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WORLD AGRICULTURE TOWARDS 2030/2050

The 2012 Revision

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World agriculture towards 2030/2050: the 2012 revision

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Abstract

This paper is a re-make of Chapters 1-3 of the Interim Report *World Agriculture: towards 2030/2050* (FAO, 2006). In addition, this new paper includes a Chapter 4 on production factors (land, water, yields, fertilizers). Revised and more recent data have been used as basis for the new projections, as follows: (a) updated historical data from the Food Balance Sheets 1961-2007 as of June 2010; (b) undernourishment estimates from *The State of Food Insecurity in the World 2010* (SOFI) and related new parameters (CVs, minimum daily energy requirements) are used in the projections; (c) new population data and projections from the UN *World Population Prospects - Revision of 2008*; (d) new GDP data and projections from the World Bank; (e) a new base year of 2005/2007 (the previous edition used the base year 1999/2001); (f) updated estimates of land resources from the new evaluation of the *Global Agro-ecological Zones* (GAEZ) study of FAO and IIASA. Estimates of land under forest and in protected areas from the GAEZ are taken into account and excluded from the estimates of land areas suitable for crop production into which agriculture could expand in the future; (g) updated estimates of existing irrigation, renewable water resources and potentials for irrigation expansion; and (h) changes in the text as required by the new historical data and projections.

Like the interim report, this re-make does not include projections for the Fisheries and Forestry sectors. Calories from fish are, however, included, in the food consumption projections, along with those from other commodities (e.g. spices) not analysed individually.

The projections presented reflect the magnitudes and trajectories we estimate the major food and agriculture variables may assume in the future; they are not meant to reflect how these variables may be required to evolve in the future in order to achieve some normative objective, e.g. ensure food security for all, eliminate undernourishment or reduce it to any given desired level, or avoid food overconsumption leading to obesity and related Non-Communicable Diseases.

Keywords: agricultural outlook, food demand, production growth, nutrition, crop production, global outlook, land use, irrigation, crop yields.

JEL classification: FO1, O13, Q11, Q17, Q18, Q21, Q24, Q25

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The authors alone are responsible for any remaining errors. The opinions expressed in this paper are the authors' and do not necessarily reflect those of FAO.

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In the presentation of statistical material, countries are, where appropriate, aggregated in the following main economic groupings: "Developed countries" and "Developing countries", as listed in the Appendix. The designation "developed" and "developing" economies is intended for statistical convenience and does not necessarily express a judgement about the stage of development reached by a particular country.

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CHAPTER 1

OVERVIEW

Introduction

The perceived limits to producing food for a growing global population have been a source of debate and preoccupations for ages. Already in the third century AD, Tertullian, a church leader, raised the issue.[1] The debate gathered momentum in the late eighteenth century, following Malthus, and more recently with Paul Ehrlich's Population Bomb. Yet, world food production grew faster than population and per capita consumption increased. Population increased to 6.9 billion in 2010, up from 2.5 billion in 1950 and 3.7 billion in 1970. The UN population projections –from the medium variant of the 2008 release employed here– indicate that the world total could reach 9.15 billion in 2050. Thus, we expect an increase of 2.25 billion over the next 40 years, which is lower than the 3.2 billion increase that materialized between 1970 and 2010. This deceleration will impact world agriculture by lowering its rate of growth compared to the past.

World average per capita availability of food for direct human consumption, after allowing for waste, animal-feed and non-food uses, improved to 2,770 kcal/person/day in 2005/2007. Thus, in principle, there is sufficient global aggregate food consumption for nearly everyone to be well-fed. Yet this has not happened: some 2.3 billion people live in countries with under 2,500 kcal, and some 0.5 billion in countries with less than 2,000 kcal, while at the other extreme some 1.9 billion are in countries consuming more than 3,000 kcal. The reasons are fairly well known: mainly poverty, which has many facets, but is in many low-income countries linked to failures to develop agriculture and limited access to food produced in other countries.

This study aims to provide insights into how the situation may develop to 2050, based on the exogenous assumption that world GDP will be 2.5-fold the present one, and per capita income will be 1.8-fold. All projections are surrounded in uncertainty; but expected developments in food and feed demand are subject to less uncertainty than other variables, particularly demand stemming from novel uses of agricultural products and the underlying land and water resources requirements. Recently, the use of such products as feedstocks for the production of biofuels has been growing in importance: this is the case of maize use for ethanol in the US, of sugar cane in Brazil, of vegetable oils and cereals in the EU to produce biodiesel and ethanol. Should such trends continue, biofuels could prove to be a major disruptive force, possibly benefiting producers but harming low-income consumers.

While at present the continuation of these trends does not seem likely, the high degree of uncertainty suggests the need to analyze alternative scenarios, which are not handled in this paper. We rather take into account whatever we know today about present and likely future use of agricultural products for biofuels over the next ten years by relying on projections to 2020 produced by the OECD-FAO medium-term agricultural outlook (OECD-FAO, 2010). Accordingly, we assume that current policies and mandates foreseen to 2020 in major

[1] "The scourges of pestilence, famine, wars, and earthquakes have come to be regarded a blessing to overcrowded nations, since they serve to prune away the luxuriant growth of the human race." *De Anima*, quoted in Hardin (1998).

producing countries remain in place, and then maintain the same quantities of agricultural products used for biofuels for the subsequent projection years.

The main drivers: population and income

Assumptions on population growth are derived from the United Nations World Population Prospects-the 2008 Revision (UN, 2009). The expected fall in global demographic growth over the next forty years (0.75 percent per year between 2005/2007 and 2050, down from 1.7 percent between 1963 and 2007) is expected to translate into a reduced growth rate of agricultural consumption. However, it is important to note that the slowdown in global population growth is made up of continuing fast growth in some countries and slowdowns or declines in others. The majority of countries whose population growth is expected to be fast in the future are precisely those showing inadequate food consumption and high levels of undernourishment. Most of them are in sub-Saharan Africa. This region's population growth rate is expected to fall from 2.8 percent in the past to a still high 1.9 percent per year in the period to 2050, while the rest of the world declines from the past 1.6 percent to 0.55 percent per year. Successive revisions of demographic outlooks, moreover, suggest that population growth in these very countries is projected to slow down much less than previously anticipated: in the 2002 revision of the UN Population Prospects –used in FAO (2006) – sub-Saharan Africa was projected to reach a population of 1,557 million or 17 percent of the world total in 2050. In the projections employed in this study, the region is projected to reach 1,753 million or 19 percent of the world total in 2050. In the just published 2010 revision (UN, 2011), the region's projected population in 2050 has been raised further to 1,960 million or 21 percent.

Such drastic changes in many food-insecure countries can alter significantly the projected developments in world food security. The combination of low per capita food consumption and high population growth in several countries of sub-Saharan Africa can be a serious constraint to improving food security, especially where semi-arid agriculture is predominant and import capacity is limited.

In terms of economic growth, the long time horizon of this study implies visualizing a world that, in principle, would be significantly different from the present one. According to some projections to 2050, the world would be immensely richer and characterized by less pronounced relative income gaps between developed and countries currently classified as "developing", many of which will no longer belong to this group in the future. We kept this traditional classification for the sake of preserving the link between historical experience and possible future outcomes. The GDP assumptions adopted in this study were kindly made available by the Development Prospects Group of the World Bank. This is one of the most conservative scenarios among those available for several countries.[2] Still, GDP in 2050 is projected to be a multiple of the current levels, and developing countries are expected to grow faster than developed ones. While in relative terms there will be convergence in per capita incomes, absolute gaps will continue increasing.

Will incomes in low-income countries increase sufficiently to reach levels allowing eliminating, or significantly reducing, poverty and the associated undernourishment? On this point we cannot be very sanguine: there are at present 45 developing countries with per capita GDP under $1,000. Fifteen of them may still show less than $1,000 in 2050. This is a rough indication that significant poverty may continue to prevail in 2050 in a world that, according

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[2] Less conservative GDP projections are available from the World Bank itself (van der Mensbrugghe *et al.*, 2011), the IPPC (2007a), the CEPII (Foure *et al.*, 2010), or PricewaterhouseCoopers (Hacksworth, 2006). For more limited sets of countries projections are also available from Goldman Sachs (2007).

to the GDP projections employed, would be over 80 percent richer in terms of average per capita incomes. Food consumption projections mirror this prospect, with several countries projected to show levels of per capita food consumption that imply persistence of significant prevalence of undernourishment in 2050.

Structural changes in diets: towards satiety and over-nutrition

Overall demand for agricultural products is expected to grow at 1.1 percent per year from 2005/2007-2050, down from 2.2 percent per year in the past four decades.[3] Population growth, increases in per capita consumption and changes in diets leading to the consumption of more livestock products are the main drivers of such expected changes.

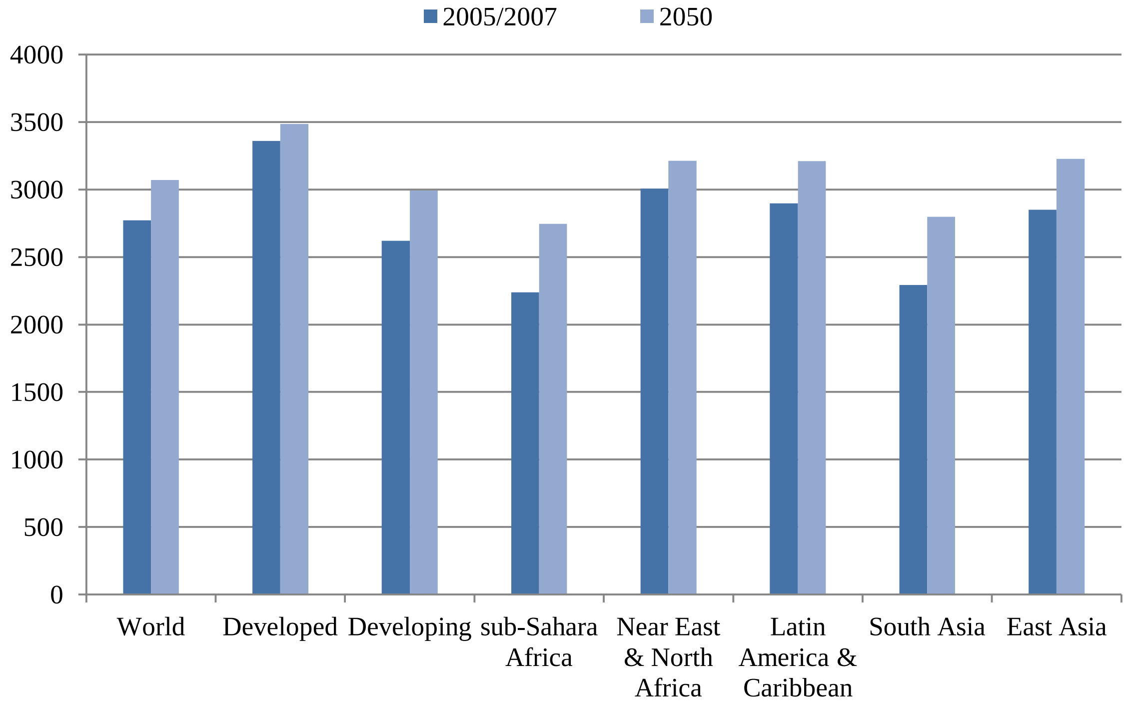
Significant parts of world population will reach per capita consumption levels that do not leave much scope for further increases. Negative growth rates of aggregate food demand may materialize in countries where per capita consumption levels are or will be high –such as Japan, Russia or others Eastern European countries– as their population starts declining in the later part of the projection period. Most developed countries have largely completed the transition to livestock based diets, while not all developing countries – for instance India – will likely shift in the foreseeable future to levels of meat consumption typical of western diets. Thus the growth of world food production needed to meet the growth of demand will be lower than in the past, even after accounting for increases in per capita consumption and changes in diets. This is a theme running throughout the narrative presenting the findings of the present study.

Considering the main regions, of particular interest is the extent to which the two with low and largely inadequate food consumption per capita – sub-Saharan Africa and South Asia – may, unlike it happened in the past, progress to higher levels (Figure 1.1). South Asia’s level is not different from that of 10 or 20 years ago, while sub-Saharan Africa has made some, but totally inadequate, progress. South Asia’s average is heavily weighted with India, which, despite high growth in per capita incomes in the last ten years, is characterized by the paradox that its per capita food consumption (in kcal/person/day) has not improved. In our projections and over the longer term, both regions break with past history of no, or sluggish, improvement: by 2050 they may reach levels near those that the other three developing regions have at present.

Other regions, as well as developed countries as a group, will also increase their levels of consumption, even where this seems to be more than sufficient and health reasons would dictate otherwise. Worse, the same phenomenon seems to emerge in several developing countries with low national averages, where significant segments of the population are hit by the obesity epidemic when undernourishment is still widely prevalent. These countries are confronted with a double burden of malnutrition, resulting in novel challenges and strains in their health systems. In the end, some 4.7 billion people or 52 percent of world population may live in countries with national averages of over 3,000 kcal/person/day in 2050, up from 1.9 billion or 28 percent at present. In parallel, those living in countries with under 2,500 kcal may fall from 2.3 billion or 35 percent of world population at present, to 240 million or 2.6 percent in 2050.

[3] The terms “demand” and “consumption” are used interchangeably. Unless otherwise specified, both terms comprise all forms of use, i.e. food, feed, seed and industrial use as well as losses and waste. Demand for, as well as supply from, changes in stocks is disregarded in the projections. Given the long time horizon of the study, projections of stock changes would not add much to the main quantifications while unnecessarily complicating the analysis.

