African countries are also significant, while the Americas have relatively low freshwater aquaculture production per unit area of land or water, although the potential is there (Bostock *et al.*, 2010; Aguilar-Manjarrez *et al.*, 2010). While in Africa and Latin America there is still important room for freshwater aquaculture growth, the use of freshwaters for this sector will become more restricted due to urban development and high competition for land, and especially freshwater resources in countries and regions with high population density, such as in Asia. Fish production in the coastal and offshore marine environment offers alternative and new opportunities for aquaculture and for the supply of world food fish when freshwater and land become more scarce (FAO, 2010a).

Agricultural demand towards to 2050

Demand for food and fibre towards 2050

It is expected that world population will grow from the current about 6.9 billion to about 9 billion in 2050. Demand for food and fibre will grow more quickly as incomes and standards of nutrition rise and populations move towards more land- and water-intensive diets, in particular the consumption of more meat and dairy products. Current trends and model simulations indicate that global cereal demand will grow from roughly 2.1 billion tonnes today to about 3 billion tonnes in 2050 (FAO, 2006b). Thus, by 2050, the world will be demanding the production of almost an extra billion tonnes of cereal grain annually, and 200 million additional tonnes of livestock products.

Production response

Estimates of growth in crop production (Bruinsma, 2009) are that world agricultural production could rise by about 1.3 percent annually to 2030 and by 0.8 percent annually over the period 2030–50. To keep pace with population growth, food production is expected to rise slightly faster in developing countries than in developed countries: 1.5 percent a year from 2005–2030, and 0.9 percent a year over 2030–50. These estimates are based on an assessment of production capacity to respond to effective demand. Globally, the result would be a 43 percent increase in output by 2030, and 70 percent by 2050 over 2005–7 levels. Regionally, the fastest rates of growth of cereals production are anticipated in sub-Saharan Africa, where demographic pressure remains strong, and in Latin America and Australasia, where there is scope for expansion of commercial food production (Table 1.12).

These rates are lower than those over the last half-century (Table 1.12). Estimates of future growth are based on projections that about four-fifths of the growth in developing countries could come from intensification in the form of yield increases (71 percent) and higher cropping intensities (8 percent). The share of intensification would be even higher in land-scarce regions such as South Asia (95 percent), and Near East and North Africa (100 percent). By contrast, arable land expansion is expected to remain a factor in crop production growth in some areas of sub-Saharan Africa and Latin America, although less so than in the past (Bruinsma, 2009). However, this is likely to lead to losses in important ecosystem and cultural services. Furthermore, even with a doubling of production in developing countries by 2050, 5 percent of their population would remain undernourished (Table 1.13).

TABLE 1.12: HISTORICAL AND PROJECTED GROWTH IN CEREAL PRODUCTION

Continent Regions	Annual growth in cereal production (%) 1961–2006	 2006–2050
Africa	**2.4**	**1.9**
Northern Africa	3.0	1.6
Sub-Saharan Africa	2.3	2.0
Americas	**2.0**	**1.2**
Northern America	1.8	1.0
Central America and Caribbean	1.7	1.8
Southern America	2.6	1.7
Asia	**2.5**	**0.7**
Western Asia	2.4	1.0
Central Asia	1.1	0.8
South Asia	2.3	1.1
East Asia	2.5	0.3
Southeast Asia	2.9	0.8
Europe	**1.1**	**0.3**
Western and Central Europe	1.5	0.2
Eastern Europe and Russian Federation	0.3	0.5
Oceania	**2.3**	**2.0**
Australia and New Zealand	2.3	2.0
Pacific Islands	-	-
World	**2.0**	**0.9**
High-income	1.6	0.8
Middle-income	2.1	0.8
Low-income	2.4	1.2
Low-income food deficit	**2.7**	**0.9**
Least-developed	**1.9**	**1.9**

Source: FAO (2010a)

TABLE 1.13: PROJECTED GROWTH IN AGRICULTURAL PRODUCTION: MOST LIKELY OUTCOMES

	Agricultural production index			Remaining undernourished	
	2005–7	2030	2050	%	Millions
World	100	143	170	n.a.	n.a.
Developing countries	100	158	197	4.8	370

Source: Alexandratos (2009)

Implications for irrigated agriculture

Potential for intensification in irrigation

The area equipped for irrigation is projected to increase by about 6 percent by 2050. Water withdrawals for irrigation are projected to increase by about 10 percent by 2050. Irrigated food production is projected to increase by 38 percent, due to projected increases in cropping intensities and increases in productivity (Tubiello and van der Velde, 2010). Overall, the scope to improve both land and water productivity on irrigation schemes is considerable, as illustrated by the large discrepancies observed between schemes and within schemes.

