CHAPTER 4

Crop production and natural resource use

4.1 Introduction

This chapter discusses the main agronomic factors underlying the projections of crop production presented in Chapter 3. The focus is on crop production in developing countries, for which the projections were unfolded into land and yield projections under rainfed (five land classes) and irrigated conditions. Although the underlying analysis was carried out at the level of individual countries, the discussion here is limited to presenting the results at the level of major regions, which unavoidably masks wide intercountry differences. The parameters underlying the livestock production projections will be discussed in Chapter 5. Selected technology issues such as the scope for further yield increases, technologies in support of sustainable agriculture and the role of biotechnology are discussed in Chapter 11. Issues of environment and the possible impact of climate change on crop production are the subjects of Chapters 12 and 13.

4.2 Sources of growth in crop production

Aggregate crop production at the world level is projected to grow over the period to 2030 at 1.4 percent p.a., down from the annual growth of 2.1 percent of the past 30 years (Table 4.1). For the developing countries as a group, the corresponding growth rates are 1.6 and 3.1 percent p.a., respectively (or 1.8 and 2.7 percent p.a., excluding China). The reasons for this continuing deceleration in crop production growth have been explained in Chapter 3.

The projected increase in world crop production over the period from 1997/99 to 2030 is 55 percent, against 126 percent over the past period of similar length. Similar increases for the developing countries as a group are 67 and 191 percent, respectively. The only region where the projected increase would be about the same as the historical one would be sub-Saharan Africa, namely 123 and 115 percent, respectively. The faster growth in the developing countries, as compared to the world average, means that by 2030 this group of countries will account for almost three-quarters (72 percent) of world crop production, up from two-thirds (67 percent) in 1997/99 and just over half (53 percent) 30 years earlier.

Table 4.1 Annual crop production growth

	1969-99	1979-99	1989-99	1997/99 -2015	2015-30	1997/99 -2030
				Percentage		
All developing countries	3.1	3.1	3.2	1.7	1.4	1.6
excl. China	2.7	2.7	2.5	2.0	1.6	1.8
excl. China and India	2.7	2.6	2.5	2.0	1.7	1.9
Sub-Saharan Africa	2.3	3.3	3.3	2.6	2.5	2.5
Near East/North Africa	2.9	2.9	2.6	1.8	1.5	1.6
Latin America and the Caribbean	2.6	2.3	2.6	1.8	1.6	1.7
South Asia	2.8	3.0	2.4	2.1	1.5	1.8
East Asia	3.6	3.5	3.7	1.3	1.1	1.2
Industrial countries	1.4	1.1	1.6	0.9	0.9	0.9
Transition countries	-0.6	-1.6	-3.7	0.7	0.7	0.7
World	2.1	2.0	2.1	1.5	1.3	1.4

There are three sources of growth in crop production: arable land expansion which, together with increases in cropping intensities (i.e. increasing multiple cropping and shorter fallow periods), leads to an expansion in harvested area; and yield growth. About 80 percent of the projected growth in crop production in developing countries will come from intensification in the form of yield increases (67 percent) and higher cropping intensities (12 percent, Table 4.2). The share due to intensification will go up to 90 percent and higher in the land-scarce regions of the Near East/North Africa and South Asia. The results for East Asia are heavily influenced by China. Excluding the latter, intensification will account for just over 70 percent of crop production growth in East Asia. Arable land expansion will remain an important factor in crop production growth in many countries of sub-Saharan Africa, Latin America and some countries in East Asia, although much less so than in the past. The estimated contribution of yield increases is partly a result of the increasing share of irrigated agriculture in total crop production (see Section 4.4.1), and irrigated agriculture is normally more "intensive" than rainfed agriculture.

The results shown in Table 4.2 should be taken as rough indications only. For example, yields here are weighted yields (1989/91 price weights) for 34 crops and historical data for arable land for many countries are particularly unreliable.[1] Data on cropping intensities for most countries are non-existent and for this study were derived by comparing data on harvested land, aggregated over all crops, with data on arable land. The projections are the end result of a detailed investigation of present and future land/yield combinations for 34 crops under rainfed and irrigated cultivation conditions, for 93 developing countries.[2] In the developed countries, the area of arable land in crop production has been stagnant since the early 1970s and recently declining. Hence growth in yields and more intensive use of land accounted for all of their growth in crop production and also compensated for losses in their arable land area.

Growth in wheat and rice production in the developing countries increasingly will have to come from gains in yield (more than four-fifths), while expansion of harvested land will continue to be a major contributor to production growth of maize,

1 See Alexandratos (1995, p. 161, 168) for a discussion on problems with land use data.

2 Unfortunately, revised data for harvested land and yields by crop for China (mainland) are not available until the results of the 1997 Chinese Agricultural Census have been processed and published. Therefore, ad hoc adjustments had to be made to base year data based on fragmentary non-official information on harvested land and yield by crop.

Table 4.2 Sources of growth in crop production (percentage)

	Arable land expansion (1)		Increases in cropping intensity (2)		Harvested land expansion (1+2)		Yield increases	
	1961 -1999	1997/99 -2030	1961 -1999	1997/99 -2030	1961 -1999	1997/99 -2030	1961 -1999	1997/99 -2030
All developing countries	23	21	6	12	29	33	71	67
excl. China	23	24	13	13	36	37	64	63
excl. China and India	29	28	16	16	45	44	55	56
Sub-Saharan Africa	35	27	31	12	66	39	34	61
Near East/North Africa	14	13	14	19	28	32	72	68
Latin America and the Caribbean	46	33	-1	21	45	54	55	46
South Asia	6	6	14	13	20	19	80	81
East Asia	26	5	-5	14	21	19	79	81
World	15		7		22		78	
All developing countries								
Crop production – rainfed		25		11		36		64
Crop production – irrigated		28		15		43		57

possibly even more so than in the past (Table 4.3). These differences are partly because the bulk of wheat and rice is produced in the land-scarce regions of Asia and the Near East/North Africa while maize is the major cereal crop in sub-Saharan Africa and Latin America, regions where many countries still have room for area expansion. As discussed in Chapter 3, an increasing share of the increment in the production of cereals, mainly coarse grains, will be used in livestock feed. As a result, maize production in the developing countries is projected to grow at 2.2 percent p.a. against "only" 1.3 percent for wheat and 1.0 percent for rice. Such contrasts are particularly marked in China where wheat and rice production is expected to grow only marginally over the projection period, while maize production is expected to nearly double. Hence there will be a corresponding decline in the wheat and rice areas but an increase of 36 percent in the maize area.

The actual combination of the factors used in crop production (land, labour and capital) in the different countries will be determined by their relative prices. For example, taking the physical availability of land as a proxy for its relative scarcity and hence price, one would expect land to play a greater role in crop production the less scarce and cheaper it is. For the 60 countries out of the 93 developing countries studied in detail, which at present use less than 60 percent of their land estimated to have some rainfed crop production potential (see Section 4.3.1), arable land expansion is projected to account for one-third of their crop production growth. In the group of 33 land-scarce countries – defined here as countries with more

Table 4.3 Sources of growth for major cereals in developing countries (percentage)

	Harvested land expansion		Yield increases	
	1961 - 1999	1997/99 - 2030	1961 - 1999	1997/99 - 2030
Wheat	22	17	78	83
Rice	23	14	77	88
Maize	30	49	70	51

Table 4.4 Shares of irrigated production in total crop production of developing countries

Shares (percentage)	Arable land	All crops Harvested land	All crops Production	Cereals Harvested land	Cereals Production
Share in 1997/99	21	29	40	39	59
Share in 2030	22	32	47	44	64
Share in increment 1997/99–2030	33	47	57	75	73

than 60 percent of their suitable land already in use – the contribution of land expansion is estimated to be less than 10 percent.

For the developing countries, this study made an attempt to break down crop production by rainfed and irrigated land in order to analyse the contribution of irrigated crop production to total crop production. It is estimated that in the developing countries at present, irrigated agriculture, with about a fifth of all arable land, accounts for 40 percent of all crop production and almost 60 percent of cereal production (Table 4.4). It should be emphasized that, apart from some major crops in some countries, there are only very limited data on irrigated land by crops and the results presented in Table 4.4 are almost entirely based on expert judgement (see Appendix 2 for the approach followed in this study). Nevertheless, the results suggest an increasing importance of irrigated agriculture, which accounts for a third of the total increase in arable land and for over 70 percent of the projected increase in cereal production.

4.3 Agricultural land

At present some 11 percent (1.5 billion ha) of the globe's land surface (13.4 billion ha) is used in crop production (arable land and land under permanent crops). This area represents slightly over a third (36 percent) of the land estimated to be to some degree suitable for crop production. The fact that there remain some 2.7 billion ha with crop production potential suggests that there is still scope for further expansion of agricultural land. However, there is also a perception, at least in some quarters, that there is no more, or very little, land to bring under cultivation. In what follows, an attempt is made to shed some light on these contrasting views by first discussing the most recent estimates of land with crop production potential and some constraints to exploiting such suitable areas (Section 4.3.1). Then the projected expansion of the agricultural area during the next three decades (to 2030) is presented in Section 4.3.2, while Section 4.3.3 speculates about whether or not there will be an increasing scarcity of land for agriculture.

4.3.1 Land with crop production potential for rainfed agriculture

Notwithstanding the predominance of yield increases in the growth of agricultural production, land expansion will continue to be a significant factor in those developing countries and regions where the potential for expansion exists and the prevailing farming systems and more general demographic and socio-economic conditions favour it. One of the frequently asked questions in the debate on world food futures and sustainability is: how much land is there that could be used to produce food to meet the needs of the growing population? Since the late 1970s, FAO has conducted a series of studies to determine the suitability of land for growing various crops. Recently, a new study was undertaken together with the International Institute for Applied Systems Analysis (IIASA) to refine the methods, update databases and extend the coverage to all countries in the world by including also countries in temperate and boreal climates, which were previously not covered. A summary description of the method is given in Box 4.1 and a full description and presentation of results can be found in Fischer, van Velthuizen and Nachtergaele (2000).

Table 4.5 gives some results for selected crops and input levels. At a high input level (commercial farm operations, see Box 4.1), over 1.1 billion ha would be suitable for growing wheat at an average maximum attainable yield level of 6.3 tonnes/ha, i.e. taking into account all climate, soil and terrain constraints. At the low technology level (subsistence farming), 1.5 billion ha would be suitable, but at an average maximum yield level of only 2.3 tonnes/ha. The suitable area at this lower input level is greater because, for example, tractors (high input level) cannot be used on steep slopes. For developing countries alone, the estimates are 314 million ha and 5.3 tonnes/ha under the high technology level because most of the suitable area for wheat at this input level is in the developed countries. For the other crops shown, the bulk of the suitable area is in the developing countries.

Summing over all crops and technology levels considered (see Box 4.1), it is estimated that about 30 percent of the world's land surface, or 4.2 billion ha, is suitable for rainfed agriculture (Table 4.6). Of this area, the developing countries have some 2.8 billion ha of land of varying qualities that have potential for growing rainfed crops at yields above an "acceptable" minimum level. Of this land, nearly 960 million ha are already in cultivation. The remaining 1.8 billion ha would therefore seem to provide significant scope for further expansion of agriculture in developing countries. However, this favourable impression must be much qualified if a number of considerations and constraints are taken into account.

First, the method of deriving the land suitability estimates: it is enough for a piece of land to support a single crop at a minimum yield level for it to be deemed suitable. For example, large tracts of land in North Africa permit cultivation of only olive trees. These lands therefore are counted as "suitable" although one might have little use for them in practice (see also Box 4.2 for further similar qualifications).

Table 4.5 Land with rainfed crop production potential for selected crop and input levels

	Actual 1997/99		Total suitable			Very suitable		Suitable		Moderately suitable		Marginally suitable	
	A	Y	% of land	A	Y	A	Y	A	Y	A	Y	A	Y
Wheat – high input													
World	226	2.6	8.5	1139	6.3	160	9.4	397	7.8	361	5.2	221	3.0
All developing	111	2.5	4.1	314	5.3	38	8.2	97	6.7	105	4.7	74	2.7
Transition countries	51	2.0	15.6	359	6.3	44	9.6	107	8.2	130	5.3	78	3.4
Industrial countries	65	3.3	14.3	466	6.9	78	9.9	193	8.1	125	5.4	69	2.9
Wheat – low input													
World	226	2.6	11.3	1510	2.3	175	4.1	403	2.9	487	2.0	445	1.2
All developing	111	2.5	6.1	467	1.7	31	3.1	101	2.4	152	1.7	183	1.0
Transition countries	51	2.0	18.5	425	2.6	47	4.4	127	3.2	151	2.3	100	1.3
Industrial countries	65	3.3	19.0	617	2.5	97	4.2	175	3.1	183	2.1	161	1.2
Rice – high input													
World	161	3.6	12.5	1678	4.3	348	6.2	555	4.9	439	3.6	337	2.2
All developing	157	3.6	21.4	1634	4.3	347	6.2	549	4.9	423	3.6	315	2.2
Transition countries	0.5	2.5	0.0	1	3.2	0	0.0	0	7.6	0	4.3	1	2.6
Industrial countries	4	6.5	1.3	44	4.1	1	9.0	6	6.4	16	4.6	21	2.6
Maize – high input													
World	144	4.2	11.6	1557	8.2	246	13.2	439	10.3	393	7.4	479	4.3
All developing	99	2.8	18.2	1382	8.0	221	13.2	359	10.3	339	7.3	463	4.3
Transition countries	9	3.9	0.5	11	6.9	1	13.4	8	7.3	2	5.3	1	3.4
Industrial countries	38	7.7	5.0	163	9.6	24	13.9	73	10.7	52	7.7	15	4.6
Soybean– high input													
World	72	2.1	10.3	1385	2.4	183	4.0	353	3.1	415	2.2	434	1.3
All developing	41	1.8	16.8	1277	2.4	173	4.0	324	3.1	372	2.2	407	1.3
Transition countries	0.7	1.3	0.1	3	3.0	1	4.2	1	3.2	1	2.3	0	1.5
Industrial countries	30	2.6	3.2	105	2.6	10	4.1	27	3.3	42	2.4	26	1.5

Notes: A=area in million ha; Y=average attainable yield in tonnes/ha. The 1997/99 data are not distinguished by input level as information does not exist. The area data for 1997/99 refer to harvested area and elsewhere in the table to arable area.