Figure 1.1 Per capita food consumption (kcal/person/day)



Concerning the commodity composition of food consumption, while developing countries are expected to move towards more livestock products, differences with the consumption levels of meat and milk of developed countries may remain substantial (Figure 1.2). That is, many developing countries will be slow in adopting western type livestock-based diets. Some major countries, like China[4] and Brazil, have moved rapidly in that direction. But they are bound to slow down as they reach higher consumption levels, a trend that will be reinforced for aggregate demand by the prospect that both countries are to enter a phase of declining population during the later part of the projection period.

Most other developing countries are not following this rapid transition pattern. For some of them it is a question of slow gains in incomes and persistence of significant poverty. But in others, food habits are not changing fast, even under rapid income growth. As mentioned, India is a case in point (in meat, not in milk whose consumption has been growing rapidly), due also to religious factors: taboos on cattle meat in India and pig-meat in Muslim countries are factors that act as a brake to the growth of meat consumption; within the meat sector they favour rapid growth of poultry, which has been gaining market share in total meat consumption for several reasons (price, health attributes). In conclusion, the much heralded meat revolution in the developing countries is likely to remain a slow starter, now that the big push given by China in the past is becoming weaker and other populous countries like India are not following that path with anything like the same force.

In developed countries the small increases or declines in per capita consumption will eventually translate into falling aggregate consumption in the later part of the projection period, given that population is projected to peak in the early 2040s.[5] Some developing

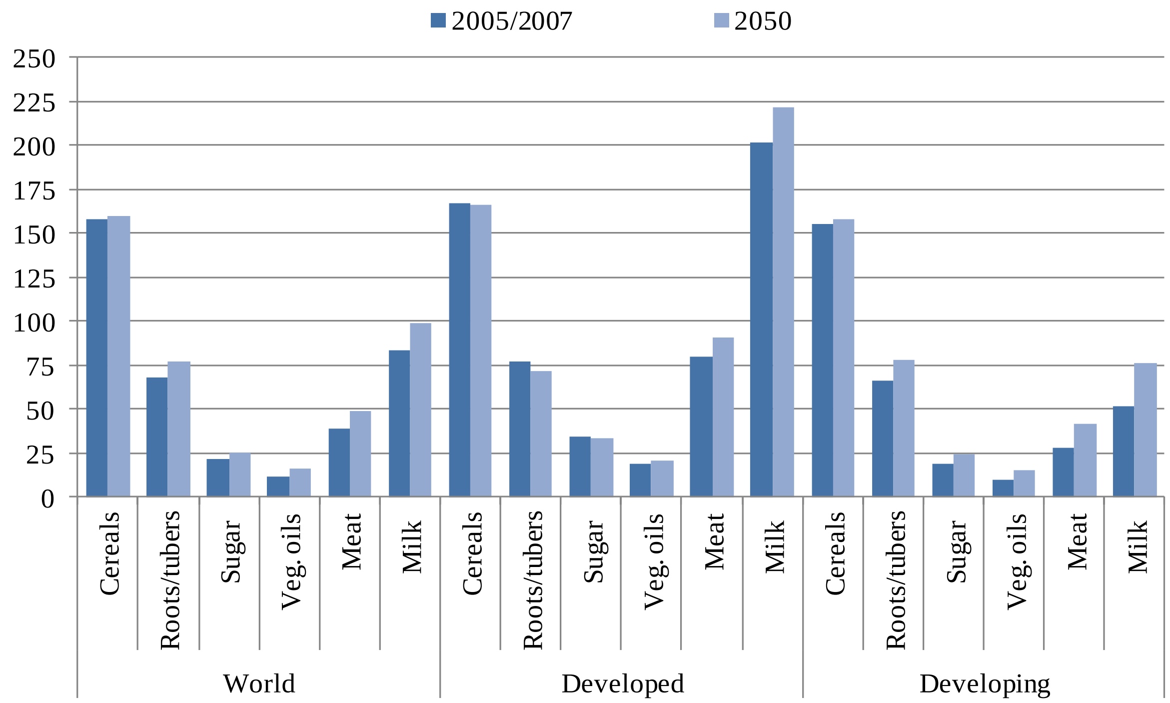
[4] Unless indicated otherwise, references to China refer to China Mainland.

[5] We refer to food consumption in terms of primary produce. Aggregate food expenditure may still grow, due to the increasing share of services associated with food consumption.

countries reaching high levels of per capita food consumption and entering a phase of declining population will likely experience similar patterns of aggregate food demand. China for instance, where population is expected to peak in the early 2030s; or Brazil, where population is expected to peak in the early 2040s.

To conclude, declining population and the high levels of consumption per capita achieved in some major countries may contribute to slowdown the growth of aggregate demand. What may happen to total consumption of agricultural goods will depend, however, also on the extent to which non-food uses, such as biofuels, take up the slack. A mentioned, this development is only partially analyzed in this paper.

Figure 1.2 Food consumption per capita, major commodities (kg/person/year)



Commodity specifications and details by region are given in Chapter 2, Tables 2.5 and 2.6.

Undernourishment, however, will still be looming large in some regions and population groups

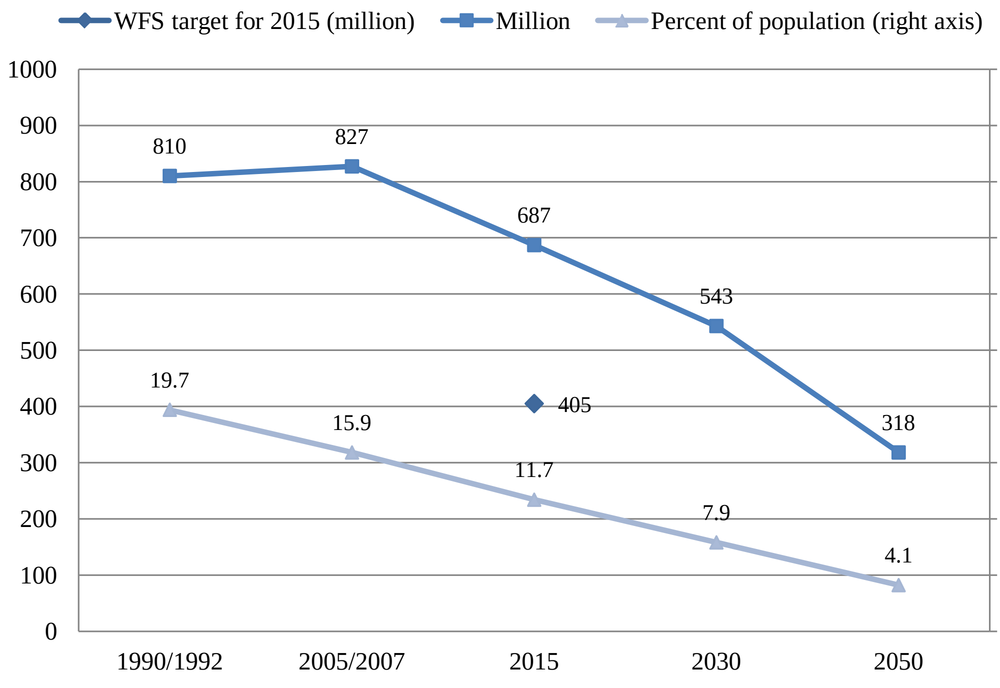
Projections of consumption per capita in kcal/person/day (derived from the projections commodity by commodity) are also employed to estimate the prevalence of undernourishment. This is defined as percent of population in each country that is below a Minimum Dietary Energy Requirement – (MDER) (FAO, 2010).[6] The 1996 World Food Summit adopted a target of reducing the numbers undernourished in the developing countries by 50 percent by 2015, starting from the average of 1990/1992 which was 810 million. The latest FAO estimate indicates that the numbers were still 827 million in 2005/2007 (FAO, 2010). No progress in reducing them has been made, though the percent of the population

[6] The methodology and data for estimating undernourishment are currently under review in FAO (FAO, 2011a:10).

affected did fall from 20 percent to 16 percent. Absolute numbers, however, increased because total population increased. If the target had been set in terms of percent of population, as it was later done for the Millennium Development Goals (MDGs), some progress would have been registered.

Figure 1.3 shows projections of the prevalence of undernourishment in developing countries. Absolute numbers of the undernourished may decline slowly rather than increase as it happened in the past. However, the percent of population that is undernourished is expected to fall by about 4 points to 2015, just as it had between 1990/1992 and 2005/2007, when it was associated with a small increase in the absolute numbers. Now the expected reduction in the percent of population is associated with a decline in the absolute numbers of the undernourished, given that between 2005/2007 and 2015 population is expected to increase less than between 1990/1992 and 2005/2007.

Figure 1.3 Prevalence of undernourishment, developing countries



Past 2015, the decline in absolute numbers is estimated to continue. Still, the halving target of the 1996 World Food Summit may not be achieved before the second half of the 2040s. Halving the percentage may instead be achieved shortly after 2015. The reason for such slow projected progress is that countries with low food consumption per capita and high prevalence of undernourishment in 2005/2007 are also those with high population growth, many of them in sub-Saharan Africa.

It is noted that the 1996 WFS (absolute) halving target is much more difficult to reach than the Millennium Development Goal target (MDG1), which is set in terms of halving the proportion of people who suffer from hunger between 1990 and 2015. Monitoring progress towards the WFS halving target will always show countries with high population growth rates as making less progress than countries with low population growth rates, even when both make the same progress towards the MDG1 target. Finally, an additional reason why progress may be slow is the increase in the share of adults in total population. This raises the average MDER of the countries and, *ceteris paribus*, contributes to making the incidence of undernourishment higher than it would otherwise be. For any given level of national average kcal/person/day, a higher proportion of the population will fall below the new higher MDER.

Production growth slows down, but absolute increases are expected to be significant

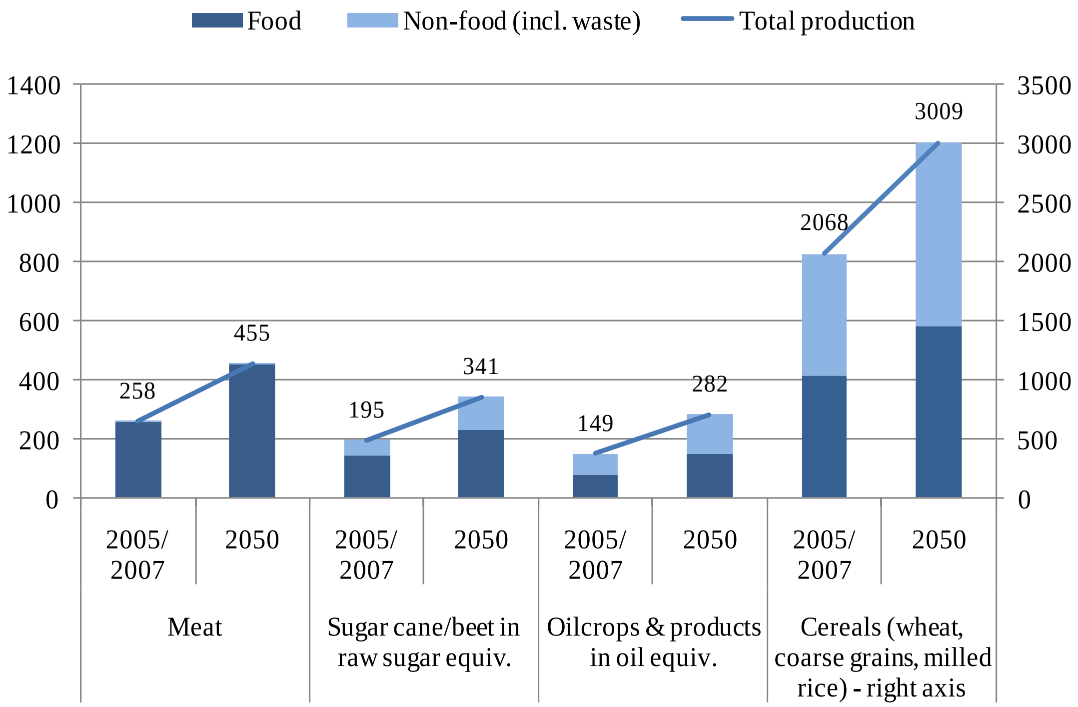
The projected growth rate of total world consumption of all agricultural products is 1.1 percent p.a. from 2005/2007-2050. Since at the world level (but not for individual countries or regions) consumption equals production, this means global production in 2050 should be 60 percent higher than that of 2005/2007.