It is projected that cropping intensities on irrigated land actually in use will increase worldwide from 127 percent to 129 percent by 2050. In developing countries, higher intensities are expected, rising from 143 percent in 2005–7 to 147 percent by 2050 (Bruinsma, 2009; Frenken, 2010). These increases are technically feasible, and the best-managed systems already have cropping intensities of 200 percent or more. Key factors in achieving higher intensities will be modernization of infrastructure and institutional change to improve water service, together with the development of profitable agricultural markets (Nachtergaele *et al.*, 2010b).

Scope for expanding irrigated area

The potential for expansion of irrigated areas is difficult to establish. Past efforts by countries to assess their irrigation potential have resulted in estimates that combine land and water resources, economic and environmental considerations. Yet irrigation potential should be calculated on the basis of river basins, the logical geographical unit for water resources. When countries share common rivers, the risk is that the same water is double-counted in assessing irrigation potential in several countries. Furthermore, many irrigation potential estimates date from when environmental concerns were less acute and other sectors of water use were less demanding than today.

While potential for irrigation development is still abundant in several water-rich regions, it is in water-scarce regions where limits have already been reached. Sub-Saharan Africa and Latin America are the two regions that have exploited the least of their evaluated irrigation potential. In sub-Saharan Africa there is technically ample scope for expansion of irrigation. Highland areas such as the Fouta-Djallon and the Ethiopian highlands, for example, produce high volumes of runoff, but have low levels of water infrastructure. Subject to the availability of suitable sites and favourable economics, areas such as these could see diversion and development of irrigated agriculture. At the other extreme, the countries of Northern Africa, West Asia, Central Asia, and large parts of South Asia and East Asia have reached or are reaching their potential. Among these countries, FAO estimates that eight countries have expanded their irrigation beyond its potential, while 20 countries (including China) are above 75 percent of their potential.

The rate of expansion of land under irrigation is slowing substantially. Based on a comparison between supply (irrigation potential) and demand (for agricultural products), FAO has projected that the global area equipped for irrigation may increase at a relatively modest rate to reach 318 Mha in 2050, compared with around 301 Mha in 2006 (Table 1.14). This would represent an increase of around 6 percent (0.12 percent per year). Most of this expansion is projected to take place in developing countries. This rate of increase is much slower than in recent years; between 1961 and 2009, irrigated area worldwide grew at 1.6 percent a year, and at over 2 percent in the least-developed countries.

TABLE 1.14: AREA EQUIPPED FOR IRRIGATION PROJECTED TO 2050

Continent Regions	Area equipped for irrigation				
	Area (million hectares)			Annual growth (%)	
Year	1961	2006	2050	1961–2006	2006–2050
Africa	**7.4**	**13.6**	**17.0**	**1.3**	**0.5**
Northern Africa	3.9	6.4	7.6	1.0	0.4
Sub-Saharan Africa	3.5	7.2	9.4	1.5	0.6
Americas	**22.6**	**48.9**	**46.5**	**1.6**	**–0.1**
Northern America	17.4	35.5	30.0	1.5	–0.4
Central America and Caribbean	0.6	1.9	2.4	2.5	0.5
Southern America	4.7	11.6	14.1	1.9	0.5
Asia	**95.6**	**211.8**	**227.6**	**1.7**	**0.2**
Western Asia	9.6	23.6	26.9	1.9	0.3
Central Asia	7.2	14.7	15.0	1.5	0.0
South Asia	36.3	85.1	85.6	1.8	0.0
East Asia	34.5	67.6	76.2	1.4	0.3
Southeast Asia	8.0	20.8	23.9	2.0	0.3
Europe	**12.3**	**22.7**	**24.6**	**1.3**	**0.2**
Western and Central Europe	8.7	17.8	17.4	1.5	0.0
Eastern Europe and Russian Federation	3.6	4.9	7.2	0.6	0.9
Oceania	**1.1**	**4.0**	**2.8**	**2.7**	**–0.8**
Australia and New Zealand	1.1	4.0	2.8	2.7	–0.8
Pacific Islands	0.001	0.004	–	2.9	–
World	**139.0**	**300.9**	**318.4**	**1.6**	**0.1**
High-income	26.7	54.0	45.1	1.5	–0.4
Middle-income	66.6	137.9	159.4	1.5	0.4
Low-income	45.8	108.9	113.8	1.8	0.1
Low-income food-deficit	**82.5**	**187.6**	**201.9**	**1.7**	**0.2**
Least-developed	**6.1**	**17.5**	**18.4**	**2.2**	**0.1**