Box 4.1 Summary methodology of estimating land potential for rainfed agriculture

For each country an evaluation was made of the suitability of land for growing 30 crops[1] under rainfed conditions and various levels of technology. The basic data for the evaluation consist of several georeferenced data sets: the inventory of soil characteristics from the digital FAO-UNESCO Soil Map of the World (SMW; FAO, 1995a), an inventory of terrain characteristics contained in a digital elevation model (DEM; EROS Data Center, 1998), and an inventory of climate regimes (New, Hulme and Jones, 1999). The data on temperature, rainfall, relative humidity, wind speed and radiation are used, together with information on evapotranspiration, to define the length of growing periods (LGPs), i.e. the number of days in a year when moisture availability in the soil and temperature permit crop growth.

The suitability estimates were carried out for grid cells at the 5 arc minute level (9.3 by 9.3 km at the equator), by interfacing the soil, terrain and LGP characteristics for each grid cell with specific growth requirements (temperature profile, moisture, nutrients, etc.) for each of the 30 crops under three levels of technology. These levels of technology are: low, using no fertilizers, pesticides or improved seeds, equivalent to subsistence farming; intermediate, with some use of fertilizers, pesticides, improved seeds and mechanical tools; and high, with full use of all required inputs and management practices as in advanced commercial farming. The resulting average attainable yields for each cell, crop and technology alternative were then compared with those obtainable under the same climate and technology on land without soil and terrain constraints, termed here the maximum constraint-free yield (MCFY). The land in each grid cell is for each crop (and technology level) subdivided into five suitability classes on the basis of the average attainable yield as a percentage of the MCFY, as follows – very suitable (VS): at least 80 percent; suitable (S): 60 to 80 percent; moderately suitable (MS): 40 to 60 percent and marginally suitable (mS): 20 to 40 percent. Not suitable (NS) land is that for which attainable yields are below 20 percent of the MCFY.

The result of this procedure is an inventory of land suitability by grid cell for each crop and technology level. To make statements of the overall suitability for rainfed agriculture, one has to aggregate the suitability estimates for all crops and technology levels.[2] There are various ways of doing this (e.g. one could add up over crops by applying value (prices) or energy (calories) weights to arrive at an "average" crop). Here the method applied in Fischer, van Velthuizen and Nachtergaele (2000) was followed: For each grid cell, first the largest (i.e. out of all the crops considered) extent of very suitable and suitable area under the high technology level was taken. Then the part of the largest very suitable, suitable and moderately suitable area under the intermediate technology, exceeding this first area, was added. Finally the part of the largest very suitable, suitable, moderately suitable and marginally suitable area under the low technology, exceeding this second area, was added. The rationale for this methodology is that it is unlikely to make economic sense to cultivate moderately and marginally suitable areas under the high technology level, or to cultivate marginally suitable areas under the intermediate technology level. The result of this is the maximum suitable area in each grid cell under what was dubbed the "mixed" input level. Table 4.6 shows the results of aggregating over all grid cells in each country.

It is noted, however, that some of the land classified as not suitable on the basis of this evaluation is used for rainfed agriculture in some countries, e.g. where steep land has been terraced or where yields less than the MCFY are acceptable under the local economic and social conditions (see also Box 4.2). For these reasons, land reported as being in agricultural use in some countries exceeds the areas deemed here as having rainfed crop production potential.

1 These crops are: wheat (2 types), rice (3 types), maize, barley (2 types), sorghum, millet (2 types), rye (2 types), potato, cassava, sweet potato, phaseolus bean, chickpea, cowpea, soybean, rapeseed (2 types), groundnut, sunflower, oil palm, olive, cotton, sugar cane, sugar beet and banana.

2 For a full explanation of the methodology, see Fischer, van Velthuizen and Nachtergaele (2000). The estimate of total potential land of 2 603 million ha in developing countries, excluding China, is about 3 percent higher than the 2 537 million ha estimated for the 1995 edition of this study (Alexandratos, 1995). This is due to the more refined methodology followed in the present study, new climate and terrain data sets, the increase in the number of crops for which suitability was tested (from 21 in 1995 to 30 in the present study), and a different method of aggregation.

Second, the land balance (land with crop production potential not in agricultural use) is very unevenly distributed among regions and countries. Some 90 percent of the remaining 1.8 billion ha is in Latin America and sub-Saharan Africa, and more than half of the total is concentrated in just seven countries (Brazil, the Democratic Republic of the Congo, the Sudan, Angola, Argentina, Colombia and Bolivia). At the other extreme, there is virtually no spare land available for agricultural expansion in South Asia and the Near East/North Africa. In fact, in a few countries in these two latter regions, the land balance is negative, i.e. land classified as not suitable is made productive through human intervention such as terracing of sloping land, irrigation of arid and hyperarid land, etc. and is in agricultural use. Even within the relatively land-abundant regions, there is great diversity of land availability, in terms of both quantity and quality, among countries and subregions.

Third, much of the land also suffers from constraints such as ecological fragility, low fertility, toxicity, high incidence of disease or lack of infrastructure. These reduce its 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. Alexandratos (1995, Table 4.2) shows that over 70 percent of the land with rainfed crop production potential in sub-Saharan Africa and Latin America suffers from one or more soil and terrain constraints. Natural causes as well as human intervention can also lead to deterioration of the productive potential of the resource, for example through soil erosion or salinization of irrigated areas. Hence this evaluation of suitability may contain elements of overestimation (see also Bot, Nachtergaele and Young, 2000) and much of the land balance cannot be considered to be a resource that is readily usable for food production on demand.

There is another cause for the land balance to be overestimated: it ignores land uses other than for growing the crops for which it was evaluated. Thus, forest cover, protected areas and land used for human settlements and economic infrastructure are not taken into account. Alexandratos (1995) estimated that forests cover at least 45 percent, protected areas some 12 percent and human settlements some 3 percent of the land balance, with wide regional differences. For example, in the land-scarce region of South Asia, some 45 percent of the land with crop production potential but not yet in agricultural use is estimated to be occupied by human settlements. This leaves little doubt that population growth and further urbanization will be a significant factor in reducing land availability for agricultural use in this region.

Table 4.6 Land with rainfed crop production potential

	Total land surface	Share of land suitable (%)	Total land suitable	Very suitable	Suitable	Moderately suitable	Marginally suitable	Not suitable
	Million ha							
Developing countries	7 302	38	2 782	1 109	1 001	400	273	4 520
Sub-Saharan Africa	2 287	45	1 031	421	352	156	103	1 256
Near East/North Africa	1 158	9	99	4	22	41	32	1 059
Latin America and the Caribbean	2 035	52	1 066	421	431	133	80	969
South Asia	421	52	220	116	77	17	10	202
East Asia	1 401	26	366	146	119	53	48	1 035
Industrial countries	3 248	27	874	155	313	232	174	2 374
Transition countries	2 305	22	497	67	182	159	88	1 808
World*	13 400	31	4 188	1 348	1 509	794	537	9 211

* Including some countries not covered in this study.

Box 4.2 Estimating the land potential for rainfed agriculture: some observations[1]

The evaluation of land potential undertaken in the global agro-ecological zones (GAEZ) study starts by taking stock of (i) the biophysical characteristics of the resource (soil, terrain, climate); and (ii) the growing requirements of crops (solar radiation, temperature, humidity, etc.). The data in the former set are interfaced with those in the second set and conclusions are drawn on the amount of land that may be classified as suitable for producing each one of the crops tested (see Fischer, van Velthuizen and Nachtergaele, 2000).

The two data sets mentioned above can change over time. Climate change, land degradation or, conversely, land improvements, together with the permanent conversion of land to non-agricultural uses, all contribute to change the extent and characteristics of the resource. This fact is of particular importance if the purpose of the study is to draw inferences about the adequacy of land resources in the longer term.

In parallel, the growth of scientific knowledge and the development of technology modify the growing requirements of the different crops for achieving any given yield level. For example, in the present round of GAEZ work the maximum attainable yield for rainfed wheat in subtropical and temperate environments is put at about 12 tonnes/ha in high input farming and about 4.8 tonnes/ha in low input farming. Some 25 years ago, when the first FAO agro-ecological zone study was carried out (FAO, 1981b), these yields were put at only 4.9 and 1.2 tonnes/ha, respectively. Likewise, land suitable for growing wheat at, say, 5 tonnes/ha in 30 years time may be quite different from that prevailing today, if scientific advances make it possible to obtain such yields where only 2 tonnes/ha can be achieved today. A likely possibility would be through the development of varieties better able to withstand stresses such as drought, soil toxicity and pest attack. Scientific knowledge and its application will obviously have an impact on whether or not any given piece of land will be classified as suitable for producing a given crop.

Land suitability is crop-specific. To take an extreme example, more than 50 percent of the land area in the Democratic Republic of the Congo is suitable for growing cassava but less than 3 percent is suitable for growing wheat. Therefore, before statements can be made about the adequacy or otherwise of land resources to grow food for an increasing population, the information about land suitability needs to be interfaced with information about expected demand patterns – volume and commodity composition of both domestic and foreign demand. For example, the Democratic Republic of the Congo's ample land resources suitable for growing cassava will be of little value unless there is sufficient domestic or foreign demand for the country's cassava, now or in the future.

Declaring a piece of land as suitable for producing a certain crop implicitly assumes that people find it worthwhile to exploit the land for this purpose. In other words, land must not only possess minimum biophysical attributes in relation to the requirements of the crops for which there is, or will be, demand, but it must also be in a socio-economic environment in which people consider it an economic asset. For example, in low-income countries, people will exploit land even if the yields or, more precisely, the returns to their work, are low relative to the urgency to secure their access to food. This means that the price of food is high relative to their income and that the opportunities of earning higher returns from other activities are limited as well. Thus, what qualifies as land with an acceptable production potential in a poor country may not be so in a high-income one. An exception would be if poor quality of land were compensated by a larger area per person with access to mechanization[2] so that returns to work in farming would generate income not far below earnings from other work. Obviously, the socio-economic context within which a piece of land exists and assumes a given value or utility, changes over time: what qualifies today as land suitable for farming may not be so tomorrow.

It is no easy task to account fully for all these factors in arriving at conclusions concerning how much land with crop production potential there is. For example, if food became scarce and its real price rose, more land would be worth exploiting and hence be classified as agricultural than would otherwise be the case. Therefore, depending on how such information is to be used, one may want to adopt different criteria and hence generate alternative estimates.

1 Adapted from Alexandratos and Bruinsma (1999).

2 Relatively low-yield rainfed but internationally competitive agriculture (wheat yields of 2.0-2.5 tonnes/ha compared with double that in western Europe) is practised in such high-income countries as the United States, Canada and Australia. But this is in large and fully mechanized farms permitting the exploitation of extensive areas that generate sufficient income per holding even if earnings per ha are low.

These considerations underline the need to interpret estimates of land balances with caution when assessing land availability for agricultural use. Cohen (1995) summarizes and evaluates all estimates made of available cultivable land, together with their underlying methods, and shows their extremely wide range. Young (1999) offers a critique of the more recent estimates of available cultivable land, including those given in Alexandratos (1995), and states that "an order-of-magnitude estimate reaches the conclusion that in a representative area with an estimated land balance of 50 percent, the realistic area is some 3 to 25 percent of the cultivable land".

4.3.2 Expansion of land in crop production

There is a widespread perception that there is no more, or very little, new land to bring under cultivation. Some of this perception may be well grounded in the specific situations of land-scarce countries and regions such as Japan, South Asia and the Near East/North Africa. Yet this perception may not apply, or may apply with much less force, to other parts of the world. As discussed above, there are large tracts of land with varying degrees of agricultural potential in several countries, most of them in sub-Saharan Africa and Latin America, with some in East Asia. However, this land may lack infrastructure, be partly under forest cover or be in wetlands that have to be protected for environmental reasons, or the people who would exploit it for agriculture lack access to appropriate technological packages or the economic incentives to adopt them.

In reality, expansion of land in agricultural use takes place all the time. It does so mainly in countries that combine growing needs for food and employment with limited access to technology packages that could increase intensification of cultivation on land already in agricultural use. The data show that expansion of arable land continues to be an important source of agricultural growth in sub-Saharan Africa, South America and East Asia, excluding China (Table 4.7).[3]

The projected expansion of arable land in crop production shown in Tables 4.7, 4.8 and 4.9, has been derived for the rainfed and irrigated land classes. In each country the following factors have been taken into account: (i) actual data or, in many cases, estimates for the base year 1997/99 on harvested land and yield by crop in each of the two classes; (ii) total arable land and cropping intensity in each class; (iii) production projections for each crop; (iv) likely increases in yield by crop and land class; (v) increases in the irrigated area; (vi) likely increases in cropping intensities; and (vii) the land balances for rainfed agriculture described in the preceding section, and for irrigated land discussed in the following section. This method was used only for the 93 developing countries covered in this study (see Appendix 1). For the developed countries or country groups, only projections of crop production have been made, which were then translated into projections for total harvested land and yield by crop.