Box 1.1 **Measuring the increase in aggregate agricultural production (all crop and livestock products)**

Here, a small digression is in order. The projections of the earlier study (FAO, 2006) formed the basis on which a number of statements were made in subsequent years as to by how much world agricultural production would increase up to 2050. In particular, in mid-2009 we compared the 2050 projection (that had been generated in 2003-05, from base year 1999/2001) with world agricultural production for 2005/2007, as was known then from provisional data. It implied a 70 percent increase in 44 years (from average 2005/2007-2050). In the current projections the aggregate volume of world agricultural production in 2050 is about the same as in the earlier ones, though the commodity composition and pattern of uses (food, feed, etc) is different (e.g. somewhat less meat but the same 3.0 billion tonnes of cereals with a smaller share going to feed and more to biofuels). However, the revised data for world production in 2005/2007 are now higher than was known provisionally in mid-2009. As a result world production is projected to increase by 60 percent from 2005/2007-2050. In practice, nothing changed in terms of projected aggregate world production. We considered worth putting in this clarification because the 70 percent seems to have assumed a life of its own – see, for example, Economist (2011);Tomlinson (2010); sometimes it has been interpreted (erroneously) as implying 70 percent increase in world production of grain (e.g. Feffer,2011). We hasten to add that the percent increase in the aggregate volume is not a very meaningful indicator. The volume index adds together very dissimilar products (oranges, grain, meat. milk, coffee, oilseeds, cotton, etc) using price weights for aggregation (the issue is explained in more detail in Chapter 3, Box 3.1). Anyone interested in food and agriculture futures can use more meaningful metrics, e.g. tonnes of grain, of meat, food consumption per capita in terms of kg/person/year or kcal/person/day, yields, land use, etc. For this reason we start by giving selected key numbers below. Another point of clarification: the projected increases are those required to match the projected demand as we think it may develop, not what is "required to feed the projected world population or to meet some other normative target". Our projection is not a normative one: if a country's income growth, production and import potentials are judged not to be sufficient to raise per capita consumption to levels required for eliminating food insecurity then projected per capita consumption is less than required.

Concerning the main product groups, percentage increases shown by growth rates may be small compared with those of the past, but the absolute volumes involved are nonetheless substantial (Figure 1.4). For example, world cereals production is projected to grow at 0.9 percent per year from 2005/2007 to 2050, down from the 1.9 percent per year of 1961-2007. However, world production, which increased by 1,225 million tonnes between 1961/63 and 2005/2007, is projected to increase by another 940 million tonnes in the next 44 years, to reach 3 billion tonnes by 2050.

Figure 1.4 World production and use, major products (million tonnes)



Achieving such production increases will not be easier than in the past; rather, the contrary often holds for a number of reasons. Land and water resources are now much more stressed than in the past and are becoming scarcer, both in quantitative terms (per capita) and qualitative ones, following soil degradation, salinization of irrigated areas and competition from uses other than for food production. Growth of crop yields has slowed down considerably, and fears are expressed that the trend may not reverse. The issue is not whether yields would grow at the past high rates, as they probably would not, apart from the individual countries and crops. Rather, the issue is whether the lower growth potential, together with modest increases in cultivated land, is sufficient to meet the increased requirements. Climate change, furthermore, looms large as a risk that would negatively affect the production potentials of agricultural resources in many areas of the world.

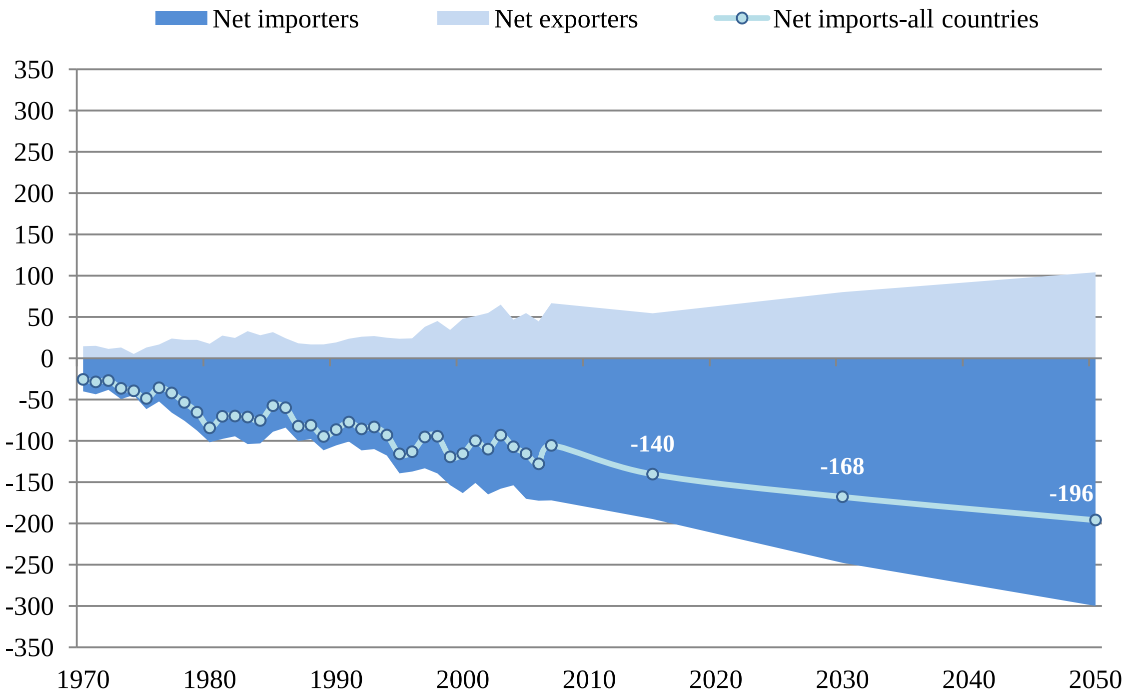
In general, the sustainability of the food production system is being questioned. Doubts are cast on the possibility to continue doing more of the same, that is, using high levels of external inputs in production, increasing the share of livestock in total output, expanding cultivated land and irrigation, and transporting products over long distances. Many advocate the need for "sustainable intensification" of production (Royal Society, 2009; *Nature*, 2010; Godfray *et al.*, 2010). Will it be possible to achieve the projected quantities of production? We shall show what we consider are possible combinations of land and water use and yield growth that could underlie the production projections.

Trade will expand, especially from and to developing countries

Developing countries have been traditionally net importers of cereals: net exporters of rice and net importers of wheat and coarse grains. The great majority of developing countries are growing net importers, some very large ones, for instance Mexico, Saudi Arabia, the Republic of Korea, Egypt, Algeria and Taiwan Province of China. At the same time, net exporting developing countries have been increasing their exports. To the traditional net exporters of South America and the rice exporters of Asia have been added recently for most years India and China. These two countries, traditional exporters of rice, have become net exporters of other cereals. China's net exports of coarse grains grew from about the mid-80s; India has been an occasional net exporter of wheat in the last decade. Their role as net exporters of cereals may be diminished in the future, but the traditional exporters as a group would increase further their exports, and countries like Brazil may also become a net exporter.

Developing countries as a group are projected to continue increasing their net imports of cereals from the rest of the world. This will mirror increasing net exports of developed countries as a group (Figure 1.5). Traditional exporters such as North America, the EU and Australia have increased sales only modestly in the last decade, while new entrants such as the Russian Federation and Ukraine have been supplying a growing share of world exports. These trends are projected to continue and the latter two countries will become of increasing importance as suppliers of wheat and coarse grains.

Figure 1.5 Developing countries: net cereals trade (million tonnes)



A country is defined as net importer or exporter according to its net balance in each year.

Developments in other major commodity groups suggest continuing buoyancy of trade in oilseeds and derived products. Many developing countries will continue increasing vegetable oil imports for food purposes, while imports in developed countries will continue primarily for non-food uses, including biodiesel production. Increasingly, exports will be supplied by major exporters from Southeast Asia and South America. Developed countries as a whole are expected to become growing net importers.

Trade in meat has been characterized by fairly rapid import growth in Japan and the Russian Federation, as well in some developing countries. Developing countries as a group have become growing net importers of meat from the mid-1970s, but this trend has been reversed in recent years following the expansion of exports from Brazil. In the projection period, it is expected that increases in imports by developing countries will be counterbalanced by exports from the same country group. In parallel, import requirements by the major developed importers are likely to decline in the long term as their consumption slows down, following population declines and attainment of high levels of per capita consumption. The net result will likely be that the major developed exporters of meat will see little growth, a trend pointing to an eventual decline in their net exports in the longer term.

How will production respond? Some more land and water use, with yields slowing down

As mentioned above, resource constraints for agricultural production have become more stringent than in the past while growth of yields is slowing down. This is a primary reason why people express fears that there are growing risks that world food production may not be enough to feed a growing population and ensure food security for all.

It is worth recalling, in this respect, that food security is only weakly linked to the capacity of the world as a whole to produce food, to the point of becoming nearly irrelevant, at least for two reasons:

(a) there are sufficient spare food production resources in certain parts of the world, waiting to be employed if only economic and institutional frameworks would so dictate;

(b) production constraints are and will continue to be important determinants of food security; however, they operate and can cause Malthusian situations to prevail, at the local level and often because in many such situations production constraints affect negatively not only the possibility of increasing food supplies but can be veritable constraints to overall development and prime causes of the emergence of poverty traps.

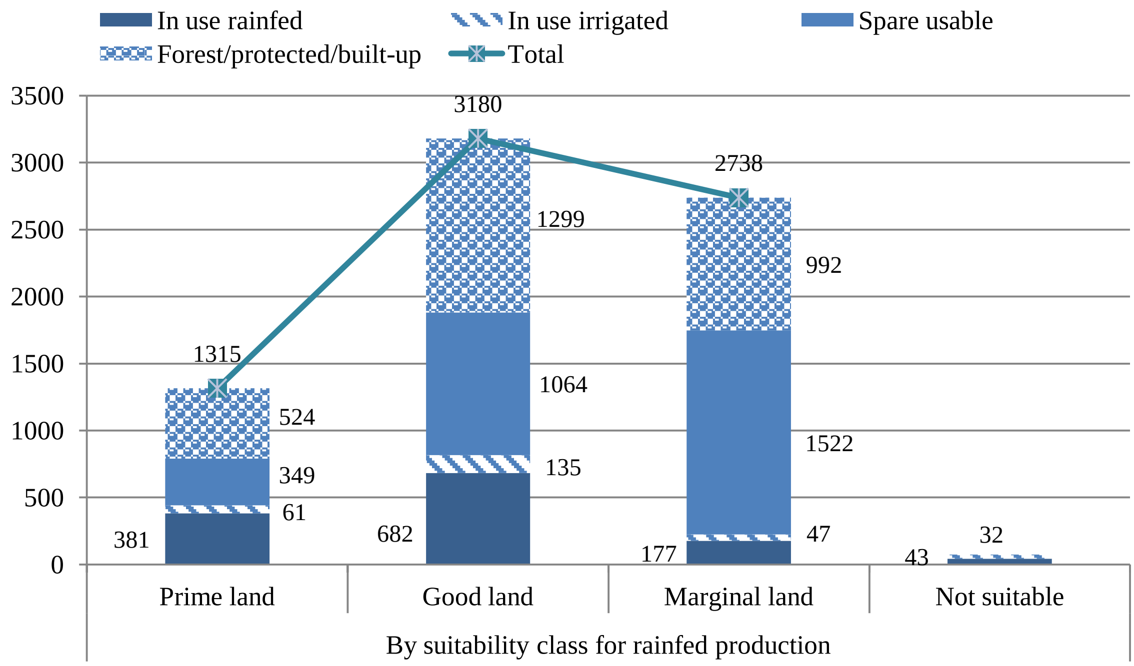
The proposition that ensuring food security for the growing population will become increasingly difficult because there are today fewer unused land and water resources and more limited yield growth potential compared to the past is not a good yardstick for judging future prospects. Rather, the issue is whether resources are sufficient for meeting future requirements that, as noted, will be growing at a much lower rate than in the past.

This paper analyzes prospects for the main agronomic parameters underlying projections of production.

Concerning **land**, information on the suitability for crop production – undertaken by IIASA and FAO in the Global Agro-ecological Zones study (GAEZ) which updated an earlier version (Fischer *et al.*, 2002, 2011) – indicates that at the global level there is a significant amount of land with rainfed production potential of various degrees of suitability: 7.2 billion hectares (ha), of which 1.6 billion is currently in use for crop production, including irrigated. Land-in-use includes some 75 million ha which in the GAEZ evaluation are classified as non-suitable. Part of such non-suitable land-in-use is made-up of irrigated desert. This leaves a balance of 5.7 billion ha. However not all of it should be considered as potentially usable for crop production, for two reasons. Firstly, 2.8 billion ha is under forest, in protected areas or is already occupied by non-agricultural uses which will be growing in the future, such as human settlements, infrastructure, etc; and, secondly, 1.5 billion ha of the remaining 2.9 billion is of poor quality for rainfed crops, classified as marginally suitable and very marginally suitable, no matter that the land presently in use includes some 220 million ha of such land of which 47 million ha is irrigated.

This leaves some 1.4 billion ha of *prime land* (class very suitable in the GAEZ classifications) and *good land* (classes suitable and moderately suitable) that could be brought into cultivation if needed, albeit often at the expense of pastures and requiring considerable development investments, e.g. infrastructures, fighting diseases, etc. (Figure 1.6).

Figure 1.6 World land availability with potential for rainfed crops (million ha)



Source: Chapter 4, Table 4.6 (from the GAEZ).