Sources: FAO (2006b, 2010b,c)

The expansion of the area equipped for irrigation is projected to be strongest (in absolute terms) in the more land-scarce regions hard-pressed to raise crop production through more intensive cultivation practices. Middle-income countries are projected to add 21 Mha, and the low-income food-deficit countries about 14 Mha. By contrast, high-income countries in North America, Western Europe and Australasia are expected to reduce their irrigated area. Irrigated areas in Eastern Europe, the Russian Federation and Central Asia are expected to return towards the levels prior to the break-up of the Soviet Union. Although the overall arable area in China is expected to decrease further, the irrigated area is projected to continue to expand through conversion of rainfed land. Most of the expansion of irrigated land will be achieved by converting land in use in rainfed agriculture into irrigated land. The pressure on water resources will continue to increase everywhere, even in places where water resources are already stretched, like Northern Africa and large parts of Asia (Table 1.15).

Non-conventional sources of water

Use of non-conventional sources of water as an alternative to freshwater, although currently a minor source, is increasing in certain regions and countries. Globally, only 1 percent of the water used in agriculture consists of treated wastewater or desalinated water. However, in regions such as the Arabian Peninsula, the rate of use is around 10 percent, and in countries such as Kuwait, Malta or Qatar, non-conventional sources of water constitute more than 50 percent of the water used, of which around 40 percent is desalinated water and 10 percent wastewater. The top five countries reporting the highest annual per capita volume of treated waste water used for irrigation (cubic metres per year per capita) are Kuwait (82.3), United Arab Emirates (71.1), Qatar (51.7), Israel (46.4) and Cyprus (31.9) (Mateo-Sagasta and Burke, 2010). While desalinated water is still rarely used for irrigated agriculture, mainly because of the high cost of desalination, peri-urban agriculture often relies on urban wastewater to satisfy water needs.

Implications for rainfed agriculture

Although irrigated agriculture is expected to produce most of the increased production needed in coming years, rainfed agriculture, which currently accounts for 60 percent of all agricultural output in developing countries, will remain an important contributor to the world's food production. Bruinsma (2003) projected that 43 percent of the production increment over 1997–2030 would come from rainfed agriculture. If considerable expansion of rainfed cultivated area is to be avoided, the productivity of rainfed cultivation would need to rise.