The overall result for developing countries is a projected net increase in the arable area of 120 million ha (from 956 in the base year to 1 076 in 2030), an increase of 12.6 percent (see Table 4.7).[4] The increase for the period 1961/63 to 1997/99 was 172 million ha, an increase of 25 percent. Not surprisingly, the bulk of this projected expansion is expected to take place in sub-Saharan Africa (60 million), Latin America (41 million) and East Asia, excluding China (14 million), with almost no land expansion in the Near East/North Africa and South Asia regions and even a decline in the arable land area in China. The slowdown in the expansion of arable land is mainly a consequence of the projected slowdown in the growth of crop production and is common to all regions.

The projected increase of arable land in agricultural use is a small proportion (6.6 percent) of the total unused land with rainfed crop production potential. What does the empirical evidence show concerning the rate and process of land expansion for agricultural use in the developing countries? Microlevel analyses have generally established that under the socio-economic and institutional condi-

3 Historical data for China have been drastically revised upwards from 1985 onwards, which distorts the historical growth rates in Table 4.7 for East Asia (and for the total of developing countries).

4 As mentioned in Section 4.2, data on arable land are unreliable for many countries. Therefore base year data were adjusted and are shown in column (4) as "1997/99 adjusted".

Table 4.7 Total arable land: past and projected

	Arable land in use						Annual growth		Land in use as % of potential		Balance	
	1961 /63	1979 /81	1997 /99	1997 /99 adj.	2015	2030	1961 -1999	1997/99 -2030	1997 /99	2030	1997 /99	2030
	(million ha)						(% p.a.)		(%)		(million ha)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Sub-Saharan Africa	119	138	156	228	262	288	0.77	0.72	22	28	803	743
Near East/ North Africa	86	91	100	86	89	93	0.42	0.23	87	94	13	6
Latin America and the Caribbean	104	138	159	203	223	244	1.22	0.57	19	23	863	822
South Asia	191	202	205	207	210	216	0.17	0.13	94	98	13	4
excl. India	29	34	35	37	38	39	0.37	0.12	162	168	-14	-16
East Asia	176	182	227	232	233	237	0.89	0.06	63	65	134	129
excl. China	72	82	93	98	105	112	0.82	0.43	52	60	89	75
Developing countries	676	751	848	956	1 017	1 076	0.68	0.37	34	39	1 826	1 706
excl. China	572	652	713	822	889	951	0.63	0.46	32	37	1 781	1 652
excl. China and India	410	483	543	652	717	774	0.81	0.54	27	32	1 755	1 633
Industrial countries	379	395	387				0.07		44		487	
Transition countries	291	280	265				-0.19		53		232	
World	1 351	1 432	1 506				0.34		36		2 682	

Source: Column (1)-(3): FAOSTAT, November 2001.
Note: "World" includes a few countries not included in the other country groups shown.

tions (land tenure, etc.) prevailing in many developing countries, increases in output are obtained mainly through land expansion, where the physical potential for doing so exists. For example, in a careful analysis of the experience of Côte d'Ivoire, Lopez (1998) concludes that "the main response of annual crops to price incentives is to increase the area cultivated". Similar findings, such as the rate of deforestation being positively related to the price of maize, are reported for Mexico by Deininger and Minten (1999). Some of this land expansion is taking place at the expense of long rotation periods and fallows, a practice still common to many countries in sub-Saharan Africa, with the result that the natural fertility of the soil is reduced. Since fertilizer use is often uneconomic, the end result is soil mining and stagnation or outright reduction of yields.

The projected average annual increase in the developing countries' arable area of 3.75 million ha (120/32), compared with 4.8 million (172/36) in the historical period, is a net increase. It is the total of gross land expansion minus land taken out of production for various reasons, for example because of degradation or loss of economic viability. An unknown part of the new land to be brought into agriculture will come from land currently under forests. If all the additional land came from forested areas, this would imply an annual deforestation rate of 0.2 percent, compared with the 0.8 percent (or 15.4 million ha p.a.) for the 1980s and 0.6 percent (or 12.0 million ha p.a.) for the 1990s (FAO, 2001c). The latter estimates, of course, include deforestation from all causes, such as informal non-recorded agriculture, grazing, logging, gathering of fuelwood, etc.

The arable area in the world as a whole expanded between 1961/63 and 1997/99 by 155 million ha (or 11 percent), the result of two opposite trends: an increase of 172 million ha in the developing countries and a decline of 18 million ha in the developed ones. This decline in the arable area in the latter group has been accelerating over time (-0.3 percent p.a. in the industrial countries and -0.6 percent p.a. in transition countries during 1989-99). The longer-term forces determining such declines are sustained yield growth combined with a continuing slowdown in the growth of demand for their agricultural products. In addition, there are more temporary phenomena such as policy changes in the industrial countries and political and economic transition problems in the former centrally planned countries. No projections were made for arable land in the developed countries but, assuming a continuation of these trends, one would expect a further decline in the developed countries' arable area. However, this decline in arable area could in part be offset by the emerging trend towards a de-intensification of agriculture in these countries through increasing demand for organic products and for environmentally benign cultivation practices, and a possible minor shift of agriculture to temperate zones towards the end of the projection period because of climate change. The net effect of these countervailing forces could be a roughly constant or only marginally declining arable area in the developed countries. Arable area expansion for the world as a whole therefore would more or less equal that of the developing countries.

Although the developing countries' arable area is projected to expand by 120 million ha over the projection period, the harvested area will expand by 178 million ha or 20 percent, because of increases in cropping intensities (Table 4.8). The increase of harvested land over the historical period (1961/63 to 1997/99) was 221 million ha or 38 percent. Sub-Saharan Africa alone accounts for 63 million ha, or 35 percent, of the projected increase in harvested land, the highest among all regions. This is a consequence of the high and sustained growth in crop production projected for this region (see Table 4.1) combined with the region's scope for further land expansion. The other region for which a considerable expansion of the harvested area is foreseen, albeit at a slower pace than in the past, is Latin America with an increase of 45 million ha.

As mentioned before, the quality of the data for arable land use leaves much to be desired (see also Young, 1998). The data of harvested or sown areas for the major crops are more reliable. They show that expansion of harvested area continues to be an important source of agricultural growth, mainly in sub-Saharan Africa, but also in Southeast Asia and, to a lesser extent, in Latin America. Overall, for the developing countries, excluding China, the harvested area under the major crops (cereals, oilseeds, pulses, roots/tubers, cotton, sugar cane/beet, rubber and tobacco) grew by 10 percent during the ten years from 1987/89 to 1997/99, or about 1 percent p.a. This is only slightly higher than the growth rate of 0.9 percent p.a. projected for all crops for the 21-year period 1988/90-2010 in Alexandratos, 1995 (p. 165).

The overall cropping intensity for developing countries will rise by about 6 percentage points over the projection period (from 93 to 99 percent). Cropping intensities continue to rise through shorter fallow periods and more multiple cropping. An increasing share of irrigated land in total agricultural land contributes to more multiple cropping. About one-third of the arable land in South and East Asia is irrigated, a share which is projected to rise to 40 percent in 2030. The high irrigation share is one of the reasons why the average cropping intensities in these regions are considerably higher than in the other regions. Average cropping intensities in developing countries, excluding China and India which together account for more than half of the irrigated area in the developing countries, are and will continue to be much lower.

The rise in cropping intensities has been one of the factors responsible for increasing the risk of land degradation and threatening sustainability, when it is not accompanied by technological change to conserve the land, including adequate and balanced use of fertilizers to compensate for soil nutrient removal by crops. It is expected that this risk will continue to exist because in many cases the socio-economic conditions will not favour the promotion of the technological changes required to ensure the sustainable intensification of land use (see Chapter 12 for a further discussion of this issue).

Table 4.8 Arable land in use, cropping intensities and harvested land

		Total land in use			Rainfed use			Irrigated use		
		A	CI	H	A	CI	H	A	CI	H
Sub-Saharan Africa	1997/99	228	68	154	223	67	150	5	86	4.5
	2030	288	76	217	281	75	210	7	102	7
Near East/North Africa	1997/99	86	81	70	60	72	43	26	102	27
	2030	93	90	83	60	78	46	33	112	37
Latin America and the Caribbean	1997/99	203	63	127	185	60	111	18	86	16
	2030	244	71	172	222	68	150	22	100	22
South Asia	1997/99	207	111	230	126	103	131	81	124	100
	2030	216	121	262	121	109	131	95	137	131
East Asia	1997/99	232	130	303	161	120	193	71	154	110
	2030	237	139	328	151	122	184	85	169	144
All above	1997/99	956	93	885	754	83	628	202	127	257
	2030	1 076	99	1 063	834	87	722	242	141	341
excl. China	1997/99	822	83	679	672	76	508	150	114	171
	2030	951	90	853	769	81	622	182	127	230
excl. China/India	1997/99	652	75	489	559	70	392	93	105	97
	2030	774	83	641	662	77	507	112	119	134

Note: A=arable land in million ha; CI=cropping intensity in percentage; H=harvested land in million ha.

4.3.3 Is land for agriculture becoming scarcer?[5]

As noted in the preceding section, land in agricultural use (arable land and land under permanent crops) in the world as a whole has increased by only 155 million ha or 11 percent to about 1.5 billion ha between the early 1960s and the late 1990s. Nevertheless there were very significant changes in some regions. For example, the increase was over 50 percent in Latin America, which accounted for over one-third of the global increase. During the same period, the world population nearly doubled from 3.1 billion to over 5.9 billion. By implication, arable land per person declined by 40 percent, from 0.43 ha in 1961/63 to 0.26 ha in 1997/99. In parallel, there is growing preoccupation that agricultural land is being lost to non-agricultural uses. In addition, the ever more intensive use of land in production through multiple cropping, reduced fallow periods, excessive use of agrochemicals, spread of monocultures, etc. is perceived as leading to land degradation (soil erosion, etc.) and the undermining of its long-term productive potential.

These developments are seen by many as having put humanity on a path of growing scarcity of land as a factor in food production, with the implication that it is, or it will be in the near future, becoming increasingly difficult to produce the food required to feed the ever-growing human population. Are these concerns well founded? Any discourse about the future should be as precise as possible concerning the magnitudes involved: how much land there is (quantity, quality, location) and how much more food, what type of food and where it is required, now or at any given point of time in the future. The brief discussion of historical developments and, in particular, of future prospects in world food and agriculture presented in Chapters 2 and 3, provides a rough quantitative framework for assessing such concerns.

The evidence presented above about historical developments does not support the notion that it has been getting increasingly difficult for the world to extract from the land an additional unit of food. Rather the contrary has been happening, as shown by the secular decline in the real price of food. This

5 Adapted from Alexandratos and Bruinsma (1999).

secular decline indicates that it has been getting easier for humanity to produce an additional unit of food relative to the effort required to produce an additional unit of an "average" non-food product. This statement applies to the world as a whole, not necessarily to particular locations, and is valid only under particular conditions which are, essentially, the absence of market failures and ethical acceptability of the resulting distribution of access to food by different population groups.

The notion that resources for producing food, in which land is an important constituent, have been getting more abundant rather than scarcer in relative terms, i.e. in relation to the aggregate stocks of resources of the global economy, appears counter-intuitive. How can it be reconciled with the stark fact that the world population nearly doubled while land in agricultural use increased by only 11 percent, meaning that land per capita declined by some 40 percent? The answer is to be found in the fact that over the same period yields per ha of cropped area increased, as did the cropping intensity in the areas where a combination of irrigation and agro-ecological conditions permitted it and the growth of the demand for food justified it economically. For example, during the 36-year period when world average grain yields more than doubled from 1.4 tonnes/ha in 1961/63 to 3.05 tonnes/ha in 1997/99 and the overall cropping intensity probably increased by some 5 percentage points, the amount of arable land required to produce any given amount of grain declined by some 56 percent. This decline exceeded the above-mentioned 40 percent fall in the arable land per person which occurred during the same period.

In this comparison of physical quantities, land for food production is seen to have become less scarce, not scarcer. The economic evidence, a declining real price of food, corroborates in a general sense the conclusion that it has also become less scarce relative to the evolution of the demand for food and relative to what has been happening in the other sectors of the economy. However, as noted, such economic evidence properly refers to the decreasing relative scarcity of the aggregate resource base for food production in which land is only one component together with capital, labour, technology, etc. rather than to land alone.[6] In practice, what we call land today is a composite of land in its natural form and capital investments embodied in it such as irrigation infrastructure, levelling, fencing and soil amendments. It follows that any further discussion of the prospective role of land in meeting future food needs has to view it as just one component, indeed one of changing and probably declining relative weight, in the total package of factors that constitute the resource base of agriculture which, as the historical record shows, is flexible and adaptable.

Concerning the future, a number of projection studies have addressed and largely answered in the positive the issue as to whether the resource base of world agriculture, including its land component, can continue to evolve in a flexible and adaptable manner as it did in the past, and also whether it can continue to exert downward pressure on the real price of food (see, for example, Pinstrup-Andersen, Pandya-Lorch and Rosegrant, 1999). The largely positive answers mean essentially that for the world as a whole there is enough, or more than enough, food production potential to meet the growth of effective demand, i.e. the demand for food of those who can afford to pay farmers to produce it.