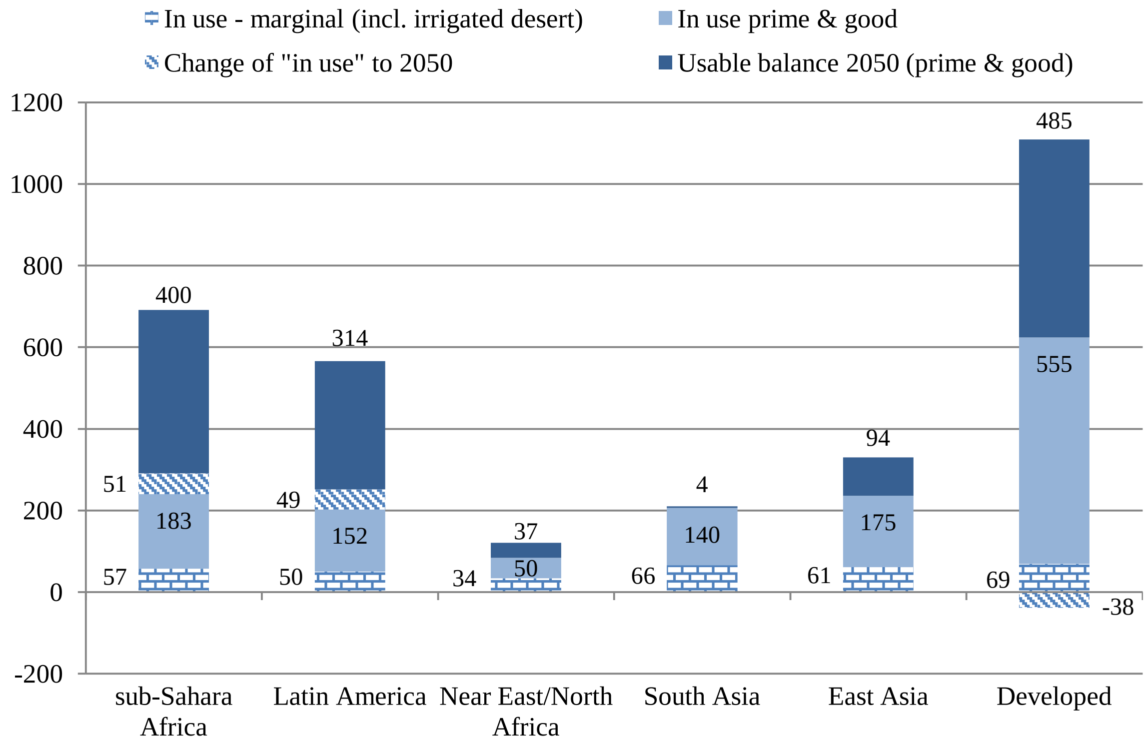
What part of this reserve may come under cultivation in the future? Not much, given the projected moderate growth in crop production and the potential to obtain the production increases by raising yields rather than area expansion. We project that for the world as a whole, net-land under crops may have to increase by some 70 million ha by 2050 (increase in the developing countries, decline in the developed). The area harvested may increase by almost twice that amount as a result of increased multiple cropping and reduced fallows.

The projected 70 million ha increase is the result of a 132 million ha expansion in the countries that are projected to increase land under crops (most of it in countries of sub-Saharan Africa and Latin America), and a 63 million ha decline in countries that are projected to reduce it (most of it in the developed countries but some also in developing ones). Assuming all the increase will take place in land classified as prime and good outside forest and protected areas presently, it will account for only a small part of the 1.4 billion ha of the global land reserve in these classes, and there may remain some 1.3 billion ha free but usable land in 2050 (Figure 1.7).

The above discussion may create the impression that there are no land constraints to increasing production. That would be wrong. Spare land is often not readily accessible due to, for instance, lack of infrastructure or because it is located in areas far away from markets or because it suffers from other constraints such as the incidence of disease. All these factors can make it very costly and uneconomical to exploit for agriculture. Secondly, and most important, much of the spare land is located in a small number of countries, therefore land constraints can be significant at the country or regional level. Thirteen countries account for 60 percent of the 1.4 million ha in the classes prime and good which is not yet in crop production and not in forest, protected areas or built-up[7], and the distribution of yet unexploited lands is very unequal even at the regional level (Figure 1.7).

[7] In ascending order: Madagascar, Mozambique, Canada, Angola, Kazakhstan, the Democratic Republic of the Congo, China, the Sudan, Australia, Argentina, Russian Federation, the United States of America, and Brazil.

Figure 1.7 Land in use at present, increase to 2050 and remaining balance in 2050



Source: Chapter 4, Tables 4.7-4.8.
Note: the data for land presently in use refer predominantly to 1999/2001 (from the GAEZ), but supplemented by data from FAOSTAT for 2005/2007.

Thus, it is not very relevant to speak of global numbers concerning abundance or scarcity of land resources. Countries that face land scarcities and would need to expand food supplies will not necessarily have access to the productive potential of these lands. This constraint can lead to increased trade or, as recent experience has shown, to investments in land where this is abundant or eventually to migration. These are not very promising avenues for poor and food-insecure countries with high demographic growth and scarcity of own land and water resources. Thus, local resource scarcities will likely continue to be a veritable constraint in the quest for achieving food security for all.

Water is another critical resource. Irrigation has been an important contributor to yield growth that underpinned much of the production increases over the past decades. Yields of irrigated crops are well above those of rainfed ones: even if they would remain unchanged in the future, a shift from rainfed to irrigated production systems would *per se* imply an increase in average yields.

World irrigated areas are estimated to be some 300 million ha, more than twice the level of the early 1960s. This refers to the area equipped for irrigation, 80-90 percent of which is thought to be in use. The potential for further expansion of irrigation, however, is limited. There are plenty of renewable water resources globally; but they are extremely scarce in regions such as the Near East/North Africa, or Northern China, where they are most needed.

It must also be noted that the very concept of irrigation potential for further expansion is not unambiguous: renewable water resources that are adequate for irrigating any given amount of land today may not be so in the future, as non-irrigation claims on water resources may reduce availability for irrigation. Moreover, potential impacts of climate change may alter precipitation and evapotranspiration patterns, hence affecting renewable water resources[8]. Likewise, irrigation based on non-renewable resources, e.g. using fossil water in desert irrigation schemes, is not counted in the irrigation potential.

Subject to these provisos, it is estimated that globally there remain some 180 million ha in developing countries (no estimates are available for the developed countries) that offer possibilities for irrigation expansion, beyond the 235 million ha presently equipped in these countries. We project that 20 million ha of this reserve may be used by 2050 for net expansion in developing countries, making for total projected area of 253 million ha in these countries and a world total of 322 million ha, given that irrigated area in the developed countries should remain at around the present 68 million ha.

This amount is in addition to whatever new irrigation is required to replace the part of existing irrigated areas that may be irremediably lost to degradation, water shortages, etc. By implication, in 2050 the remaining yet unexploited reserve in the developing countries will be less, probably much less, than 160 million ha if the global area equipped and usable for agriculture is to be 322 million ha in 2050. Gross investment in irrigation over the entire period to 2050 would need to be a multiple of that implied by the small net expansion, because existing irrigation schemes depreciate and need to be restored or replaced. Rough estimates of such investment requirements are given in Schmidhuber, Bruinsma and Bödeker (2011).

Most of the world irrigated agriculture is today in developing countries. It accounts for some 40 percent of their harvested area under cereals but for some 60 percent of their cereals production. Nearly one half of the irrigated area of the developing countries is in India and China. One third of the projected increase will likely be in these two countries (Figure 1.8).

The renewable water resources that would underpin the expansion of irrigation are extremely scarce in several countries. Irrigation water withdrawals from such resources are only 6.6 percent globally and even less in some regions. However, in the Near East/North Africa and in South Asia they already account for 52 percent and 40 percent respectively, in 2005/2007; For some countries these percentages are higher, even though they are part of regions with overall plentiful resources, e.g. some countries of Central America and the Caribbean.

Any country using more than 20 percent of its renewable resources for irrigation is considered as crossing the threshold of impending water scarcity. There are already 22 countries (developing but including some in the Central Asia region) that have crossed this threshold, 13 of them in the critical over 40 percent class. It is estimated that four countries (Libya, Saudi Arabia, Yemen and Egypt) use volumes of water for irrigation larger than their annual renewable resources. For these and many other countries the scope for maintaining irrigated production, let alone obtaining increases, depends crucially on exploiting whatever margins there exist for using irrigation water more efficiently[9]. This can provide some limited relief in the water scarce regions, particularly in the region that needs it most, the Near East/North Africa.

Finally, concerning **yields**, as noted, they have been the mainstay of production increases in the past. For cereals, the world average yield was 1.44 tonnes/ha in the first half of the 1960s (average 1961-65), 2.4 tonnes/ha in the first half of the 1980s and is now

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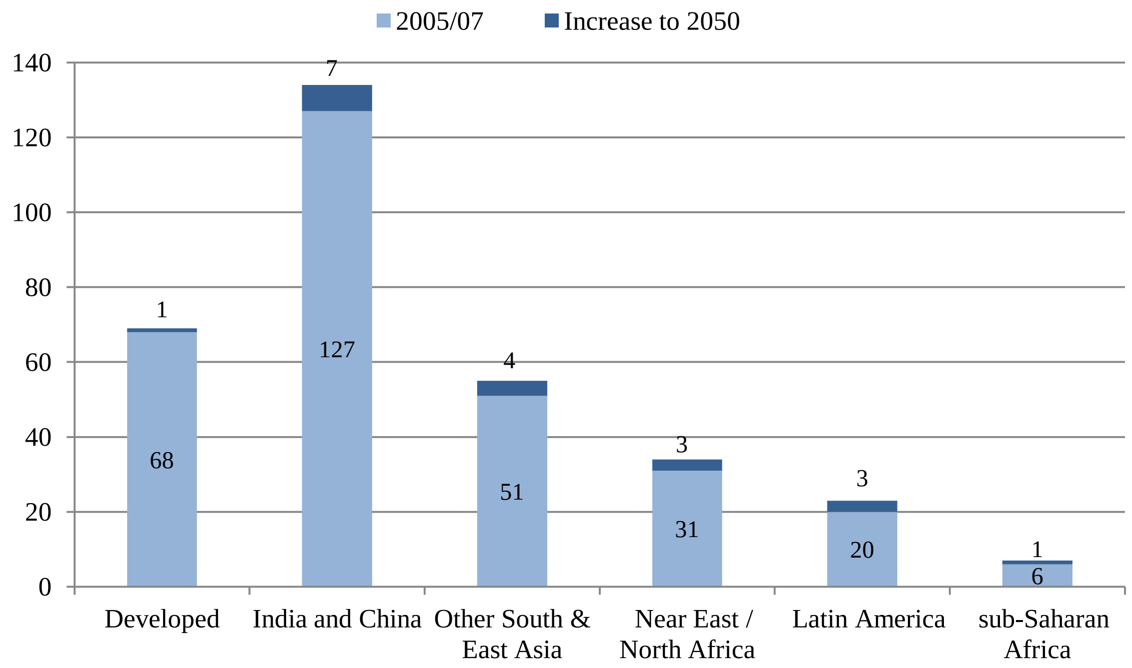
[8] Renewable water resources of a given area are defined as the sum of the annual precipitation and net incoming flows (transfers through rivers from one area to another) minus evapotranspiration, runoff and groundwater recharge.

[9] Water use efficiency in irrigation: the ratio between the crop water requirements and irrigation water withdrawals. Crop water requirements are estimated as consumptive water use in irrigation (deficit between potential crop evapotranspiration and precipitation minus runoff and groundwater recharge) plus water needed for land preparation (and weed control in the case of paddy rice).

3.4 tonnes/ha (average 2005/2007). On average it has been growing in a nearly perfect linear fashion with increments of 44 kg/year on average, as it can be seen in Figure 1.9. A linear growth pattern implies a falling growth rate: 44 kg was 3.1 percent of the 1.44 tonnes/ha of the early 1960s, but it was 1.8 percent of the 2.4 tonnes/ha of the early 1980s and only 1.3 percent of the current 3.4 tonnes/ha. Recently, this has become a source of concern about the capacity of world agriculture to produce enough food for the growing population. Is this concern justified?

Figure 1.8 Irrigated area, 2005/2007 and 2050 (million ha)



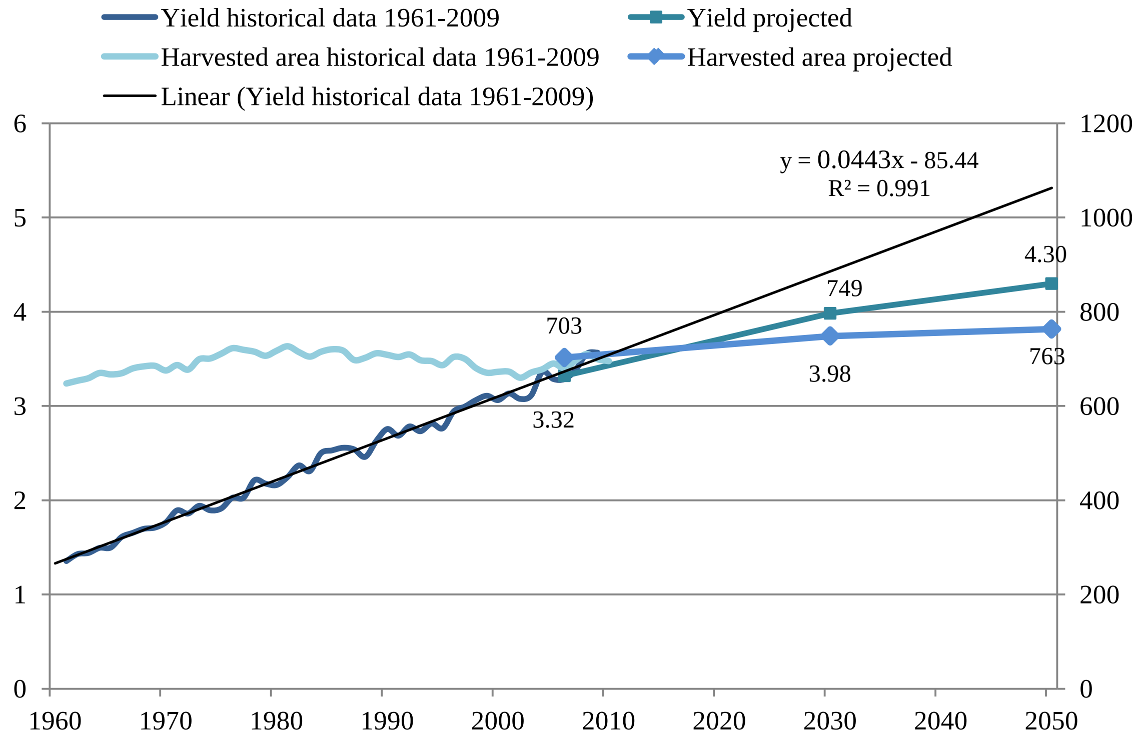
Source: Chapter 4, Table 4.10.