TABLE 1.15: ANNUAL LONG-TERM AVERAGE RENEWABLE WATER RESOURCES AND IRRIGATION WATER WITHDRAWAL, 2006, 2050

Continent Regions	Precipitation (mm)	Renewable water resources * (km³)	Water use ratio ** (%)		Irrigation water withdrawal (km³)		Pressure on water resources due to irrigation (%)	
			2006	2050	2006	2050	2009	2050
Africa	**678**	**3 931**	**48**	**53**	**184**	**222**	**5**	**6**
Northern Africa	96	47	69	81	80	95	170	204
Sub-Saharan Africa	815	3 884	30	32	105	127	3	3
Americas	**1 091**	**19 238**	**41**	**41**	**385**	**438**	**2**	**2**
Northern America	636	6 077	46	46	258	244	4	4
Central America and Caribbean	2 011	781	30	33	15	23	2	3
Southern America	1 604	12 380	28	29	112	171	1	1
Asia	**827**	**12 413**	**45**	**48**	**2 012**	**2 073**	**16**	**17**
Western Asia	217	484	47	56	227	251	47	52
Central Asia	273	263	48	50	150	133	57	50
South Asia	1 602	1 766	55	58	914	889	52	50
East Asia	634	3 410	37	42	434	458	13	13
Southeast Asia	2 400	6 490	19	21	287	342	4	5
Europe	**540**	**6 548**	**48**	**48**	**109**	**100**	**2**	**2**
Western and Central Europe	811	2 098	43	43	75	81	4	4
Eastern Europe and Russian Federation	467	4 449	67	67	35	19	1	0
Oceania	**586**	**892**	**41**	**41**	**19**	**25**	**2**	**3**
Australia and New Zealand	574	819	41	41	19	25	2	3
Pacific Islands	2 062	73	–	–	0.05	–	–	–
World	**809**	**43 022**	**44**	**47**	**2 710**	**2 858**	**6**	**7**
High-income	622	9 009	45	45	383	317	4	4
Middle-income	872	26 680	39	42	1 136	1 330	4	5
Low-income	876	7 332	50	52	1 191	1 212	16	17
Low-income food-deficit	**881**	**13 985**	**48**	**51**	**1 813**	**1 992**	**13**	**14**
Least-developed	**856**	**4 493**	**28**	**31**	**190**	**263**	**4**	**6**

* Refers to internal renewable water resources; excludes 'incoming flows' at the regional level.

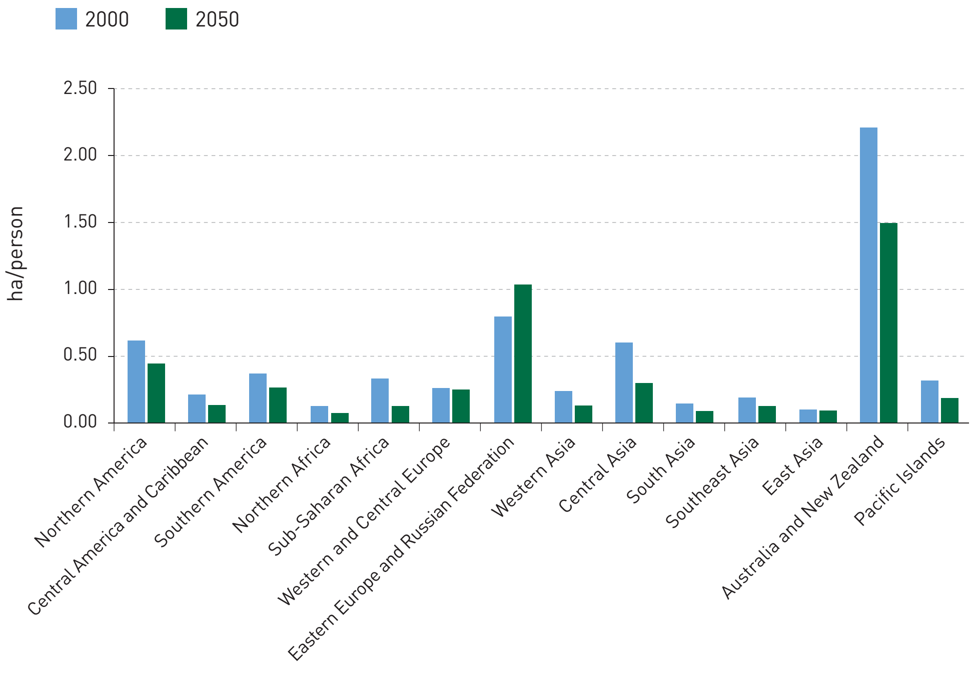
** The water use ratio is the ratio of the irrigation water requirement to the amount of water withdrawn for irrigation

Source: FAO (2010c)

Opportunities for expansion of rainfed agriculture

In some areas, cultivated land is already very limited in relation to population. Overall, developing countries are more constrained by land shortages than developed countries. Availability of cultivated land per capita in the developed world (0.5 ha) is twice that of developing countries (0.2 ha). The per capita availability of cultivated land is less than 0.1 ha in East Asia, compared to more than 2 ha in Australia. Apart

FIGURE 1.6: CULTIVATED LAND, PER CAPITA, 2000, 2050



Source: adapted from Fischer et al. (2010)

from Central Asia, no region of the developing world has as much land per capita as the developed world average (Figure 1.6), and the situation is deteriorating.