The preceding discussion refers to the evidence about land scarcities that can be deduced from the evolution of global magnitudes, whether aggregates such as world population, averages such as world per capita values of key variables, or food price trends observable in world markets. However, observing, interpreting and projecting the evolution of global aggregates can go only part of the way towards addressing the issues often raised in connection with the role of land in food production, essentially those issues pertaining to the broader nexus of food security and the environment. A more complete consideration of the issue, which goes beyond the scope of this report, will require an analysis at a more disaggregated level and going beyond the use of conventional economic indicators of scarcity or abundance. It should also address the following issues. First, whether land availability for food production is likely to become, or has been already, a significant

6 The role of agricultural land as a resource contributing to human welfare, as the latter is conventionally measured by GDP, has been on the decline. Johnson (1997) says that "agricultural land now accounts for no more than 1.5 percent of the resources of the industrial nations".

Table 4.9 Irrigated (arable) land: past and projected

	Irrigated land in use					Annual growth		Land in use as % of potential		Balance	
	1961 /63	1979 /81	1997 /99	2015	2030	1961 -1999	1997/99 -2030	1997 /99	2030	1997 /99	2030
	(million ha)					(% p.a.)		(%)		(million ha)	
	(1)	(2)	(3)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Sub-Saharan Africa	3	4	5	6	7	2.0	0.9	14	19	32	30
Near East/ North Africa	15	18	26	29	33	2.3	0.6	62	75	17	11
Latin America and the Caribbean	8	14	18	20	22	1.9	0.5	27	32	50	46
South Asia	37	56	81	87	95	2.2	0.5	57	67	61	47
excl. India	12	17	23	24	25	1.9	0.2	84	89	4	3
East Asia	40	59	71	78	85	1.5	0.6	64	76	41	27
excl. China	10	14	19	22	25	2.1	0.9	40	53	29	23
All above	103	151	202	221	242	1.9	0.6	50	60	200	161
excl. China	73	106	150	165	182	2.1	0.6	44	54	188	157
excl. China/India	48	67	93	102	112	2.0	0.6	41	50	132	114
Industrial countries	27	37	42			1.3					
Transition countries	11	22	25			2.6					
World	142	210	271			1.8					

Source: Columns (1)- (3): FAOSTAT, November 2001.

constraint to solving problems of food insecurity at the local level. Second, whether the market signals which tell us that the resources for producing food, land among them, have been getting relatively less scarce, are seriously flawed because they fail to account for the environmental costs and eventual future risks associated with the expansion and intensification of agriculture.

4.4 Irrigation and water use

4.4.1 Expansion of irrigated land

The projections of irrigation presented below reflect a composite of information on existing irrigation expansion plans in the different countries, potentials for expansion and need to increase crop production. The projections include some expansion in informal (community-managed) irrigation, which is important in sub-Saharan Africa. Estimates of "land with irrigation potential" are notoriously difficult to make for various reasons (see Alexandratos, 1995, p. 160-61) and should be taken as only rough orders of magnitude.[7]

The aggregate result for the group of developing countries shows that the area equipped for irrigation in this group of countries will expand by 40 million ha (20 percent) over the projection period (Table 4.9). This means that some 20 percent of the land with irrigation potential not yet

7 FAO (1997a) states concerning such estimates: "Irrigation potential: area of land suitable for irrigation development (it includes land already under irrigation). Methodologies used in assessing irrigation potential vary from one country to another. In most cases, it is computed on the basis of available land and water resources, but economic and environmental considerations are often taken into account to a certain degree. Except in a few cases, no consideration is given to the possible double counting of water resources shared by several countries, and this may lead to an over-estimate of irrigation potential at the regional level. Wetlands and floodplains are usually, but not always, included in irrigation potential".

equipped at present will be brought under irrigation, and that 60 percent of all land with irrigation potential (403 million ha) would be in use by 2030.

The expansion of irrigation will be strongest (in absolute terms) in the more land-scarce regions hard-pressed to raise crop production through more intensive cultivation practices, such as South Asia (+14 million ha), East Asia (+14 million ha) and the Near East/North Africa. Only small additions will be made in the more land-abundant regions of sub-Saharan Africa and Latin America, although they may represent an important increase in relative terms. The importance of irrigated agriculture has already been discussed in Section 4.2. Because of a continuing increase in cropping intensity on both existing and newly irrigated areas, the harvested irrigated area will expand by 84 million ha and will account for almost half of the increase in all harvested land (Table 4.8).

The projected expansion of irrigated land by 40 million ha is an increase in net terms. It assumes that losses of existing irrigated land resulting from, for example, water shortages or degradation because of salinization, will be compensated through rehabilitation or substitution by new areas for those lost. The few existing historical data on such losses are too uncertain and anecdotal to provide a reliable basis for drawing inferences about the future. However, if it is assumed that 2.5 percent of existing irrigation must be rehabilitated or substituted by new irrigation each year, that is, if the average life of irrigation schemes were 40 years, then the total irrigation investment activity over the projection period in the developing countries must encompass some 200 million ha, of which four-fifths would be for rehabilitation or substitution and the balance for net expansion.

The projected net increase in arable irrigated land of 40 million ha is less than half of the increase over the preceding 36 years (100 million ha). In terms of annual growth it would be "only" 0.6 percent, well below the 1.9 percent for the historical period. The projected slowdown reflects the projected lower growth rate of crop production combined with the increasing scarcity of suitable areas for irrigation and of water resources in some countries, as well as the rising costs of irrigation investment.

Most of the expansion of irrigated land is achieved by converting land in use in rainfed agriculture or land with rainfed production potential but not yet in use, into irrigated land. Part of the irrigation, however, takes place on arid and hyperarid land which is not suitable for rainfed agriculture. It is estimated that of the 202 million ha irrigated at present, 42 million ha are on arid and hyperarid land and of the projected increase of 40 million ha, about 2 million ha will be on such land. In some regions and countries, irrigated arid and hyperarid land form an important part of the total irrigated land at present in use: 18 out of 26 million ha in the Near East/North Africa, and 17 out of 81 million ha in South Asia.

The developed countries account for a quarter of the world's irrigated area, 67 out of 271 million ha (Table 4.9). Their annual growth of irrigated area reached a peak of 3.0 percent in the 1970s, dropping to 1.1 percent in the 1980s and to only 0.3 percent in 1990-99. This evolution pulled down the annual growth rate for global irrigation from 2.4 percent in the 1970s to 1.3 percent in the 1980s and 1990-99. Perhaps it is this sharp deceleration in growth which led some analysts to believe that there is only limited scope for further irrigation expansion. As already said, no projections by land class (rainfed, irrigated) were made for the developed countries. However, given the share of developing countries in world irrigation and the much higher crop production growth projected for this group of countries, it is reasonable to assume that the world irrigation scene will remain dominated by events in the developing countries.

4.4.2 Irrigation water use and pressure on water resources

One of the major questions concerning the future of irrigation is whether there will be sufficient freshwater to satisfy the growing needs of agricultural and non-agricultural users. Agriculture already accounts for about 70 percent of the freshwater withdrawals in the world and is usually seen as the main factor behind the increasing global scarcity of freshwater.

The estimates of the expansion of land under irrigation presented in the preceding section in part provide an answer to this question. The assessment of irrigation potential already takes into account water limitations and the projections to 2030 assume that agricultural water demand will not exceed available water resources. Yet, as discussed above, the concept of irrigation potential has severe limitations and estimates of irrigation potential can vary over time, in relation to the country's economic situation or as a result of competition for water for domestic and industrial use. Estimates of irrigation potential are also based on renewable water resources, i.e. the resources replenished annually through the hydrological cycle. In those arid countries where mining of fossil groundwater represents an important part of water withdrawal, the area under irrigation is usually larger than the irrigation potential.

Renewable water resources available to irrigation and other uses are commonly defined as that part of precipitation which is not evaporated or transpired by plants, including grass and trees, which flows into rivers and lakes or infiltrates into aquifers. The annual water balance for a given area in natural conditions, i.e. without irrigation, can be defined as the sum of the annual precipitation and net incoming flows (transfers through rivers from one area to another) minus evapotranspiration.

Table 4.10 shows the renewable water resources for 93 developing countries. Average annual precipitation is around 1 040 mm. In developing regions, renewable water resources vary from 18 percent of precipitation and incoming flows in the most arid areas (Near East/North Africa) where precipitation is a mere 180 mm per year, to about 50 percent in humid East Asia, which has a high precipitation of about 1 250 mm per year. Renewable water resources are most abundant in Latin America. These figures give an impression of the extreme variability of climatic conditions facing the 93 developing countries, and the ensuing differences observed in terms of water scarcity: those countries suffering from low precipitation and therefore most in need of irrigation are also those where water resources are naturally scarce. In addition, the water balance presented is expressed in yearly averages and cannot adequately reflect seasonal and interannual variations. Unfortunately, such variations tend to be more pronounced in arid than in humid climates.

The first step in estimating the pressure of irrigation on water resources is to assess irrigation water requirements and withdrawals. Precipitation provides part of the water crops need to satisfy their transpiration requirements. The soil, acting as a buffer, stores part of the precipitation water and returns it to the crops in times of deficit. In humid climates, this mechanism is usually sufficient to ensure satisfactory growth in rainfed agriculture. In arid climates or during the dry season, irrigation is required to compensate for the deficit resulting from insufficient or erratic precipitation. *Consumptive water use in irrigation* therefore is defined as the volume of water needed to compensate for the deficit between potential evapotranspiration and effective precipitation over the growing period of the crop. It varies considerably with climatic conditions, seasons, crops and soil types. In this study, consumptive water use in irrigation has been computed for each country on the basis of the irrigated and harvested areas by crop as estimated for the base year (1997/99) and projected for 2030 (see Box 4.3 for a brief explanation of the methodology applied). As mentioned before, in this study the breakdown by crop over rainfed and irrigated land was performed only for the 93 developing countries.

However, it is *water withdrawal for irrigation*, i.e. the volume of water extracted from rivers, lakes and aquifers for irrigation purposes, which should be used to measure the impact of irrigation on water resources. Irrigation water withdrawal normally far exceeds the consumptive water use in irrigation because of water lost during transport and distribution from its source to the crops. In addition, in the case of rice irrigation, additional water is used for paddy field flooding to facilitate land preparation and for plant protection.

For the purpose of this study, *irrigation efficiency* has been defined as the ratio between the estimated consumptive water use in irrigation and irrigation water withdrawal. Data on country water withdrawal for irrigation has been collected in the framework of the AQUASTAT programme (see FAO, 1995b, 1997a, 1997b and 1999b). Comparison of these data with the consumptive use of irrigation was used to estimate irrigation efficiency at the regional level. On average, for the 93 developing countries, it is estimated that irrigation efficiency was around 38 percent in 1997/99, varying from 25 percent in areas of abundant water resources (Latin America) to 40 percent in the Near East/North Africa region and 44 percent in South Asia where water scarcity calls for higher efficiencies (Table 4.10).

To estimate irrigation water withdrawal in 2030, an assumption had to be made about possible

Table 4.10 Annual renewable water resources (RWR) and irrigation water requirements

		Sub-Saharan Africa	Latin America and the Caribbean	Near East/ North Africa	South Asia	East Asia	All developing countries
Precipitation	mm	880	1 534	181	1 093	1 252	1 043
Internal RWR	km^3	3 450	13 409	484	1 862	8 609	28 477
Net incoming flows	km^3	0	0	57	607	0	0
Total RWR	km^3	3 450	13 409	541	2 469	8 609	28 477
Irrigation water withdrawal							
Irrigation efficiency 1997/99	%	33	25	40	44	33	38
Irrigation water withdrawal 1997/99	km^3	80	182	287	895	684	2 128
idem as percentage of RWR	%	2	1	53	36	8	7
Irrigation efficiency 2030	%	37	25	53	49	34	42
Irrigation water withdrawal 2030	km^3	115	241	315	1 021	728	2 420
idem as percentage of RWR	%	3	2	58	41	8	8

Note: RWR for all developing countries exclude the regional net incoming flows to avoid double counting.

developments in the irrigation efficiency of each country. Unfortunately, there is little empirical evidence on which to base such an assumption. Two factors, however, will have an impact on the development of irrigation efficiency: the estimated levels of irrigation efficiency in 1997/99 and water scarcity. A function was designed to capture the influence of these two parameters, bearing in mind that improving irrigation efficiency is a very slow and difficult process. The overall result is that efficiency will increase by 4 percentage points, from 38 to 42 percent (Table 4.10). Such an increase in efficiency would be more pronounced in water-scarce regions (e.g. a 13 percentage point increase in the Near East/North Africa region) than in regions with abundant water resources (between 0 and 4 percentage points in Latin America, East Asia and sub-Saharan Africa). Indeed, it is expected that, under pressure from limited water resources and competition from other uses, demand management will play an important role in improving irrigation efficiency in water-scarce regions. In contrast, in humid areas the issue of irrigation efficiency is much less relevant and is likely to receive little attention.

For the 93 countries, irrigation water withdrawal is expected to grow by about 14 percent, from the current 2 128 km^3/yr to 2 420 km^3/yr in 2030 (Table 4.10). This increase is low compared to the 33 percent increase projected in the harvested irrigated area, from 257 million ha in 1997/99 to 341 million ha in 2030 (see Table 4.8). Most of this difference is explained by the expected improvement in irrigation efficiency, leading to a reduction in irrigation water withdrawal per irrigated hectare. A small part of this reduction is also a result of changes in cropping patterns for some countries such as China, where a substantial shift in the irrigated area from rice to maize production is expected: irrigation water requirements for rice production are usually twice those for maize.