Up to about 2006 the world was abundantly supplied with cereals, while the growth rate of yields kept falling. This is evidenced by the trend towards decline of the real price of cereals, at least up to the mid-1980s, and its near constancy thereafter up to the major rise in the price index in the years 2007-08. While the price rise was the result of confluence of many factors, a major one has been the sudden spurt in demand caused by the diversion of significant quantities of cereals to the production of biofuels (Alexandratos, 2008; Mitchell, 2008). If such spurts in demand from the non-food sector were repeated in the future (something not foreseen in these projections), the falling growth rate of yields could prove to be significant constraint to meeting projected demand.

However, with the projected slowdown in the growth of demand a further decline in the growth rate of yields, unless it were nearly catastrophic, would be compatible with the need to produce the quantities required. If the linear growth of cereal yields continued at 44 kg/year, by 2050 the growth rate would have fallen further to 0.8 percent p.a. Yet the world would be producing more grain than required by the projected demand even if there were no increase in the area cultivated. This is because even with this falling growth rate of yield, in 2050 the average would have grown to 5.42 tonnes/ha by 2050, and world production would be 3.8 billion tonnes, hence more than our projected demand of 3.28 billion tonnes.[10]

While analysing the matter at hand in terms of global averages is fairly meaningless, it is nonetheless instructive for illuminating the debate on the significance of the decline of the global yield growth rate for food security in the long term future. What matters, however, is what individual countries can achieve in the light of their prospective needs for increasing production, their resource endowments and initial conditions. Several countries and regions have a long history of near stagnant yields and resource endowments and policy environments that are not very promising. Based on a country by country and crop by crop examination, and distinguishing between rainfed and irrigated production, we estimate that global cereals yields could grow from 3.3 tonnes/ha in the base year to 4.30 tonnes/ha in 2050 (Figure 1.9).

Figure 1.9 World cereals, average yield and harvested area



Much depends also on the type of cereals that would be needed to meet the future demand – wheat, rice or coarse grains. Roughly the same pattern applies: the world average wheat yield is projected to rise from 2.8 tonnes/ha in the base year to 3.8 in 2050; it would have reached 4.8 if the linear trend continued to 2050. Rice yield rises from 4.1 tonnes/ha to 5.3 tonnes/ha (vs. 6.5) and coarse grains, most of which is maize, from 3.2 tonnes/ha to 4.2 tonnes/ha (vs. 5.2 in the extrapolation). As noted, these global averages are a composite of a multitude of projections for the individual countries and cereal crops in a fair amount of detail[11], distinguishing between rainfed and irrigated yield gains and area expansion (in some

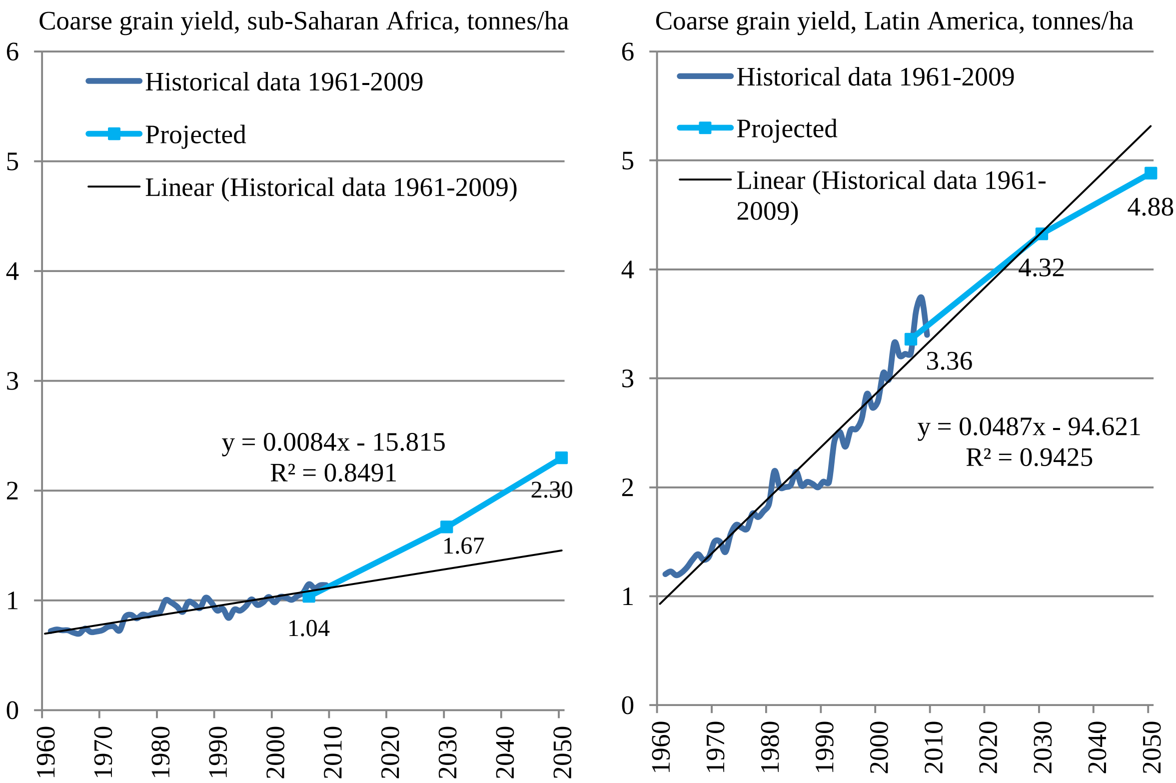
[10]These cereal quantities include rice in paddy – as is appropriate when we discuss yields –and the 3.28 billion tonnes is equivalent to the 3 billion tonnes for 2050 we presented earlier which includes rice in milled form as is appropriate when we discuss consumption.

[11] For example, areas and yields for coarse grains are projected separately for maize, barley, sorghum, millet and other coarse grains.

countries area contraction as prospective yield increases are more than sufficient to meet their projected demand – domestic and for net export as the case may be).

Not all projections follow the implicit global pattern of yields growing less fast than indicated by a continuation of the linear trends. This is true even for country group averages like regions and, *a fortiori*, for those of the individual countries. Figure 1.10 provides an illustration of average regional coarse grains yields showing contrasting outcomes for sub-Saharan Africa (projected yields well above those implied by a trend continuation) and Latin America (opposite) (Figure 1.10).

Figure 1.10 Coarse grain yield, sub-Saharan Africa and Latin America



The key question is not so much whether global average yields can continue growing at the rates experienced in the past, but rather whether some countries and regions can in the future deviate from the past path of nearly stagnant yields, as it is the case for coarse grains in sub-Saharan Africa. As indicated in a recent World Bank paper, technical and resource potential seems to be available in many countries of Sub-Saharan Africa, at least for maize (Smale *et al.*, 2011). And similar evidence seems to hold for other major food crops of the region, such as cassava, whose yield may grow much faster than indicated by past trends (Nweke *et al.*, 2002). However, much depends on assumptions of the policy environment, and on the possibility that it may become more supportive than in the past, as assumed in this paper.

World average yields for other major crops follow similar patterns to those of cereals.

To conclude, falling growth rates of global average yields are not necessarily a harbinger of impending catastrophe; rather, local constraints to increasing yields can be. These may limit the role that yield growth can play in improving local food supplies in countries which mostly need them. Such constraints can be agro-ecological, for instance in the case of dryland millets and sorghum in the Sudano-Sahelian zone; but they can be combined with inadequate investment in agricultural research and other policies, or with near exhaustion of the exploitable yield gap in countries that are already achieving fairly high yields (Bruinsma, 2011; Fischer, T. *et al.*, 2011).

Global resources are sufficient, but the devil is local

Based on our assessment of world agricultural resources, it seems that at the global level there should be no major constraints to increasing agricultural produce by the amounts required to satisfy the additional demand generated by population and income growth to 2050. Agricultural output as a whole would increase by about 60 percent over the levels of 2005/2007, for both food and non-food uses, but with the latter including only moderate increases in the use of crops as feedstocks for producing biofuels. This conclusion reflects mainly the prospect that global demand will grow at much lower rates than in the past, for the following reasons.

- First, population growth will be lower than in the past, and population will peak and decline in several major countries and regions such as Japan, Europe, China and Brazil.
- Second, more countries and population groups will be gradually attaining levels of per capita food consumption beyond which there is little scope for major further increases. Structural changes in diets, at the same time, will continue to determine shifts from staples to livestock products and fruit and vegetables.
- Third, while these factors will impact the bulk of world demand and make it grow at rates lower than in the past, there are several countries which will need to increase food consumption faster than in the past: they are those that start with low levels of food consumption per capita and many of them will continue to have high population growth rates. However, such potential may not be expressed fully as effective demand in all of them because they may still have low incomes and significant poverty for a long time to come. 45 of the 98 developing countries we project individually have presently incomes per capita of less than $1,000; 15 of them may still have incomes under $1,000 in 2050 according to the economic growth projections used here. There are 65 countries with food/capita under 2700 kcal/person/day and a population of 2.8 billion: 16 of them, with a population of 800 million, may still have less than 2700 kcal/person/day in 2050.

These developments imply that world production would need to increase at rates much lower than in the past, e.g. total agricultural output by 1.1 percent p.a. from 2005/2007 to 2050, down from 2.2 percent p.a. in the preceding equal period, and cereals by 0.9 percent p.a. vs. 1.9 percent. Notwithstanding lower growth rates, absolute quantities involved are substantial: cereals production must increase by 940 million tonnes to reach 3 billion tonnes projected for 2050; meat by 196 million tonnes to reach 455 million tonnes by 2050; and oilcrops by 133 million tonnes to reach 282 million tonnes (oil equivalent) by2050.

The fact that world's natural resources and the yield growth potential may be sufficient to attain these increases represents *per se* no guarantee that such increases will be forthcoming. Underlying our projections is the assumption that the necessary investments will be undertaken, and the right policies will be followed providing incentives to farmers, particularly in countries whose food demand must be primarily satisfied by domestic production.

These are global magnitudes, but they are built up from country by country and commodity by commodity projections. If we had analysed the issues by treating the world as one entity or a few major regions, we could stop here and conclude that all is well and there are no major constraints to producing all the food required for the growing population and the improvement of per capita consumption to levels that would eliminate hunger and some more. However, as often, the devil is in the details. It is recalled that thirteen countries account for

60 percent of the 1.4 billion ha of the global land classified as prime or good for rainfed crop production but not yet so used, and that are not in forest, protected areas or built-up. At the other extreme, many countries have no such land reserves left, and often cultivate land of marginal quality.

Addressing the issue how much and what food can be produced or imported in each country, forces us to tone down such optimism. This is because, as noted, several countries start with adverse initial conditions, of low national average food availability, high undernourishment, high population growth and also poor land and water resource endowments. Since they have to depend predominantly on own production for food supplies, it is difficult to visualize a situation whereby they raise national average per capita food consumption to levels that ensure that no segment of their population will have per capita food below minimum requirements for good nutrition.

As all statements about possible future states of the world, our projections are subject to many uncertainties. Some of them, specific to food security outcomes, all referring to downside risks, are worth listing here.

- Successive revisions of the population projections suggest that some negative aspects of population growth may be more serious than incorporated in this study. It is not so much that projected global population may turn out to be higher (9.3 billion in 2050 in the 2010 release of the UN projections) than the 9.15 billion assumed in the projections used here (from the 2008 release). The additional food required could be easily produced globally. The problem is that all of the increment and some more (206 million) originates in upward revisions in the projected population of sub-Saharan Africa. This does not augur well for the food security prospects of the region and the world. The improvements projected in this study may turn out to be too optimistic if the new population projections materialized.

- Climate change may also affect adversely the prospect of achieving the food security improvements projected in this study. Most climate models indicate that the agricultural potential of the developing countries may be more adversely affected than the world average. The high dependence of several of them on agriculture makes them particularly vulnerable in this respect. Studies that have looked into this matter provide very disparate answers ranging from catastrophic to mildly pessimistic (see Alexandratos, 2011b for a critical evaluation of such findings as of 2009).

- Finally, the increased integration between agriculture and the energy market fostered by the growing use of crops in biofuels production represents a potential disrupting element in the future. Much of the biofuels production in some of the major producing countries is currently driven by mandates and subsidies. However, should economic realities dictate and energy prices increase significantly, biofuels may become competitive without support policies. The option that biofuels could expand only into land not suitable for food crop production is not tenable in an environment of laissez-faire markets. Given the disproportionately large size of the energy markets relative to those for food and the stronger economic position of those demanding more energy vs. those needing more food, care must be taken to protect access to food by vulnerable population groups in the face of rising food prices. At the same time, it must be recognized that judiciously expanded biofuels sector has the potential of benefiting development in countries with abundant resources suitable for the production of biofuel feedstocks.