Under strong demographic pressure in the coming decades, the per capita availability of land in developing countries is expected to halve (to 0.12 ha) by 2050, resulting in increasing pressures for expanding the cultivated area (Fischer *et al.*, 2010).

Suitability of further land for cultivation

Worldwide, land suitable for cropping (prime and good categories combined) is about 4.4 billion ha (4.0 billion ha if areas with protected status are excluded). This is considerably more than the 1.6 billion ha currently cultivated (Table 1.16). There is thus a large area of currently uncultivated land that could theoretically be brought into production. However, much of this land is effectively not available for crop production. In addition, it is generally of lower food potential than existing cultivated land: much of the presently agriculturally unused land suffers from constraints such as ecological fragility, low fertility, toxicity, high incidence of disease or lack of infrastructure. These constraints reduce productivity, require high input use and management skills to permit its sustainable use, or require prohibitively high investments to be made accessible or disease-free. Fischer *et al.* (2002) show that over 70 percent of the land with rainfed crop production potential in sub-Saharan Africa and Latin America suffers from one or more of these constraints.

TABLE 1.16: GLOBAL AVAILABILITY AND QUALITY OF LAND RESOURCES SUITABLE FOR CROP PRODUCTION (VALUE IN BRACKETS EXCLUDES LAND WITH PROTECTION STATUS)

Land quality	Cultivated land (billion ha)	Grassland and woodland ecosystems (billion ha)	Forest land (billion ha)	Other land (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: Fischer et al. (2010)

Thus, much of the land would be capable of producing only at low to medium average yields. Typical medium average yields for winter wheat are in the range 3–5 t/ha, or for wetland rice 3–6 t/ha. Only with very intensive management and high levels of inputs could most of these lands produce maximum attainable yields of up to 10t/ha for winter wheat and 9t/ha for wetland rice. In addition, there would be a high opportunity cost to conversion from existing land use. All of this land currently forms part of existing ecosystems with high economic, social and environmental value, which would be lost by change of use. A large fraction may not available for crop production due to its protected status, its carbon sequestration and biodiversity value (including forests), and its current use for feeding the world's 3.5 billion ruminant livestock (Fischer *et al.*, 2010).

Finally, land with crop production potential not in agricultural use is unevenly distributed between regions and countries, and does not always correspond to where the market and economic opportunities for expanded production exist. In the developing world, the regions with the largest apparent potential for agricultural expansion are sub-Saharan Africa and Southern America. In the developed world, Europe, Russia, Northen America and Australia have large areas of suitable land. Half of the total balance is concentrated in just seven countries: Brazil, Democratic Republic of the Congo, Angola, Sudan, Argentina, Colombia and Bolivia. At the other extreme, there is virtually no spare land available for agricultural expansion in the agricultural areas of South Asia, East Asia, the Near East and Northern Africa.

Conclusions

This chapter has shown how global land and water resources have been exploited to respond to large increase in demand. Most of the additional agricultural production has been derived from intensification, particularly on prime agricultural land with the application of irrigation. Rainfed systems in the tropics and mountain regions, by contrast, have exhibited slower increases in productivity and have proved more vulnerable to food insecurity and poverty. Many uses of land and water systems are continuing to impose negative impacts on ecosystem services, both on- and off-site.

Yet world food production could increase by 70 percent over the next 40 years (and could double in developing countries). While it is likely that production will respond to rising demand, it is the way it will achieve it that will be important. Success will therefore be measured not just in terms of a stable and reliable supply of quality food for the world's population. The environmental sustainability of the main land and water systems, and their capacity to satisfy the livelihood requirements of both urban and rural populations, will be important criteria as well.

Policy-makers will need to take decisions on trade-offs between production and environment. It is only in the light of full information on the consequences for socio-economic outcomes and environmental impacts that decisions can be make. Decisions will need to be accompanied by measures to reduce negative impacts of policy decisions, and risks will require management if production is to meet rising demand without further degradation of land and water resources, or without compromising food security and poverty targets.