Irrigation water withdrawal in 1997/99 was estimated to account for only 7 percent of total water resources for the 93 countries (Table 4.10). However, there are wide variations between regions, with the Near East/North Africa region using 53 percent of its water resources in irrigation while Latin America barely uses 1 percent of its resources. At the country level, variations are even higher. Of the 93 countries, ten already used more than 40 percent of their water resources for irrigation in the base year (1997/99), a situation which can be considered critical. An additional eight countries used more than 20 percent of their water resources, a threshold sometimes used to indicate impending water scarcity. Yet the situation should not change

Box 4.3 Summary methodology of estimating water balances

The estimation of water balances for any year is based on five sets of data, namely four digital georeferenced data sets for precipitation (Leemans and Cramer, 1991), reference evapotranspiration (Fischer, van Velthuizen and Nachtergaele, 2000), soil moisture storage properties (FAO, 1998b), extents of areas under irrigation (Siebert and Döll, 2001) and irrigated areas for all major crops for 1997/99 and 2030 from this study. The computation of water balances is carried out by grid cells (each of 5 arc minutes, 9.3 km at the equator) and in monthly time steps. The results can be presented in statistical tables or digital maps at any level of spatial aggregation (country, river basin, etc.). They consist of annual values by grid cell for the actual evapotranspiration, water runoff and consumptive water use in irrigation.

For each grid cell, the actual evapotranspiration is assumed to be equal to the reference evapotranspiration (ET_0, in mm; location-specific and calculated with the Penman-Monteith method; Allen *et al.*, 1998, New, Hulme and Jones, 1999) in those periods of the year when precipitation exceeds reference evapotranspiration or when there is enough water stored in the soil to allow maximum evapotranspiration. In drier periods of the year, lack of water reduces actual evapotranspiration to an extent depending on the available soil moisture. Evapotranspiration in open water areas and wetlands is considered to be equal to reference evapotranspiration.

For each grid cell, runoff is calculated as that part of the precipitation that does not evaporate and cannot be stored in the soil. In other words, runoff is equal to the difference between precipitation and actual evaporation. Runoff is always positive, except for areas identified as open water or wetland, where actual evapotranspiration can exceed precipitation.

Consumptive use of water in irrigated agriculture is defined as the water required in addition to water from precipitation (soil moisture) for optimal plant growth during the growing season. Optimal plant growth occurs when actual evapotranspiration of a crop is equal to its potential evapotranspiration.

Potential evapotranspiration of irrigated agriculture is calculated by converting data or projections of irrigated (sown) area by crop (at the national level) into a cropping calendar with monthly occupation rates of the land equipped for irrigation.[1] The table below gives, as an example, the cropping calendar of Morocco for the base year 1997/99:[2]

Crop under irrigation	Irrigated area ('000 ha)	Crop area as share (percentage) of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
Wheat	592	47	47	47	47						47	47	47
Maize	156			12	12	12	12	12					
Potatoes	62					5	5	5	5	5			
Beet	34				3	3	3	3	3	3			
Cane	15	1	1	1	1	1	1	1	1	1	1	1	1
Vegetables	156					12	12	12	12	12			
Citrus	79	6	6	6	6	6	6	6	6	6	6	6	6
Fruit	88	7	7	7	7	7	7	7	7	7	7	7	7
Groundnuts	10					1	1	1	1	1			
Fodder	100	8	8							8	8	8	8
Sum over all crops[3]	1 305	70	69	74	77	49	49	49	36	44	70	70	70
Equipped for irrigation	1 258												
Total cropping intensity	104%												

1 India and China have been subdivided into respectively four and three units for which different cropping calendars have been made to distinguish different climate zones in these countries.

2 For example, wheat is grown from October to April and occupies 47 percent (592 thousand ha) of the 1 258 thousand ha equipped for irrigation.

3 Including crops not shown above.

The (potential) evapotranspiration (ET_c in mm) of a crop under irrigation is obtained by multiplying the reference evapotranspiration with a crop-specific coefficient ($ET_c = K_c * ET_0$). This coefficient has been derived (according to FAO, 1998b) for four different growing stages: the initial phase (just after sowing), the development phase, the mid-phase and the late phase (when the crop is ripening before harvesting). In general, these coefficients are low during the initial phase, high during the mid-phase and again lower in the late phase. It is assumed that the initial, the development and the late phase all take one month for each crop, while the mid-phase lasts a number of months. For example, the growing season for wheat in Morocco starts in October and ends in April, as follows: initial phase: October ($K_c = 0.4$); development phase: November ($K_c = 0.8$); mid-phase: December – March ($K_c = 1.15$); and late phase: April ($K_c = 0.3$).

Multiplying for each grid cell its surface equipped for irrigation with the sum over all crops of their evapotranspiration and with the cropping intensity per month results in the potential evapotranspiration of the irrigated area in that grid cell. The difference between the calculated evapotranspiration of the irrigated area and actual evapotranspiration under non-irrigated conditions is equal to the consumptive use of water in irrigated agriculture in the grid cell.

The method has been calibrated by comparing calculated values for water resources per country (i.e. the difference between precipitation and actual evapotranspiration under non-irrigated conditions) with data on water resources for each country (as given in FAO 1995b, 1997b and 1999b). In addition, the discharge of major rivers as given in the literature was compared with the calculated runoff for the drainage basin of these rivers. If the calculated runoff values did not match the values as stated in the literature, correction factors were applied to one or more of the basic input data on precipitation, reference evapotranspiration, soil moisture storage and open waters.

Finally, the water balance for each country and year is defined as the difference between the sum of precipitation and incoming runoff on the one hand and the sum of actual evapotranspiration and consumptive use of water in irrigated agriculture in that year on the other. This is therefore the balance of water without accounting for water withdrawals for other needs (industry, household and environmental purposes).

drastically over the period of the study, with only two more countries crossing the threshold of 20 percent. If one adds the expected additional water withdrawals needed for non-agricultural use, the picture will not be much different since agriculture represents the bulk of water withdrawal.

Nevertheless, for several countries, relatively low national figures may give an overly optimistic impression of the level of water stress: China, for instance, is facing severe water shortages in the north while the south still has abundant water resources. Already by 1997/99, two countries (the Libyan Arab Jamahariya and Saudi Arabia) used volumes of water for irrigation larger than their annual renewable water resources. Groundwater mining also occurs in parts of several other countries of the Near East, South and East Asia, Central America and in the Caribbean, even if at the national level the water balance may still be positive. In a survey of irrigation and water resources in the Near East region (FAO, 1997c), it was estimated that the amount of water required to produce the net amount of food imported in the region in 1994 would be comparable to the total annual flow of the Nile river at Aswan.

In concluding this discussion on irrigation, for the 93 developing countries as a whole, irrigation currently represents a relatively small part of their total water resources and there remains a significant potential for further irrigation development. With the relatively small increase in irrigation water withdrawal expected between 1997/99 and 2030, this situation will not change much at the aggregate level. Locally and in some countries, however, there are already very severe water shortages, in particular in the Near East/North Africa region.

4.5 Land-yield combinations for major crops

As discussed in Section 4.2, it is expected that growth in crop yields will continue to be the mainstay of crop production growth, accounting for nearly 70 percent of the latter in developing countries. Although the marked deceleration of crop production growth foreseen for the future (Table 4.1) points to a similar deceleration in growth of yields, such growth will continue to be needed. Questions often asked are: will yield increases continue to be possible? and what is the potential for a continuation of such growth?

There is a realization that the chances of a new green revolution or of one-off quantum jumps in yields are now rather limited. There is even a belief that for some major crops, yield ceilings have been, or are rapidly being reached. At the same time, empirical evidence has shown that the cumulative gains in yields over time resulting from slower, evolutionary annual increments in yields have been far more important than quantum jumps in yields, for all major crops (see Byerlee, 1996).

In the following sections, the land-yield combinations underlying the production projections for major crops will first be discussed. Subsequently some educated guesses will be made about the potential for raising yields and for narrowing existing yield gaps.

4.5.1 Harvested land and yields for major crops

As explained in Section 4.3.2, for the developing countries the production projections for the 34 crops of this study[8] are unfolded into and tested against what FAO experts think are "feasible" land-yield combinations by agro-ecological rainfed and irrigated environment, taking into account whatever knowledge is available. Major inputs into this evaluation are the estimates regarding the availability of land suitable for growing crops in each country and each agro-ecological environment, which come from the FAO agro-ecological zones work (see Section 4.3.1). In practice they are introduced as constraints to land expansion but they also act as a guide to what can be grown where. It is emphasized that the resulting land and yield projections, although they take into account past performance, are not mere extrapolations of historical trends since they take into account all present knowledge about changes expected in the future. Box 4.4 shows an example of the results, tracked against actual outcomes.

The findings of the present study indicate that in developing countries, as in the past but even more so in the future, the mainstay of production

Table 4.11 Area and yields for the ten major crops in developing countries

	Production (million tonnes)			Harvested area (million ha)				Yield (tonnes/ha)			
	1961/63	1997/99	2030	1961/63	1997/99	1997/99 adj.*	2030	1961/63	1997/99	1997/99 adj.*	2030
Rice (paddy)	206	560	775	113	148	157	164	1.82	3.77	3.57	4.73
Wheat	64	280	418	74	104	111	118	0.87	2.70	2.53	3.53
Maize	69	268	539	59	92	96	136	1.16	2.92	2.78	3.96
Pulses	32	40	62	52	60	60	57	0.61	0.66	0.67	1.09
Soybeans	8	75	188	12	39	41	72	0.68	1.93	1.84	2.63
Sorghum	30	44	74	41	39	40	45	0.72	1.13	1.11	1.66
Millet	22	26	42	39	35	36	38	0.57	0.76	0.73	1.12
Seed cotton	15	35	66	23	25	26	31	0.67	1.44	1.35	2.17
Groundnuts	14	30	65	16	22	23	39	0.83	1.34	1.28	1.69
Sugar cane	374	1 157	1 936	8	18	19	22	46.14	63.87	61.84	88.08
Cereals	419	1 210	1 901	358	440	464	528	1.17	2.75	2.61	3.60
All 34 crops				580	801	848	1 021				

Notes: * 1997/99 adj. For a number of countries for which the data were unreliable, base year data for harvested land and yields were adjusted. Ten crops selected and ordered according to harvested land use in 1997/99, excluding fruit (31 million ha) and vegetables (29 million ha). "Cereals" includes other cereals not shown here.

[8] For the analysis of production, the commodities sugar and vegetable oil are unfolded into their constituent crops (sugar cane, beet, soybeans, sunflower, groundnuts, rapeseed, oil palm, coconuts, sesame seed, etc.), so that land-yield combinations are generated for 34 crops.

increases will be the intensification of agriculture in the form of higher yields and more multiple cropping and reduced fallow periods. This situation will apply particularly in the countries with appropriate agro-ecological environments and with little or no potential of bringing new land into cultivation. The overall result for yields of all the crops covered in this study (aggregated with standard price weights) is roughly a halving of the average annual rate of growth over the projection period as compared to the historical period: 1.0 percent p.a. during 1997/99 to 2030 against 2.1 percent p.a. during 1961-99. This slowdown in the yield growth is a gradual process which has been under way for some time and is expected to continue in the future. It reflects the deceleration in crop production growth explained earlier.

Discussing yield growth at this level of aggregation however is not very helpful, but the overall slowdown is a pattern common to most crops covered in this study with only a few exceptions such as pulses, citrus and sesame. These are crops for which a strong demand is foreseen in the future or which are grown in land-scarce environments. The growth in soybean area and production in developing countries has been remarkable, mainly as a result of explosive growth in Brazil and, more recently, in India (Table 4.11). Soybean is expected to continue to be one of the most dynamic crops, albeit with its production increasing at a more moderate rate than in the past, bringing by 2030 the developing countries' share in world soybean production to 58 percent, with Brazil, China and India accounting for three-quarters of their total.

For cereals, which occupy 58 percent of the world's harvested area and 55 percent in developing countries (Table 4.11), the slowdown in yield growth would be particularly pronounced: down from 2.1 to 0.9 percent p.a. at the world level and from 2.5 to 1.0 percent p.a. in developing countries (Table 4.12). Again this slowdown has been under way for quite some time. The differences of sources of growth and some regional aspects of the various cereal crops have been discussed in Section 4.2. Suffice it here to note that irrigated land is expected to play a much more important role in increasing maize production, almost entirely because of China which accounts for 45 percent of the developing countries' maize production and

Table 4.12 Cereal yields in developing countries, rainfed and irrigated

		Share in production		Average (weighted) yield				Annual growth			Annual growth excluding China		
		%		tonnes/ha				% p.a.			% p.a.		
		1997/99	2030	1961/63	1997/99	1997/99 adj.	2030	1961-99	1989-99	1997/99-2030	1961-99	1989-99	1997/99-2030
Wheat	total			0.87	2.70	2.53	3.55	3.3	2.0	1.1	2.6	1.7	1.2
	rainfed	35	25			1.86	2.26			0.6			0.8
	irrigated	65	75			3.11	4.44			1.1			1.2
Rice	total			1.82	3.77	3.57	4.73	2.1	1.1	0.9	2.0	1.2	1.1
(paddy)	rainfed	24	21			2.20	2.82			0.8			0.8
	irrigated	76	79			4.45	5.78			0.8			1.0
Maize	total			1.16	2.92	2.78	3.96	2.6	2.6	1.1	1.8	2.5	1.2
	rainfed	68	51			2.34	2.99			0.8			1.2
	irrigated	32	49			4.52	5.96			0.9			0.8
All cereals	total			1.17	2.75	2.61	3.60	2.5	1.7	1.0	2.0	1.7	1.1
	rainfed	41	36			1.76	2.29			0.8			1.0
	irrigated	59	64			3.93	5.30			0.9			1.1

Note: Historical data are from FAOSTAT; base year data for China have been adjusted.