What's next? Beyond 2050

Imagine you are in 2050 and the projections we have presented have come true. How should we speculate about future developments, say to 2100? Can our conclusions for the projection period to 2050 provide some clues as to what may be in store beyond 2050?

Looking at global magnitudes first, the slowdown in world population growth was a major reason why we concluded that there will be lower growth in world agriculture in the period to 2050 compared with the past. The same demographic projections employed in this paper – 2008 release, Medium Variant – suggest that the slowdown is to accelerate beyond 2050, reaching a peak of 9.43 billion in 2075 and then decline to 9.2 billion in 2100. After 2050 many countries will enter a phase of population decline. Of the 110 countries/groups in our study, eight are projected to have in 2050 lower population than in the base year 2005/2007; this number will increase to 47 countries between 2050 and 2100, and will include giants like India and China, along with the Russian Federation, Japan, Brazil, and Indonesia. In the more recent demographic projections (UN, 2011) world population would reach 10.1 billion in 2100. There will still be 51 of our countries/groups with lower population in 2100 than in 2050, including the large ones mentioned above. However, many other countries are projected to have in 2050 and 2100 populations well above those of the earlier projections of 2008 used in this study (see below). In any case, the increments in world population between 2050 and 2100 would be immensely smaller than those of the preceding 50 years. By implication, the rate at which population pressures will be building on world agriculture would continue to diminish over time.

The other major factor contributing to the global slowdown of agriculture in our projections to 2050 is the gradual attainment by a growing share of world population of medium/high per capita food consumption levels beyond which the scope for further increases is small. We started with a global average of 2770 kcal/person/day in 2005/2007. Country by country and commodity by commodity projections indicated that this quantity could rise to 3070 kcal/person/day by 2050. We can safely assume that the slowdown effect will be stronger after 2050. Such effect on aggregate agriculture will be reinforced by the prospect that most countries experiencing population declines are those which in 2050 are projected to show high levels of per capita food consumption. For example, one person less in a country consuming 80 kg of meat per capita generates a deficit of 80 kg in global demand, which *ceteris paribus* is only partly compensated by 3 additional persons in countries with 20 kg per capita.

We may conclude that for the world as a whole the pressures on agriculture to produce more food for the growing population will increase beyond 2050 by much less than indicated in our projections for the period to 2050. In order to get an idea of the magnitudes involved we extended in a rough and ready manner and for selected variables the projections from 2050 to 2080, the year just past the peak of world population according to the 2008 UN population projections. It results that global agricultural production would need to grow at 0.4 percent per year from 2050 to 2080, i.e. less than half the growth rate projected for the period 2005/2007-2050 (Table 1.1).

Table 1.1 Key variables beyond 2050

	2005/2007	2050	2080	2100
Population (million)- UN 2008 Revision	6 592	9 150	9 414	9 202
Population (million)- UN 2010 Revision	*6 584*	*9 306*	*9 969*	*10 125*
kcal/person/day	2 772	3 070	3 200	
Cereals, food (kg/capita)	158	160	161	
Cereals, all uses (kg/capita)	314	330	339	
Meat, food (kg/capita)	38.7	49.4	55.4	
Oilcrops (oil. equiv.), Food (kg/cap)	12.1	16.2	16.9	
Oilcrops (oil. equiv.), all uses (kg/cap)	21.9	30.5	33.8	
Cereals, production (million tonnes)	2 068	3 009	3 182	
Meat, production (million tonnes)	258	455	524	
Cereal yields (tonnes/ha; rice paddy)	3.32	4.30	4.83	
Arable land area (million ha)	1 592	1 661	1 630	

Barring major upheavals coming from climate change and the energy sector or other events that are difficult to foresee – such as wars or major natural catastrophes leaving long-enduring impacts – world agriculture should face no major constraints to producing all the food needed for the population of the future, provided that the research/investment/policy requirements and the objective of sustainable intensification continue to be priorities. In principle, due to the reasons mentioned above, we may see further reductions in land used in crop production in several countries, particularly those that would face declining aggregate domestic demand. Even moderate yield growth, at much lower rates than projected to 2050, would be sufficient to meet the growth of global demand.

For example, the increase in world cereals production to 2080 could be achieved through a combination of yields growing further from the 4.3 tonnes/ha we projected for 2050 (Figure 1.9) to 4.8 tonnes/ha in 2080, while harvested area in cereals could be reduced by some 50 million ha from the 763 million we projected for 2050. As regards arable land use for all crops, which is projected to increase globally from 1.59 billion ha at present to 1.66 billion ha in 2050 (Figure 1.7), it may decline to 1.63 billion ha by 2080. Irrigation requirements may also be somewhat smaller in 2080 than projected for 2050. Such outcomes would, of course, be the net result of continuing increases in arable and harvested areas in some countries and declines in others. The important thing to note is that globally total arable land for crop production may peak before 2080. However, if the radical upward revisions of the population projections in sub-Saharan Africa (the region that has the potential of expanding agriculture by means of area increases) this conclusion must be interpreted with caution.

As for the 2050 scenario, the prospect that the world as a whole may not face major constraints to producing all the food required is not equivalent to saying that food insecurity will be eliminated. As noted several times in this paper, examining the issue of food insecurity by means of global variables (e.g. can the world produce all the food needed for everyone to be well-fed?) is largely devoid of meaning.

Several developing countries may still have in 2050 per capita incomes and food consumption that imply persistence of significant incidence of undernourishment. As shown in Figure 2.9, 27 developing countries with a population of 1.36 billion (18 percent of the total) may still have over 5% incidence of undernourishment, 11 of them with a population of 436 million in the over 10% category. Thus for a number of countries the “initial conditions in 2050” (as depicted in our projections) will continue to be such that imply persistence of food insecurity past 2050, though at gradually declining levels.

This is particularly so in the light of the new population projections which have sharp upward revisions in a number of countries among those facing such adverse projected conditions in 2050. Overall, the population of the group of the above-mentioned 27 countries with more than 5 percent undernourishment in 2050 was projected to rise from the 1.36 billion in 2050 to 1.77 billion in 2100 in the 2008 population projections. The new demographic projections of 2010 indicate that their population may rise from the (revised) 1.42 billion in 2050 to 2.22 billion in 2100, with some countries having much more pronounced upwards revisions.[12] This has the potential of changing radically the pace at which further progress towards elimination of undernourishment could evolve.

For example, Zambia was projected to have a population increase from 12 million in our base year (average 2005/2007) and the estimated 43% undernourishment (in FAO, 2010) to 29 million in 2050 (with undernourishment falling to under 10% in our projections) and on to 39 million in 2100. It would be reasonable to expect that the country could look forward to the near complete elimination of undernourishment in the decades immediately following 2050, and certainly by 2100. However, the new demographic outlook can change completely the prospects: the country's population is now projected to be 45 (not 29) million in 2050 and a very high 140 (not 39) million in 2100. Any confidence we may have had for the solution of the problem shortly after 2050 is certainly shaken. There are several other countries in analogous situations though none with such stark upward revision of the demographic outlook.

In conclusion, the issue whether food insecurity will be eliminated by the end of the century is clouded in uncertainty, no matter that from the standpoint of global production potential there should be no insurmountable constraints. Even at the regional level constraints may not prove binding. Africa, where most of the countries with still significant food insecurity in 2050 will be (according to our projections), has significant food production resources to support the needed agricultural development. As shown in a recent World Bank study, Africa's agricultural "sleeping giant", the region's Guinea Savannah zone, offers good prospects for the development of commercial agriculture (World Bank, 2009); and recent studies on water resources hold that the region has significant underground water stocks which exceed those of the traditional renewable resources (MacDonald *et al.*, 2012). In parallel, the region's energy resources hold promise for the overall economic development of many countries in the region[13], provided that the notorious "resource curse" can be avoided (Sachs and Warner, 2001).

In all this discussion, talking about food security prospects over the very long term induced us to give more prominence to demographic factors than would normally be the case when discussing medium term (10-20 years) prospects. This is because in a number of countries populations are projected to be sizeable multiples of current ones: in the above mentioned case of Zambia, population in 2100 is projected to be nearly 11-fold that of 2010. Other countries with high multiples include the Niger, Malawi, Somalia, the United Republic

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[12]This group includes also countries with downward revisions in their projected population, Bangladesh being the most prominent one. The 2008 projections had a population of 222 million in 2050 (used in our projections) and 210 million in 2100. These numbers have been revised in the 2010 issue of the population projections to 194 million and 157 million, respectively. This revision largely reflects new historical data, e.g. the country's 2005/2007 (our base year) population was revised from 155 million to 142 million. We have already referred to the uncertainties associated with exercises like the present one arising out of the demographic variables used. Not only are the projections uncertain but in some cases so are the estimates of the country's present and past population.

[13] "African energy: Eastern El Dorado? At long last East Africa is beginning to realise its energy potential", *Economist*, 07 April 2012.

of Tanzania, Burkina Faso and others. Such demographic futures can set the stage for persistence of food insecurity for a long time, particularly when they concern low-income countries with poor agricultural resources and high dependence on the sector for employment and income.

Very high population increases are not the only aspect of demographic futures that may affect food security outcomes. The evolving demographic picture may also impact the development prospects, and perhaps also those of food security, in countries at the other end of the spectrum: those that experience drastic population declines. The accompanying changes in demographic structures in favour of aging populations can represent real brakes on the economies, mainly, but not only, via the increasing dependency rates, reduced dynamism and the growing stress on public finances.

PROSPECTS FOR FOOD AND NUTRITION

2.1 The broad picture: historical developments and present situation

2.1.1 Progress made in raising food consumption per person

Food consumption, in terms of kcal/person/day, is the key variable used for measuring and evaluating the evolution of the world food situation[14]. The world has made significant progress in raising food consumption per person. In the last three and a half decades it increased from an average of 2370 kcal/person/day to 2770 kcal/person/day (Table 2.1). This growth was accompanied by significant structural change. Diets shifted towards more livestock products, vegetable oils, etc. and away from staples such as roots and tubers (Tables 2.5 and 2.6).

Table 2.1 Per capita food consumption (kcal/person/day)

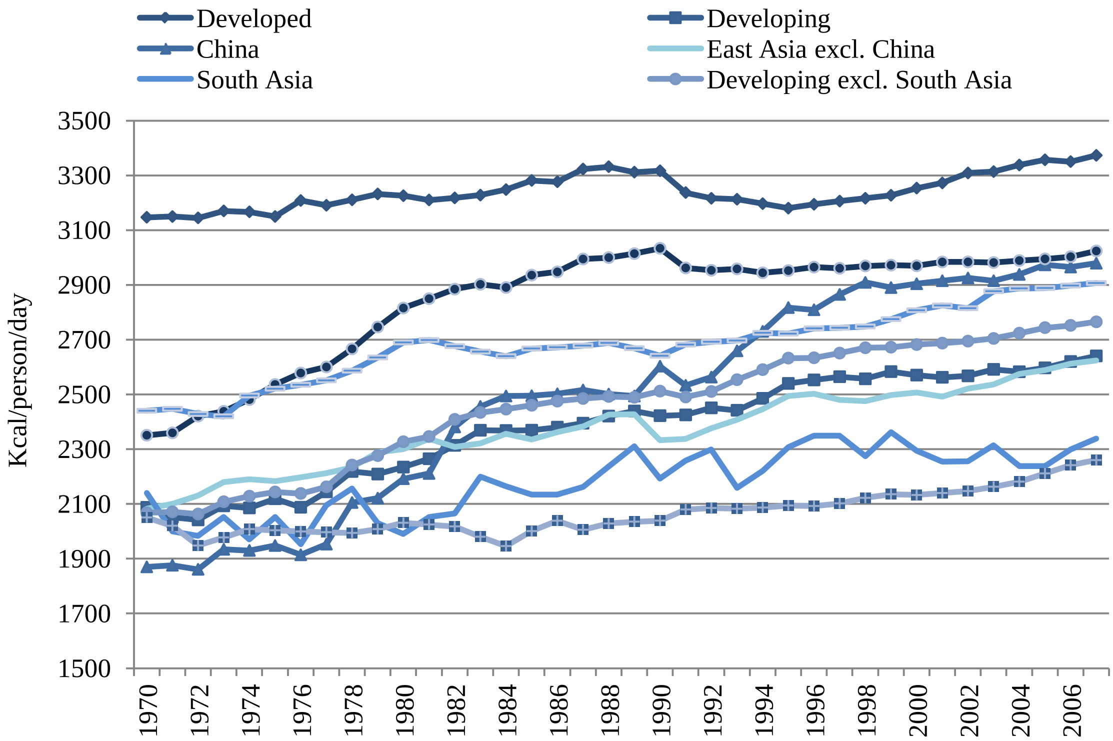
	New historical data					Projections			Comparison 1999/2001	
	1969/ 1971	1979/ 1981	1989/ 1991	1990/ 1992	2005/ 2007	2015	2030	2050	New	Old
World	**2 373**	**2 497**	**2 634**	**2 627**	**2 772**	**2 860**	**2 960**	**3 070**	**2 719**	**2 789**
Developing countries	2 055	2 236	2 429	2 433	2 619	2 740	2 860	3 000	2 572	2 654
-excluding South Asia	2 049	2 316	2 497	2 504	2 754	2 870	2 970	3 070	2 680	2 758
Sub-Saharan Africa	2 031	2 021	2 051	2 068	2 238	2 360	2 530	2 740	2 136	2 194
Near East / North Africa	2 355	2 804	3 003	2 983	3 007	3 070	3 130	3 200	2 975	2 974
Latin America and the Caribbean	2 442	2 674	2 664	2 672	2 898	2 990	3 090	3 200	2 802	2 836
South Asia	2 072	2 024	2 254	2 250	2 293	2 420	2 590	2 820	2 303	2 392
East Asia	1 907	2 216	2 487	2 497	2 850	3 000	3 130	3 220	2 770	2 872
Developed countries	3 138	3 223	3 288	3 257	3 360	3 390	3 430	3 490	3 251	3 257

The gains in the world average reflected predominantly those of the developing countries, given that the developed ones had fairly high levels of per capita food consumption already in the past. In the latter, there was a decline in the 1990s, and subsequent recovery (Figure 2.1), which reflected the transformations in the former centrally planned economies of Europe. For the developing countries, the overall progress has been decisively influenced by the significant gains made by some of the most populous among them This can be appreciated

[14]The more correct term for this variable would be "national average apparent food consumption or availability", since the data come from the national Food Balance Sheets rather than from consumption surveys. The term "food consumption" is used in this sense here and in other chapters.

by noting how much larger is the increase of the population-weighted average (from 2055 to 2620) compared with that of the simple average of the 98 developing countries analysed individually in this study (from 2170 to 2500). There are currently 8 developing countries with a population of 100 million or more. Four of them (Mexico, Brazil, Nigeria and China) account for one third of the population of the developing countries and have per capita food consumption in the range 2700-3240 kcal/person/day, up from 1920-2580 in 1970, and incidence of undernourishment in the range of 4-10 percent.