Box 4.4 Cereal yields and production: actual and as projected in the 1995 study

Since, contrary to the practice in most other projection studies, the projections presented here are not based on formal analytical methods, it may be of interest to see how well the projections of the preceding study (Alexandratos, 1995), which were based on a similar approach, tracked actual outcomes to date. The base year of the preceding study was the three-year average 1988/90 and the final projection year 2010. The detailed projections for the land-yield combinations for cereals in the 90 developing country sample, excluding China,[1] which was not covered in detail in the 1995 study, was as follows. The average yield of cereals was projected to grow by 1.5 percent p.a., from 1.9 tonnes/ha in 1988/90 to 2.6 tonnes/ha in 2010 (see table below), compared with 2.2 percent p.a. in the preceding 20 years. Ten years into the projection period, both the actual average cereal yield and cereal production in 1997/99 were close to the projected values.

	Base year: average 88/90	Projected 2010	Projected Interpolated average 97/99	Actual outcome: average 97/99
Yields (excl. China)	**kg/ha**	**kg/ha**	**kg/ha**	**kg/ha**
Wheat	1 900	2 700	2 209	2 220
Rice (paddy)	2 800	3 800	3 192	3 080
Maize	1 800	2 500	2 072	2 190
All cereals	1 900	2 600	2 173	2 184
Production (incl. China*)	**million tonnes**	**million tonnes**	**million tonnes**	**million tonnes**
Wheat	225	348	271	280
Rice (milled)	321	461	375	375
Maize	199	358	256	269
Other cereals	102	151	121	103
All cereals	847	1 318	1 023	1 027

Source: Base year data and 2010 projections from Alexandratos (1995, p. 145,169).

* China's production was projected directly, not in terms of areas and yields.

1 Problems with the land and yield data of China (Alexandratos, 1996) made it necessary to project the country's production directly, not in terms of land-yield combinations as was done for the other developing countries. The resulting projection of China's production of cereals implied a growth rate of 2.0 percent p.a. from 1988/90 to 2010. The actual outcome to 1999 has been 2.2 percent p.a.

where irrigated land allocated to maize could more than double. Part of the continued, if slowing, growth in yields is a result of a rising share of irrigated production, with normally much higher cereal yields, in total production. This fact alone would lead to yield increases even if rainfed and irrigated cereal yields did not grow at all.[9]

It is often asserted (see, for example, Borlaug, 1999) that thanks to increases in yield, land has been saved with diminished pressure on the environment as a result, such as less deforestation than otherwise would have taken place. To take cereals as an example, the reasoning is as follows. If the average global cereal yield had not grown since 1961/63 when it was 1 405 kg/ha, 1 483 million ha would have been needed to grow the 2 084 million tonnes of cereals produced in the world in 1997/99. This amount was actually obtained on an area of only 683 million ha at an average yield of 3 050 kg/ha. Therefore, 800 million ha (1 483 minus 683) have been saved because of yield increases for cereals alone. This conclusion should be qualified, however; had there been no yield growth, the most probable outcome would have been much lower production because of lower demand resulting from higher prices of cereals, and

9 This is seen most clearly for rice in developing countries, excluding China (Table 4.12) where the growth in the overall average yield of rice exceeds that of rainfed and irrigated rice. This is because the rainfed rice area is projected to remain about the same but the irrigated area is projected to increase by about one-third.

somewhat more land under cereals. Furthermore, in many countries the alternative of land expansion instead of yield increases does not exist in practice.

4.5.2 Yield gaps

Despite the increases in land under cultivation in the land-abundant countries, much of agricultural production growth has been based on the growth of yields, and will increasingly need to do so. What is the potential for a continuation of yield growth? In countries and localities where the potential of existing technology is being exploited fully, subject to the agro-ecological constraints specific to each locality, further growth, or even maintenance, of current yield levels will depend crucially on further progress in agricultural research. In places where yields are already near the ceilings obtained on research stations, the scope for raising yields is widely believed to be much more limited than in the past (see, for example, Sinclair, 1998). However, this has been true for some time now, but average yields have continued to increase, albeit at a decelerating rate. For example, wheat yields in South Asia, which accounts for about a third of the developing countries' area under wheat, increased by 45 kg p.a. in the 1960s, 35 kg in the 1970s, 55 kg in the 1980s and 45 kg in 1990-99. Yields are projected to grow by 41 kg per year over 1997/99 to 2030.

Intercountry differences in yields remain very wide, however. This can be illustrated for wheat and rice in the developing countries. Current yields in the 10 percent of countries with the lowest yields (excluding countries with less than 50 000 ha under the crop), is less than one-fifth of the yields of the best performers comprising the top decile (Table 4.13). If subnational data were available, a similar pattern would probably be seen for intranational differences as well. For wheat this gap

Table 4.13 Average wheat and rice yields for selected country groups

	1961/63		1997/99		2030	
	tonnes/ ha	as % of top decile	tonnes/ ha	as %of top decile	tonnes/ ha	as % of top decile
Wheat						
No. of developing countries included	32		32		33	
Top decile	2.15	100	5.31	100	7.44	100
Bottom decile	0.40	18	0.80	15	1.25	17
Decile of largest producers (by area)	0.87	40	2.60	49	3.89	52
All countries included	0.97	45	2.15	41	3.11	42
Major developed country exporters	1.59		3.19		4.13	
World	1.23		2.55		3.47	
Rice (paddy)						
No. of developing countries included	44		52		55	
Top decile	4.51	100	6.57	100	7.93	100
Bottom decile	0.72	16	1.14	17	2.12	27
Decile of largest producers (by area)	1.82	40	3.51	53	4.84	61
All countries included	1.88	42	3.17	48	4.30	54
World	2.07		3.43		4.52	

Notes: Only countries with over 50 000 harvested ha are included. Countries included in the deciles are not necessarily the same for all years. Average yields are simple averages, not weighted by area.

between worst and best performers is projected to persist until 2030, while for rice the gap between the top and bottom deciles may be somewhat narrowed by 2030, with yields in the bottom decile reaching 27 percent of yields in the top decile. This may reflect the fact that the scope for raising yields of top rice performers is more limited than in the past. However, countries included in the bottom and top deciles account for only a minor share of the total production of wheat and rice. Therefore it is more important to examine what will happen to the yield levels obtained by the countries which account for the bulk of wheat and rice production. Current unweighted average yields of the largest producers,[10] are about half the yields achieved by the top performers (Table 4.13). In spite of continuing yield growth in these largest producing countries, this situation will remain essentially unchanged by 2030 for wheat, with rice yields reaching about 60 percent of the top performers' yields.

Based on this analysis, a *prima facie* case could be made that there has been and still is, considerable slack in the agricultural sectors of the different countries. This slack could be exploited if economic incentives so dictated. However, the fact that yield differences among the major cereal producing countries are very wide does not necessarily imply that the lagging countries have scope for yield increases equal to intercountry yield gaps. Part of these differences may simply reflect differing agro-ecological conditions. For example, the low average yields in Mexico of its basic food crop, maize (currently 2.4 tonnes/ha), are largely attributable to agro-ecological constraints that render it unsuited for widespread use of the major yield-increasing technology, hybrid seeds, a technology which underlies the average 8.3 tonnes/ha of the United States. Hybrids are at present used in Mexico on about 1.2 million ha, out of a total harvested area under maize of 7 million ha, while the area suitable for hybrid seed use is estimated to be about 3 million ha (see Commission for Environmental Cooperation, 1999, p.137-138).

However, not all, or perhaps not even the major part, of yield differences can be ascribed to such conditions. Wide yield differences are present even among countries with fairly similar agro-ecological environments. In such cases, differences in the socio-economic and policy environments probably play a major role. The literature on yield gaps (see, for example, Duwayri, Tran and Nguyen, 1999) distinguishes two components of yield gaps: one due to agro-environmental and other non-transferable factors (these gaps cannot be narrowed); and another component due to differences in crop management practices such as suboptimal use of inputs and other cultural practices. This second component can be narrowed provided that it is economic to do so and therefore is termed the "exploitable yield gap". Duwayri, Tran and Nguyen (1999) state that the theoretical maximum yields for both wheat and rice are probably in the order of 20 tonnes/ha. On experimental stations, yields of 17 tonnes/ha have been reached in subtropical climates and of 10 tonnes/ha in the tropics. FAO (1999c) reports that concerted efforts in Australia to reduce the exploitable yield gap increased rice yields from 6.8 tonnes/ha in 1985/89 to 8.4 tonnes/ha in 1995/99, with many individual farmers obtaining 10 to 12 tonnes/ha.

In order to draw conclusions on the scope for narrowing the yield gap, one needs to separate its "non-transferable" part from the "exploitable" part. One way to do so is to compare yields obtained from the same crop varieties grown on different locations of land that are fairly homogeneous with respect to their physical characteristics (climate, soil and terrain), which would eliminate the "non-transferable" part in the comparison. One can go some way in that direction by examining the data on the suitability of land in the different countries for producing any given crop under specified technology packages. The required data comes from the GAEZ analysis discussed in Section 4.3.1. These data make it possible to derive a "national maximum obtainable yield" by weighting the yield obtainable in each of the suitability classes with the estimated land area in each suitability class. The derived national obtainable yield can then be compared with data on the actual national average yields. This comparison is somewhat distorted since the GAEZ analysis deals only with rainfed agriculture, while the national statistics include irrigated agriculture as

[10] Top 10 percent of countries ranked according to area allocated to the crop examined: China, India and Turkey for wheat; and India, China, Indonesia, Bangladesh and Thailand for rice.

well. However, the findings seem to confirm the hypothesis that a good part of the yield gap is of the second, exploitable type. For a further discussion on this topic, see Section 11.1 in Chapter 11.

4.6 Input use

4.6.1 Fertilizer consumption

As discussed in Section 4.2, the bulk of the projected increases in crop production will have to come from higher yields, with the remaining part coming from an expansion in harvested area. Both higher yields, which normally demand higher fertilizer application rates, and land expansion will lead to an increase in fertilizer use. Increases in biomass require additional uptake of nutrients which may come from both organic and mineral sources. Unfortunately, for most crops there are not enough data to estimate the relation between mineral fertilizer consumption and biomass increases. The historical relationship between cereal production and mineral fertilizer consumption is better known. One-third of the increase in cereal production worldwide and half of the increase in India's grain production during the 1970s and 1980s have been attributed to increased fertilizer consumption. The application of mineral fertilizers needed to obtain higher yields should complement nutrients available from other sources and match the needs of individual crop varieties.

Increased use of fertilizer is becoming even more crucial in view of other factors, such as the impact on soil fertility of more intensive cultivation practices and the shortening of fallow periods. There is empirical evidence that nutrient budgets[11]

Table 4.14 Fertilizer consumption by major crops

	1997/99 Share (%) in total	1997/99	2015	2030	1997/99-2030 % p.a.
		Nutrients, million tonnes			
Wheat	18.4	25.3	30.4	34.9	1.0
Rice	17.3	23.8	26.5	28.1	0.5
Maize	16.3	22.5	29.0	34.5	1.3
Fodder	6.2	8.5	9.3	10.0	0.5
Seed cotton	3.5	4.9	6.2	7.1	1.2
Soybeans	3.4	4.6	7.6	11.5	2.9
Vegetables	3.3	4.6	5.3	6.1	0.9
Sugar cane	3.2	4.4	5.5	6.6	1.3
Fruit	2.9	4.1	4.3	7.5	1.9
Barley	2.9	4.0	4.4	4.8	0.6
Other cereals	2.9	3.9	9.2	8.3	2.3
Potato	2.0	2.7	3.3	3.8	1.1
Rapeseed	1.5	2.1	3.5	5.1	2.8
Sweet potato	1.3	1.8	2.0	2.1	0.5
Sugar beet	1.0	1.4	1.6	1.7	0.6
All cereals		79.5	99.5	110.6	1.0
% of total	57.7	57.7	64.8	58.8	
All crops above		118.5	148.2	172.1	1.2
% of total	86.0	86.0	89.8	91.5	
World total		137.7	165.1	188.0	1.0

Notes: Crops with a 1997/99 share of at least 1 percent, ordered according to their 1997/99 share in fertilizer use.

[11] A nutrient budget is defined as the balance of nutrient inputs such as mineral fertilizers, manure, deposition, biological nitrogen fixation and sedimentation, and nutrient outputs (crops harvested, crop residues, leaching, gaseous losses and erosion).