Figure 2.1 kcal/person/day, by region and country groups, 1990-2007



Countries with over 100 million inhabitants that failed to make comparable progress include those in South Asia (kcal/person/day in the range 2250-2300, up from 2030-2250 in 1970). The region's food per capita has been virtually flat at low levels over the last ten years. Countries in this region still have undernourishment in the range 21-27 percent. This has dragged down the indicators for all developing countries. If we exclude South Asia, the rest of the developing countries grew from 2050 to 2750 (Table 2.1 and Figure 2.1). The failure of India's high economic growth to translate into significantly increased food consumption is a major factor why more progress was not made in the developing countries as a whole[15]. The FBS data indicate that the country has currently the same low kcal/person/day (2300) as it had 25 years ago. It accounts for 238 million of the 827 million undernourished of the developing countries. If it had made even modest progress, say to 2500 kcal/person/day, the total for the developing countries would have declined to 740 million and some progress would have been made towards the target of halving the numbers by 2015. We shall have occasion to revisit the issue of India's sluggish response of food consumption per capita to the high growth of per capita incomes (Annex 2.1). Whether this pattern of response continues or not, India's food

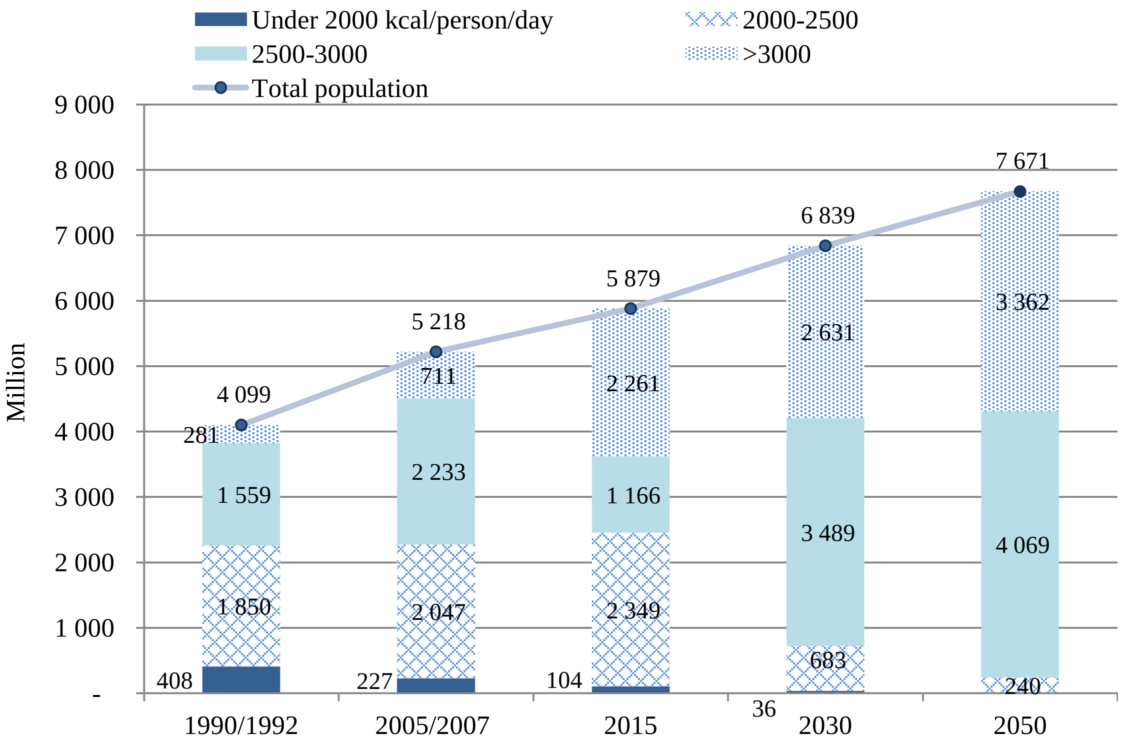
[15] India's household final consumption expenditure per capita (at constant 2005$ at Purchasing Power Parities-PPP) increased from $PPP 538 in 1980 to $PPP 1457 in 2007, i.e. by 170 percent (World Bank, World Development Indicators, accessed Jan. 2011).

demand outcomes will have a profound impact on the assessment of long-term prospects of world agriculture and nutrition.

While developments in South Asia, with 30 percent of the total population of the developing countries, explain a large part of the failure to make more progress, there are also numerous other less populous countries that failed to make much progress. There are still 20 countries with over 30 percent of their population classified as undernourished (see below). Their average food/capita was 1910 kcal/person/day in 1990/1992 (the base year of the halving target): it is about the same (1940 kcal) 15 years later (Figure 2.7). Sixteen of them are in sub-Saharan Africa, no matter that the region as a whole has shown some timid signs of accelerated rate of improvement of per capita food in the current decade, following some acceleration in economic growth and declines in poverty rates (Figure 2.8).

In 1990/1992, 2.3 billion or 55 percent of the population of the developing countries were living in countries with food/capita under 2500 kcal; the percentage has fallen to 45 percent but, with the growth in population, there are still 2.3 billion in 2005/2007 (Figure 2.2).

Figure 2.2 Developing countries: population living in countries with given kcal/person/day



2.1.2 The incidence of undernourishment[16] – past and present

The latest FAO assessment (FAO, 2010), estimates the total incidence of undernourishment in the developing countries at 827 million persons in 2005/2007[17] (16 percent of their population

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[16]The term "undernourishment" is used to refer to the status of persons whose food intake does not provide enough calories to meet their basic energy requirements. The term "undernutrition" denotes the status of persons whose anthropometric measurements indicate the outcome not only, or not necessarily, of inadequate food intake but also of poor health and sanitation – conditions that may prevent them from deriving full nutritional benefit from what they eat (FAO, 1999: 6).

[17] SOFI 2010 shows 835 million, because it includes in the developing countries the Central and Western Asian ones of the former USSR.

– Table 2.2), when average food consumption reached 2620 kcal/person/day. This estimate is not significantly different from that of fifteen years earlier, the 3-year average 1990/1992 was 810 million, but then it represented a higher proportion of their total population (20 percent). The 3-year average 1990/1992 was the base used by the 1996 WFS in setting the target of halving the numbers undernourished in the developing countries by 2015 at the latest.

Thus, there has been no progress at all towards the halving target in the first fifteen years of the period to 2015. The significant declines achieved in East Asia (mainly China) were compensated by increases in the other two regions with the highest concentrations – sub-Saharan Africa and, particularly, South Asia. If these trends continued, the halving target will certainly not be achieved by 2015 and whatever further reductions take place will further accentuate the differences among regions and countries.

Table 2.2 Incidence of undernourishment, developing countries

	Percent of population					Million						
	1990/ 1992	2005/ 2007	2015	2030	2050	1990/ 1992	2005/ 2007	2015	2030	2050	Comparison 1999/2001	
	SOFI 2010					SOFI 2010					New*	Old
Developing countries	19.7	15.9	11.7	7.9	4.1	810	827	687	543	318	794	811
Excluding South Asia	*19.1*	*13.5*	*9.8*	*6.9*	*4.1*	*555*	*496*	*408*	*333*	*225*	*515*	*511*
Sub-Saharan Africa	33.6	27.6	21.4	14.5	7.1	165	201	195	180	119	198	201
Near East / North Africa	6.0	7.4	6.0	4.7	3.4	15	32	30	29	25	31	39
Latin America and the Caribbean	12.2	8.5	6.3	4.1	2.5	54	47	38	28	18	51	55
South Asia	21.5	21.8	16.1	10.5	4.2	255	331	216	211	93	279	299
East Asia	19.2	11.0	6.8	4.2	2.8	321	279	143	94	62	232	216

* The estimates for the 1999/01 should have been higher than the ones of the Interim Report of 2006 because of the lower kcal/person/day (Table 2.1). They are lower because the MDER for that year has been revised downwards (developing country simple average from 1842 to 1781), more than compensating for the effect of the lower kcal/person/day.

The FAO estimates of undernourishment measure the extent of deficiencies in dietary energy intakes. Malnourishment due to other causes, such as deficiencies in micronutrients or inadequate absorption of the energy embodied in the food actually ingested is not accounted for in these estimates. Changes in the incidence of undernourishment[18] in each country are close correlates of changes in (a) the food consumption level (kcal/person/day), (b) the difference between it and the Minimum Dietary Energy Requirements (MDER) and (c) an index of inequality (Box 2.1). The MDER varies with changes in population structure (age and sex distribution)[19]. Such structure has changed over the period in question (between 1990/1992 and 2005/2007) with the result that the average MDER of the developing countries increased by some 40 kcal/person/day. If it were not for this change, the undernourished in 2005/2007 would have been 80 million fewer that the 827 million shown in Table 2.2.

[18] The methodology of estimation is described in FAO (2008).

[19] In a specified sex and age group, the MDER is the amount of dietary energy per person that is considered adequate to meet the energy needs for minimum acceptable weight for attained-height, maintaining a healthy life and carrying out a sedentary physical activity level. In the entire population, the MDER is the weighted average of the MDERs of the different sex and age groups in the population.

Box 2.1 Measuring the incidence of undernourishment: the key role of the estimates of food available for direct human consumption[1]

The key data used for estimating the incidence of undernourishment are those of food available for direct human consumption. These data are derived in the framework of the national Food Balance Sheets (FBS). The latter are constructed on the basis of countries' reports on their production and trade of food commodities, after estimates and/or allowances are made for non-food uses and for losses. Population data are used to express these food availabilities in per capita terms. The resulting numbers are taken as proxies for actual national average food consumption. For many countries the thus estimated per capita food consumption of the different commodities (expressed in kcal/person/day) are totally inadequate for good nutrition, hence the relatively high estimates of the incidence of undernourishment reported for them, most recently in FAO (2010). This conclusion is inferred from a comparison of the estimated kcal/person/day shown in the FBS data with what would be required for good nutrition. The parameters for the latter are well known, though not devoid of controversy. In the first place, there is the amount of dietary energy that is needed for the human body to function even without allowing for movement or activity. This is the Basal Metabolic Rate (BMR). It is in the general range 1300-1700 kcal/day for adults in different conditions (age, sex, height, bodyweight). Taking the age/sex structure and body-weights of the adult populations of the different developing countries, their national average BMRs for adults are defined. These refer to the amount of energy as a national average per adult person that must be actually absorbed if all were in a state of rest. For children, in addition to the BMR, an allowance is made for the growth requirements.

When an allowance for light activity (the Physical Activity Level – PAL, about 55 percent of the BMR, see FAO, 2008) is added, there result MDER values for the different developing countries that range between 1690 kcal and 1930 kcal/person/day (simple average: 1796), given their population structures in 2005/2007. As noted, the average was lower by 40 kcal/person/day in 1990/1992. Its increase explains in part why the numbers undernourished did not decline from the Base year of the WFS target. The average will rise further to 1840 kcal in 2030 and to 1860 in 2050 as the demographic structure changes with a rising proportion of adults: the Median age of the different developing countries rises from a range 15-37 years at present to 20-54 in 2050 – (UN, 2009). The rise in MDER means that ceteris paribus more food will be needed per person just to meet the population’s minimum requirements.

The basic principle followed in measuring undernourishment is that population groups in which an average individual has an intake below the national MDER are undernourished because they do not eat enough to maintain health, body weight and to engage in light activity. The result is physical and mental impairment, characteristics that are evidenced in the anthropometric surveys. Estimating the incidence of undernourishment means estimating the proportion of population with food intakes below these thresholds. It is noted that the notion, measurement and definition of thresholds of requirements are not devoid of controversy. For example, Svedberg (2001:12) considers that the thresholds used in the FAO measurement of undernourishment for the tropical countries are too high leading to overestimates of the incidence of undernourishment.