Table 4.15 Fertilizer consumption: past and projected

	1961 /63	1979 /81	1997 /99	2015	2030	1961 -1999	1989- 1999	1997/99 -2030
Total	**Nutrients, million tonnes**					**% p.a.**		
Sub-Saharan Africa	0.2	0.9	1.1	1.8	2.6	5.3	-1.8	2.7
Latin America and the Caribbean	1.1	6.8	11.3	13.1	16.3	6.1	4.4	1.2
Near East/ North Africa	0.5	3.5	6.1	7.5	9.1	7.3	0.8	1.3
South Asia	0.6	7.3	21.3	24.1	28.9	9.6	4.5	1.0
excl. India	0.2	1.6	4.2	5.4	6.9	9.2	4.6	1.5
East Asia	1.7	18.2	45.0	56.9	63.0	9.3	3.8	1.1
excl. China	0.9	4.1	9.4	13.8	10.3	7.0	3.2	0.3
All above	4.1	36.7	84.8	103.5	119.9	8.5	3.7	1.1
excl. China	3.3	22.6	49.2	60.4	67.3	7.6	3.5	1.0
excl. China and India	2.9	16.9	32.1	41.6	45.3	6.9	3.1	1.1
Industrial countries	24.3	49.1	45.2	52.3	58.0	1.4	0.1	0.8
Transition countries	5.6	28.4	7.6	9.3	10.1	0.7	-14.9	0.9
World	34.1	114.2	137.7	165.1	188.0	3.6	0.2	1.0
Per hectare	**kg/ha (arable land)**					**% p.a.**		
Sub-Saharan Africa	1	7	5	7	9	4.5	-2.4	1.9
Latin America and the Caribbean	11	50	56	59	67	6.0	0.0	0.6
Near East/North Africa	6	38	71	84	99	5.7	3.9	1.0
South Asia	6	36	103	115	134	9.5	4.5	0.8
excl. India	6	48	113	142	178	8.8	4.3	1.4
East Asia	10	100	194	244	266	8.3	3.6	1.0
excl. China	12	50	96	131	92	6.1	3.3	-0.1
All above	6	49	89	102	111	7.7	3.3	0.7
excl. China	6	35	60	68	71	6.9	3.2	0.5
excl. China and India	7	35	49	58	58	6.0	2.6	0.5
Industrial countries	64	124	117			1.3	0.3	
Transition countries	19	101	29			0.9	-14.4	
World	25	80	92			3.3	0.1	

Note: Kg/ha for 1997/99 are for developing countries calculated on the basis of "adjusted" arable land data. For industrial and transition countries no projections of arable land were made.

change over time and that higher yields can be achieved through reduction of nutrient losses within cropping systems. That is, increases in food production can be obtained with a less than proportional increase in fertilizer nutrient use. Frink, Waggoner and Ausubel (1998) showed this situation for maize in North America. Farmers achieve such increased nutrient use efficiency by adopting improved and more precise management practices. Socolow (1998) suggests that management techniques such as precision agriculture offer abundant opportunities to substitute information for fertilizer. It is expected that this trend of increasing efficiency of nutrient use through better nutrient management, by improving the efficiency of nutrient balances and the timing and placement of fertilizers, will continue and accelerate in the future.

Projections for fertilizer consumption have been derived on the basis of the relationship between yields and fertilizer application rates that existed during 1995/97. Data on fertilizer use by crop and fertilizer application rates (kg of fertilizer per ha) are available for all major countries and crops, accounting for 97 percent of global fertilizer use in 1995/97 (FAO/IFA/IFDC, 1999 and Harris, 1997). This relationship is estimated on a cross-section basis for the crops for which data are available and is assumed to hold also over time as yields increase (see Daberkov *et al.,* 1999). It provides a basis for estimating future fertilizer application rates required to obtain the projected increase in yields for most of the crops covered in this study. It implicitly assumes that improvements in nutrient use efficiency will continue to occur as embodied in the relationship between yields and fertilizer application rates (fertilizer response coefficients) estimated for 1995/97. For some crop categories such as citrus, vegetables, fruit and "other cereals", fertilizer consumption growth is assumed to be equal to the growth in crop production: i.e. for these crops, the base year input-output relationship between fertilizer use and crop production is assumed to remain constant over the projection period. To account fully for all fertilizer consumption, including its use for crops not covered in this study, fertilizer applications on fodder crops were assumed to grow at the same rate as projected growth for livestock (meat and milk) production, and fertilizer applications on "other crops" is at the average rate for all crops covered in the study.

The overall result, aggregated over all crops, is that fertilizer consumption will increase by 1.0 percent p.a., rising from 138 million tonnes in 1997/99 to 188 million tonnes in 2030 (Table 4.14). This is much slower than in the past for the reasons explained below. Wheat, rice and maize, which together at present account for over half of global fertilizer use, will continue to do so, at least until 2030. By 2015 maize will rival wheat as the top fertilizer user because of the projected increase in maize demand for feeding purposes in developing countries (see Chapter 3). Fertilizer applications to oilseeds (soybeans and rapeseed) are expected to grow fastest.

North America, western Europe, East and South Asia accounted for over 80 percent of all fertilizer use in 1997/99. Growth in fertilizer use in the industrial countries, especially in western Europe, is expected to lag significantly behind growth in other regions of the world (Table 4.15). The maturing of fertilizer markets during the 1980s in North America and western Europe, two of the major fertilizer consuming regions of the world, account for much of the projected slowdown in fertilizer consumption growth. In the more recent past, changes in agricultural policies, in particular reductions in support measures, contributed to a slowdown or even decline in fertilizer use in this group of countries. Increasing awareness of and concern about the environmental impacts of fertilizer use are also likely to hold back future growth in fertilizer use (see Chapter 12).

Over the past few decades, the use of mineral fertilizers has been growing rapidly in developing countries starting, of course, from a low base (Table 4.15). This has been particularly so in East and South Asia following the introduction of high-yielding varieties. East Asia (mainly China) is likely to continue to dwarf the fertilizer consumption of the other developing regions. For sub-Saharan Africa, above average growth rates are foreseen, starting from a very low base, but fertilizer consumption per hectare is expected to remain at a relatively low level. The latter probably reflects large areas with no fertilizer use at all, combined with small areas of commercial farming with high levels of fertilizer use, and could be seen as a sign of nutrient mining (see also Henao and Baanante, 1999).

Average fertilizer productivity, as measured by kg of product obtained per kg of nutrient, shows considerable variation across countries. This reflects a host of factors such as differences in agro-ecological resources (soil, terrain and climate), in management practices and skills and in economic incentives. Fertilizer productivity is also strongly related to soil moisture availability. For example, irrigated wheat production in Zimbabwe and Saudi Arabia shows a ratio of 40 kg wheat per kg fertilizer nutrient at yield levels of 4.5 tonnes/ha. Similar yields in Norway and the Czech Republic require twice as large fertilizer application rates, reflecting a considerably different agro-ecological resource base. Furthermore, a high yield/fertilizer ratio may also indicate that fertilizer use is not widespread among farmers (e.g. wheat in Russia, Ethiopia and Algeria), or that high yields are obtained with nutrients other than mineral fertilizer (e.g. manure is estimated to provide almost half of all external nutrient inputs in the EU). Notwithstanding this variability, in many cases the scope for raising fertilizer productivity is substantial. The degree to which such productivity gains will be pursued depends to a great extent on economic incentives.

The projected slowdown in the growth of fertilizer consumption is due mainly to the expected slowdown in crop production growth (Table 4.1). The reasons for this have been explained in Chapter 3. Again, this is not a sudden change but a gradual process already under way for some time, as illustrated by the annual growth rates for the last ten years (1989-99) shown in Table 4.15. In some cases it would even represent a "recovery" as compared with recent developments. As mentioned, fertilizer is most productive in the absence of moisture constraints, i.e. when applied to irrigated crops. For this reason, the expected slowdown in irrigation expansion (Section 4.4.1) will also slow the growth of fertilizer consumption. The continuing trend to increase fertilizer use efficiency, partly driven by new techniques such as biotechnology and precision agriculture, will also reduce mineral fertilizer needs per unit of crop output. There is an increasing concern about the negative environmental impact of high rates of mineral fertilizer use. Finally there is the spread of organic agriculture, and the increasing availability of non-mineral nutrient sources such as manure; recycled human, industrial and agricultural waste; and crop by-products. All these factors will tend to reduce growth in fertilizer consumption.

4.6.2 Farm power

Human labour, draught animals and engine-driven machinery are an integral part of the agricultural production process. They provide the motive power for land clearance and preparation, for planting, fertilizing, weeding and irrigation, and for harvesting, transport and processing. This section focuses on the use of power for primary tillage. Land preparation represents one of the most significant uses of power. Since land preparation is power intensive (as opposed to control intensive), it is usually one of the first operations to benefit from mechanization (Rijk, 1989). Hence any change in the use of different power sources for land cultivation may act as an indicator for similar changes in other parts of the production process.

Regional estimates of the relative contributions of different power sources to land cultivation have been developed from estimates initially generated at the country level. On the basis of existing data and expert opinion, individual countries were classified into one of six farm power categories according to the proportion of area cultivated by different power sources, at present and projected to 2030. The categories range from those where hand power predominates, through those where draught animals are the main source of power, to those where most land is cultivated by tractors. The figures were subsequently aggregated to estimate the harvested area cultivated by different power sources for each region (see Box 4.5 for details of the methodology).

Overall results. It was estimated that in 1997/99, in developing countries as a whole, the proportion of land cultivated by each of the three power sources was broadly similar. Of the total harvested area in developing countries (excluding China), 35 percent was prepared by hand, 30 percent by draught animals and 35 percent by tractors (Table 4.16). By 2030, 55 percent of the harvested area is expected to be tilled by tractors. Hand power will account for approximately 25 percent of the harvested area and draught animal power (DAP) for approximately 20 percent.

Box 4.5 Methodology to estimate farm power category

Individual countries were classified by expert opinion into one of six farm power categories according to the proportion of area cultivated by different power sources. The six categories identified are given in the table below. The percentages of the area cultivated by different power sources are indicative only and refer to harvested land, which represents the actual area cultivated in any year, taking into account multiple cropping and short-term fallow. Upper and lower limits were set for the area cultivated by each power source (bottom row in the table).

Farm power category at country level		Percentage of area cultivated by each power source		
		Hand	Draught animals	Tractors
A =	humans are the predominant source of power, with modest contributions from draught animals and tractors	>80	< 20	<5
B =	significant use is made of draught animals, although humans are still the most important power source	45-80	20-40	<20
C =	draught animals are the principal power source	15-45	>40	<20
D =	significant use is made of motorized power, including both two-wheel and four-wheel tractors	20-50	15-30	20-50
E =	tractors are the dominant power source	<5	<25	50-80
F =	fully motorized	<10	<10	>80
Minimum and maximum percentage		5-90	5-70	2-90

Where possible, country classifications were verified against existing data. Sources included a number of country farm power assessment studies commissioned by the Agricultural Engineering Branch of FAO and published reports. The classifications from various sources proved to be fairly consistent. The categories were converted into the physical area cultivated by each power source by multiplying the estimated percentage figure for each power source with the data for harvested area for the base year 1997/99 and the projected area for 2030. The country figures were subsequently aggregated to estimate the harvested area cultivated by different power sources for subregions and regions.

This approach has several advantages. First, it highlights the role of humans as a source of power in those parts of the world where they are responsible for much of the land preparation. This is essential for understanding concerns arising from future projections about the size and composition of the agricultural labour force, particularly in countries where a sizeable share of the population is expected to be affected by HIV/AIDS within the next 20 years. The significance of humans as a power source can be easily overlooked if their contribution is expressed solely as a percentage of the total power input, rather than the area they cultivate. Second, when projecting future combinations of farm power inputs at the country level, account can be taken, albeit by way of expert judgement, of the developments in the overall economy and in the agricultural sector, competing claims on resource use, and opportunities for substitution between power sources. Third, this approach is independent of estimates of inventories of draught animals and tractors, data for which are often unreliable or not readily available. The number of tractors and draught animals working in agriculture may vary considerably from published data. These numbers depend on several unknown variables, such as the working life, the proportion working in agriculture as opposed to off-farm activities, and the proportion in an operational state. Finally, the process of converting different power sources into a common power equivalent is a process fraught with difficulties and inaccuracies.

Nevertheless, there are also several limitations associated with the methodology. First, only one farm power category is selected to represent the power use for land cultivation within an entire country. This overlooks the diversity that exists inside many countries, particularly when the use of a specific power source is highly influenced by soil and terrain constraints, by cropping patterns, or is highly differentiated between commercial/estate and smallholder sectors. A second limitation is the use of a single average percentage figure for each power source to convert categories to harvested area, rather than actual percentages.

Table 4.16 Proportion of area cultivated by different power sources, 1997/99 and 2030

Region		Percentage of area cultivated by different power sources		
		Hand	Draught animal	Tractor
All developing countries	1997/99	35	30	35
	2030	25	20	55
Sub-Saharan Africa	1997/99	65	25	10
	2030	45	30	25
Near East/North Africa	1997/99	20	20	60
	2030	10	15	75
Latin America and the Caribbean	1997/99	25	25	50
	2030	15	15	70
South Asia	1997/99	30	35	35
	2030	15	15	70
East Asia	1997/99	40	40	20
	2030	25	25	50

Notes:Figures have been rounded to the nearest 5 percent. China has been excluded from the analysis because its size and diversity made it impossible to estimate a single farm power category for the country.

There are marked regional differences in the relative contributions of the power sources, both at present and in the future. Tractors are already a significant source of power in the Near East/North Africa region and in Latin America and the Caribbean: approximately half of the harvested area is currently prepared by tractor in these regions. This is expected to rise to at least 70 percent of harvested area by 2030. Draught animals are at present relatively important sources of power in the rice and mixed farming systems of South and East Asia, accounting for over one-third of harvested area. However, the shift to motorized power by 2030 will be substantial. The area cultivated by tractors will rise in South Asia from 35 percent of harvested area to 70 percent, and in East Asia (excluding China) from 20 percent to over 50 percent. This increase in area cultivated by tractor arises from two factors: an increase in total harvested area at the country level, combined with a reduction in the area cultivated by humans and draught animals as a result of substitution between power sources.

In contrast, humans are and will continue to be the main power source in sub-Saharan Africa. Almost two-thirds of the harvested area is prepared by hand at present and although this will fall to 50 percent by 2030, the physical area involved will remain broadly constant. The area cultivated by draught animals and tractors is expected to increase (both in physical area and proportional terms) but they will not offset the dominance of hand power.

When countries are classified by farm power category, some common characteristics can be observed:

- *Countries in which humans are the predominant power source*. The agricultural sector typically employs two-thirds of the workforce and generates over one-third of the GDP. During the 1990s many of these economies were almost static with annual average growth rates in total GDP of less than 1 percent and income per head below US$500.
- *Countries in which draught animals are a significant or predominant source of power*. The principal difference between the hand power and draught animal power countries is in terms of land use. The intensity of cultivation on both rainfed and irrigated land is higher and more area is under irrigation. Indeed, in all regions the highest cropping intensities occur in DAP countries. This suggests there are no labour displacement effects associated with the use of draught animals.
- *Countries in which tractors are a significant or predominant source of power.* High levels of

tractorization are generally associated with relatively well-developed economies and the production of cash crops. Non-agricultural revenues can facilitate their adoption. The increased use of tractors is consistently associated with expanding the area under irrigation, but cultivating it less intensively than in countries using hand or animal power. In these countries agriculture is no longer the dominant sector, employing less than half of the workforce and generating less than one quarter of GDP. Their economies are more buoyant and incomes per capita are at least three times as high as those in either hand power or DAP countries in the same region. The rate of growth in the agricultural workforce is small and in some countries the absolute number of people working in agriculture has started to fall. This is often considered to be one of the more significant turning points in the process of economic development.

Forces changing the composition of farm power inputs. The stimulus to change the composition of farm power inputs will come from either changes in the demand for farm power or from supply-side changes, or both. Any increase in total agricultural output (be it from area expansion, an increase in cropping intensity or an increase in yield) requires additional power, if not for technology application then for handling and processing increased volumes. Similarly, land improvements (such as terracing, drainage or irrigation structures), soil conservation and water harvesting techniques frequently place additional demands on the power resource.

In response, farmers can either increase their inputs of farm power or increase the productivity of existing inputs through the use of improved tools and equipment. Alternatively, adopting different practices or changing cropping patterns may reduce power requirements. For example, the use of no-till and direct seeding practices eliminates the need for conventional land preparation and tillage; broadcasting rice overcomes the labour-intensive activity of transplanting seedlings, and the use of draught animal power, benevolent herbicides or no-tillage with continuous soil cover (see Chapter 11) can overcome labour bottlenecks associated with weeding.

Motivations to mechanize may also arise from supply-side changes in the availability and productivity of farm power inputs, as well as a wish to reduce the drudgery of farm work. The health, nutritional status and age of the workforce affect the productivity of labour. The availability of household members for farm work is influenced by other claims on their time, such as household tasks, schooling and opportunities for off-farm work. The household composition also changes through rural-urban migration or the death of key household members. The productivity of draught animals is affected by their health and nutrition, the training of animals, operator skills and availability of appropriate implements. Productive and sustainable use of motorized inputs is dependent on operator skills, appropriate equipment and an infrastructure capable of providing timely and cost-effective access to repair and maintenance services.

The changing composition of farm power inputs will also have an impact on the division of agricultural tasks among household members. The range of tasks performed by different members of the household varies according to sex, age, culture, ethnicity and religion (see Box 4.6). It also varies according to the specific crop or livestock, sources of power input and equipment used.

Patterns of mechanization up to 2030. Most of the changes in farm power categories during the next 30 years are expected to occur in countries that already make significant use of tractors. By 2030, tractors will be the dominant source of power for land preparation in southern Africa, North Africa/Near East, South Asia, East Asia and Latin America and the Caribbean. Southeast Asia is also expected to shift from draught animals to making greater use of tractors. The reasons underlying these shifts are explained below.

In a few countries, it is expected that the present composition of farm power inputs is not sustainable. In eastern Africa, for example, the number of draught animals has been decimated in some areas through livestock disease and cattle rustling, thereby removing a principal power source from certain farming systems. The sustainability of tractor-based systems is highly dependent on the profitability of agriculture and an infrastructure capable of providing timely access to fuel and inputs for repairs and maintenance. The

Box 4.6 Gender roles and the feminization of agriculture

Women are key players in both cash and subsistence agriculture. Their daily workload is characterized by long hours, typically 12- to 14-hour days, with little seasonal variation. The use of their time tends to be fragmented, mixing farm work with household duties and other off-farm activities. The range of agricultural tasks performed by different household members varies according to sex, age, culture, ethnicity and religion. It also varies according to the specific crop or livestock activities, sources of power input and equipment used. Hence gender roles differ markedly, not only between regions and countries, but also within countries between neighbouring communities.

In sub-Saharan Africa, women contribute between 60 and 80 percent of the labour in food production. While there are significant variations in gender roles, women overall play a major role in planting, weeding, application of fertilizers and pesticides, harvesting, threshing, food processing, transporting and marketing. Men are largely responsible for clearing and preparing the land, and ploughing. They also participate alongside women in many of the other activities. In many countries men are responsible for large livestock and women for smaller animals, such as poultry, sheep and goats. Women are usually most active in collecting natural products, such as wild foods, fodder and fuelwood. Men are usually associated with the use of draught animals or tractors. However, with appropriate training and implements, women also prove to be very effective operators of mechanized inputs.

In Asia, women account for 35 to 60 percent of the agricultural labour force. Women and men often play complementary roles with a division of labour similar to that found in sub-Saharan Africa. In many Asian countries women are also very active with livestock, collecting fodder, preparing buffaloes for ploughing, feeding and cleaning other cattle, and milking. In Southeast Asia they play a major role in rice production, particularly in sowing, transplanting, harvesting and processing. Women also supply a significant amount of labour to tea, rubber and fruit plantations.

In the Near East, women contribute up to 50 percent of the agricultural workforce. They are mainly responsible for the more time-consuming and labour-intensive tasks that are carried out manually or with the use of simple tools. In Latin America and the Caribbean, the rural population has been decreasing in recent decades. Women are mainly engaged in subsistence farming, particularly horticulture, poultry and raising small livestock for home consumption.

Gender roles are dynamic, responding to changing economic, social and cultural forces. The rural exodus in search of income-earning opportunities outside agriculture, usually dominated by men, has resulted in increasing numbers of female-headed households and the “feminization” of agriculture. Similar patterns arise from the death of male heads of household. Women are being left to carry out agricultural work on their own, changing the traditional pattern of farming and the division of tasks among household members. For example, women in female-headed households without recourse to adult male labour may clear and prepare land, including ploughing with oxen (tasks which traditionally would have been performed by men).

The feminization of agriculture, most pronounced in sub-Saharan Africa but also a growing phenomenon in other parts of the world, has significant implications for the development of agriculture. The needs and priorities of both rural women and men must be taken into account in any initiative to support and strengthen the sector.

Source: Based on FAO (1998a).

failure of government-based initiatives often results from introducing a level of mechanization that is inappropriate for the state of economic development and political stability. As a result, in the absence of further government interventions, it is expected that some countries will revert to increasing the use of hand or draught animal power during the next 30 years.

Persistence of hand and animal power in sub-Saharan Africa. Human labour is the most significant power source throughout sub-Saharan Africa. The human contribution is most pronounced in Central and western Africa where it accounts for 85 and 70 percent of harvested area, respectively. These areas include the forest-based farming systems of Central Africa, characterized by shifting cultivation and the gathering of forest products, the root crop system stretching across West Africa, Central Africa and parts of East Africa, and the cash tree crop system in West Africa (FAO, 2001d). A relatively high proportion of rainfed land is under cultivation (45 percent of the potential area) but it is not used intensively as reflected in a relatively low cropping intensity of 60 percent. The presence of trees, stumps and shrubs makes it difficult to use ploughs without considerable investment of time and effort in land clearance (Boserup, 1965; Pingali, Bigot and Binswanger, 1987). Moreover, the incidence of tsetse fly (which breeds in tropical forests and forest margins) makes the area unsuitable for many types of draught animals. There is very little irrigated land.

Draught animals (predominantly work oxen) are concentrated on rainfed land in the cereal-based farming systems in the northern parts of West Africa, throughout the maize mixed systems of eastern Africa and the highland mixed systems of Ethiopia. Countries making significant use of tractors are scattered throughout the region.

Two-thirds of the countries in sub-Saharan Africa are not expected to change their power category by 2030. Although there will be some movement in the relative contributions of hand, draught animal and tractor power to land preparation, much of the region will continue to be cultivated using hand and animal power. All countries that are expected to change either from hand power to draught animal power, or from DAP to tractors, will experience lower population growth rates, higher incomes per head and higher income growth rates than those countries with the same farm power category at present that are not expected to change.

The process of urbanization in this region will provide some stimulus to switch power sources, as it not only draws labour away from the agricultural sector but also has implications for wage levels and the composition of the remaining labour force. Typically the young, able-bodied, educated and skilled migrate. The shift to urbanization is most pronounced in countries switching from DAP to tractors or already using tractors as the dominant power source. In these countries, a growth of almost 30 percent in the proportion of the population living in urban areas is expected by 2030, twice the rate of urbanization expected in countries not switching power source or shifting to DAP. Countries that will continue to use draught animals as a significant source of power will remain predominantly rural.

Another factor driving the process of change in eastern and southern Africa will be the impact of HIV/AIDS on the workforce (Box 4.7). Those countries that are expected to switch from hand power to DAP are projected to lose almost 20 percent of their agricultural labour to AIDS by 2020, that is, more than twice as much as those countries continuing to use hand power. Similarly, those shifting from DAP to tractors are expected to experience higher losses in their labour force (12 percent by 2020) than countries continuing with DAP. Some of the highest losses (16 percent by 2020) are projected for countries already making significant use of tractors. Thus the impact of HIV/AIDS will make it vital for many countries to change their source of farm power in order to overcome serious labour shortages at critical times of the farming year.

Increasing use of tractors in the Near East/North Africa and Asia. The development of regional markets and strong links with Europe are expected to be important engines of growth for North African countries. Oil wealth will continue to underpin development in the Near East. Economic development will be coupled with continued growth in non-agricultural employment and the migration of people from the land to urban areas. By 2030, over 75 percent of the population in the Near East/North Africa region will be living in urban areas. The option of using tractors becomes more viable with increasing costs of labour and increasing shortage of land for fodder production for draught animals.

Prospects for *mechanization in Asia* are based on projections of buoyant economies and high rates of growth in income per capita, but the process of urbanization would not appear to be so significant. More than half of the population in South Asia will continue to be based in rural areas by 2030. Single-axle tractors will be an increasingly important form of farm power in irrigated farming systems, which are suited to their use. The process of mechanization will be facilitated in this region by proximity to sources of manufacture, namely India (the world's largest manufacturer of tractors) and China (a source of low-cost power tillers).

Stable use of tractors in Latin America and the Caribbean. Projections for economic growth in Latin America and the Caribbean are on a par with other regions and per capita incomes are among the highest in the developing world. However, almost half of the countries in the region are not expected

Box 4.7 Household vulnerability to the loss of human and draught animal power

Households reliant on human power, and draught animals to a lesser extent, are extremely vulnerable to the loss of their principal power source. More than 15 countries in sub-Saharan Africa are projected to lose at least 5 percent of their workforce to HIV/AIDS by 2020. The pandemic will impact heavily in the agricultural sector where losses will typically account for at least 10 percent of the workforce and, in at least five countries, more than 20 percent. In a region where people are a significant, and often the dominant, source of power for both household and farm activities, this loss of labour will have a dramatic impact on rural livelihoods.

HIV/AIDS usually strikes at the heart of the household, killing women and men in their economic prime. Not only do households lose key family members but they also lose time spent by other household members caring for the sick. The situation is exacerbated by urban dwellers returning to their villages to be cared for when they become ill, thereby placing further strain on rural households. In addition to the immediate emotional, physical and financial stresses, the remaining family members have to take on the long-term care of orphan children. In some cultures, widows also have to cope with the threat of property-grabbing by the relatives of the deceased.

In parts of eastern and southern Africa, the vulnerability of rural livelihoods has been worsened by the decimation of the DAP base caused by the switch from hardy local breeds to cross-breeds, coupled with the failure to carry out regular healthcare practices and increased livestock susceptibility to disease (such as East Coast fever). Cattle rustling is also a threat, particularly in areas close to international borders. In the absence of alternative power sources, such as tractor hire, households have reverted to hand power. Areas under cultivation have fallen significantly and households that once were food self-sufficient and producers of surplus for sale, now regularly experience food shortages. Household transport has become more problematic and the opportunity to earn additional income from hiring out draught animals has also disappeared.

Food insecurity, arising from the inability to produce or purchase sufficient food for the household throughout the year, is a persistent characteristic of subsistence agriculture. Short-term coping strategies include reducing the number of meals eaten per day, with very poor households spending up to two days between meals, or by switching to less nutritious foods. The poor may gather and sell natural products (such as wild fruits, mushrooms, tubers, firewood and grass thatch) or beg for food. Households may also engage in off-farm activities, trading and making handicrafts, or rely on remittances from family members living elsewhere. Some survival strategies, such as the sale of assets to buy food, taking out loans to purchase inputs, or hiring out family labour to work on other farms, invariably place the household at greater risk in subsequent seasons. Longer-term adaptive strategies to overcome labour shortages include reallocating tasks between household members, using labour-saving technologies and switching to less labour-intensive cropping patterns and practices.

to change farm power categories during the next 30 years. Several countries are at the limits of technical change in terms of farm power. Much of their agricultural sector is already fully mechanized and any further expansion in the use of tractors will be largely constrained by topographical features, notably the Amazon basin and the mountainous regions of the Andes. In other countries (such as El Salvador, Guatemala, Mexico and Paraguay) the shift towards no-till farming and conservation agriculture may reduce or eliminate the need for the increased use of tractors. For a few countries, economic conditions are determining factors and stagnant incomes in the smallholder sector inhibit any increase in the use of tractors.