In principle, a country having national average kcal/person/day equal to the threshold would have no undernourishment problem provided all persons engage in only light activity and each person had access to food exactly according to his/her respective requirements. However, this is never the case; some people consume (or have access to) more food than their respective “light activity” requirements (e.g. because they engage in more energy-demanding work or have high household waste or simply overeat) and other people less than their requirement (usually because they cannot afford more). Thus, an allowance must be made for such unequal access. The inequality measure used in these estimates – the coefficient of variation (CV) – ranges from 0.21 to 0.36 in the different countries in 2005/2007 (a CV of 0.2 means, roughly, that the average difference of the food intake of individuals from the national average – the standard deviation – is 20 percent of the national average). Even at the lowest level of inequality generally found in the empirical data (CV=0.2), the national average kcal/person/day must be well above the MDER if the proportion of population undernourished is to be very low. For example, a country with MDER 1800 kcal and CV=0.20, must have a national average of 2700 kcal/person/day if the proportion undernourished is to be only 2.5 percent, or 2900 if it is to be 1 percent. If inequality were more pronounced, these requirements would be higher.

These numbers, or norms, are, therefore, a first guide to assessing the adequacy or otherwise of the national average food consumption levels in the FBS data and expressed in kcal/person/day. This latter number is the principal variable used to generate estimates of the incidence of undernourishment as explained elsewhere[2]. Numerous countries fall below the national average energy level (kcal/person/day) required for undernourishment to be very low, in many cases they fall below by considerable margins. Therefore, even if one knew nothing more about the incidence of undernourishment, the inevitable conclusion for these countries is that the incidence must be significant, ranging from moderate to high or very high, even when inequality of access to food is moderate. It follows that progress towards reducing or eliminating undernourishment must manifest itself, in the first place, in the form of increased per capita food consumption. This is not equivalent to saying that the food consumption shown in the FBS data is itself a variable which can be operated upon directly by policy. For it to rise, somebody must consume more food, and the food must come from somewhere – production or imports. Policies to raise national average consumption are those which enhance the purchasing power and more general access to food of those who would consume more if they had the means, for example, access to resources and technologies to improve their own food production capacities, access to non-farm employment, social policies, etc. The point made here is that changes in the national average kcal/person/day recorded in the FBS data do signal the direction and magnitude of movement towards improved or worsened food security status.

How reliable are the FBS data, since in many cases they show very low or very high levels of national average food consumption or sudden spurts or collapses? The answer is: they are as reliable as, mainly, the primary data on production and trade supplied by the countries, as well as the estimates made for the allocation of total supplies among the food and non-food uses and losses of food commodities, as well as the population data used to express them in per capita terms. It is these data and estimates that are processed, in the form of the FBS, to derive the indicators of per capita food consumption as national averages used here. Uncertainties about reliability and completeness make them less of an ideal metric for measuring food actually eaten by people. In particular, the estimates of food losses or waste in the FBS are very uncertain. They are conceptually meant to account for post-harvest to retail losses. Pre-harvest losses (e.g. those of crops in the field due to frost, drought, pests, etc, even crops not harvested because of economic or unsettled political conditions) are not accounted for since they are not included in production. Likewise they do not include post-retail waste, which can be considerable, particularly in the developed countries (Gustavsson *et al.*, 2011) leading to divergences between the estimates of the FBS and the actual food intake. For example, USDA estimates indicate that the calorie availability of 3900 kcal/day/person in the United States of America is reduced to about 2700 kcal when adjusted for "spoilage and other waste" (http://www.ers.usda.gov/Data/FoodConsumption/NutrientAvailIndex.htm)

It must also be noted that revisions of FBS data, including of the population data, are often radical (see revisions of the 1999/01 average in Table 2.1) and result in significant changes in the estimates of undernourishment (for discussion see Alexandratos, 2011a).

These shortcomings notwithstanding, the FBS are the only source of food data available for nearly all countries and through time. The need to continue improving them using all sources of related information like surveys of household budgets and food consumption is obvious.

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[1] Reproduced with amendments from FAO (1996).

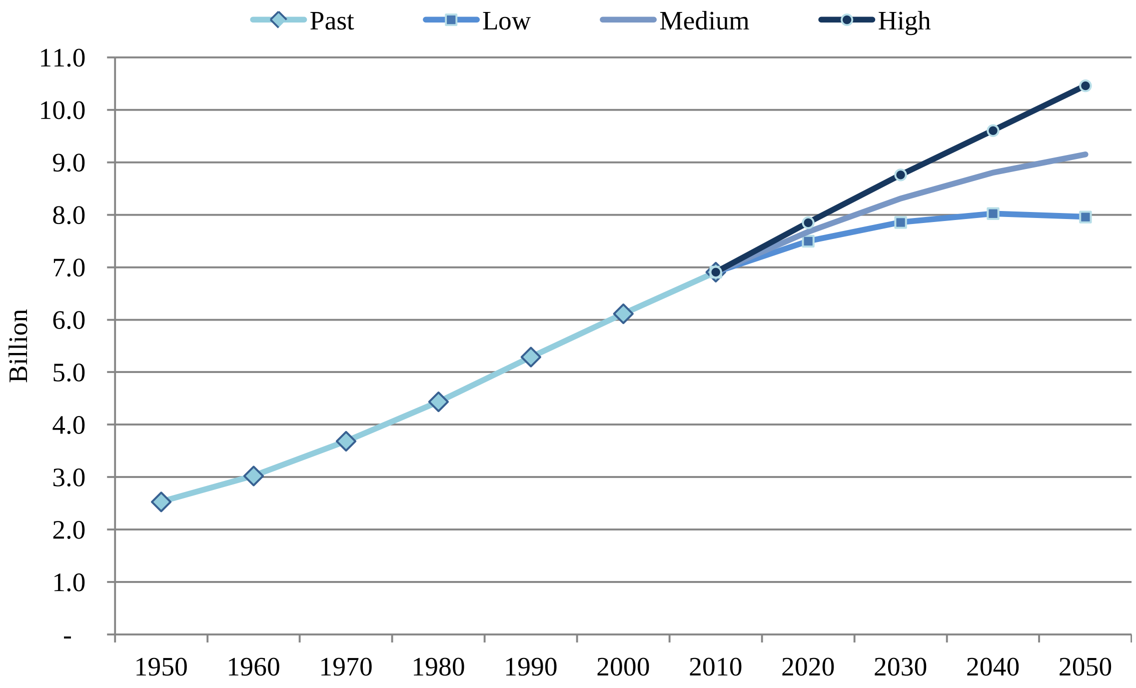
[2] These key variables (kcal/person/day, the MDER and the CV) are used as parameters of the lognormal statistical distribution (with kcal/person/day as the mean) to estimate the percentage of population undernourished, as explained in FAO (2008). The relevant data are available in http://www.fao.org/economic/ess/food-security-statistics/en/.

2.2 The outlook for food and nutrition in the projections

2.2.1 Demographics

The population data and projections used here are those of the United Nations *World Population Prospects-the 2008 Revision* (UN, 2009). There are three alternative projections: World population is projected to grow from the 6.6 billion of our base year to 8.0 billion, 9.15 billion and 10.5 billion in 2050 under the Low, Medium and High projections, respectively (Figure 2.3). We use here the Medium projection (Table 2.3). It indicates that a rather drastic slowdown in world demographic growth is in prospect. The growth rate of world population peaked in the 1960s at 2.0 percent p.a. and had fallen to 1.2 percent p.a. in the decade ending in 2010. Further deceleration will bring it down to 0.4 percent p.a. by the final decade of our projections, 2040-50. According to the Medium Variant projection world population is expected to peak around the year 2075 at 9.4 billion and then start declining slowly to 9.2 billion by 2100[20].

Figure 2.3 World population: 1950-2010 and projections (three variants)



Source: UN (2009).

Despite the drastic fall in the growth rate, the absolute annual increments continue to be large. Seventy nine million persons are being added to world population every year in the decade ending in 2010 and the number will remain at over 50 million p.a. until the mid-2030s. More rapid declines after 2035 should bring the annual increment down to 27 million by 2050[21] (Figure 2.4). Virtually all these increases will take place in the developing countries. The population of the developed countries will start declining in the late 2040s. Within the developing countries there will be increasing differentiation. East Asia will have shifted to negative demographic growth in the early 2040s. Past 2050, Latin America will be shifting to

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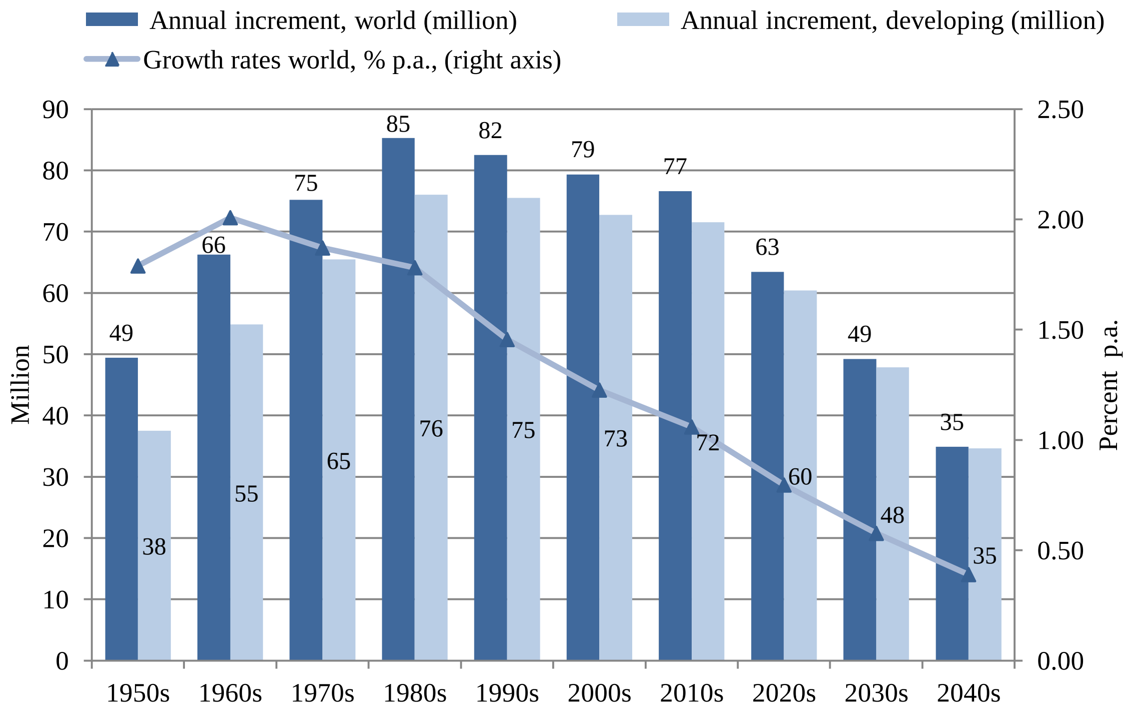
[20] In the latest 2010 revision of the of the UN population projections, world population continues to grow past 2075 to reach 10.12 billion by 2100 (Medium Variant - UN, 2011).
[21] 37 million in the 2010 revision of the UN population projections.

negative growth in the early 2060s and South Asia in the mid-2060s, while the Near East/North Africa region will be shifting in the mid-2080s. Practically, by 2080 the only region with still growing population will be sub-Saharan Africa: it will have reached 2.2 billion and will still be adding some 11 million per year[22].

Figure 2.4 Annual population increments and growth rates (medium variant)



Source: UN (2009).

Table 2.3 Population data and projections

	Population (million)						Growth rates, percent per annum			
	1970	2000	2006	2015	2030	2050	1970-2000	2006-2030	2030-2050	2006-2050
World (UN)	3688	6115	6592	7302	8309	9150	1.70	0.97	0.48	0.75
World (countries with FBS)	3676	6095	6569	7275	8276	9111	1.70	0.97	0.48	0.75
Developing countries	2597	4778	5218	5879	6839	7671	2.05	1.13	0.58	0.88
Sub-Saharan Africa	270	625	730	912	1245	1686	2.84	2.25	1.53	1.92
Near East/North Africa	181	387	432	504	615	726	2.57	1.48	0.83	1.19
Latin America and the Caribbean	282	515	556	611	682	721	2.03	0.85	0.28	0.59
South Asia	708	1375	1520	1729	2016	2242	2.24	1.18	0.53	0.89
East Asia	1147	1857	1957	2096	2247	2255	1.62	0.58	0.02	0.32
Developed countries	1079	1318	1351	1396	1437	1439	0.67	0.26	0.01	0.14

Source: World Population Prospects: The 2008 Revision (UN, 2009).

[22] Drastic upward revisions in the 2010 UN population projections have brought these numbers to 2.9 billion and 27 million, respectively.

Some countries, mostly in Africa, have demographic projections suggesting that their populations in 2050 would be rather sizeable multiples of their current ones. This prospect raises the serious issue whether significant improvements in food consumption per capita and nutrition could be achieved in the foreseeable future, particularly in the countries with heavy dependence on their agriculture for employment, income and food supplies and scarce agricultural resources (see discussion in Box 2.2). It is in such cases that one can speak of persistence of food insecurity because of constraints to increasing food production. Such constraints operate at the local level and can have a role in the persistence of food insecurity in the countries concerned, no matter that the world as a whole may have surplus food production potential. This suggests that it is often meaningless to ask the question whether the earth can produce enough food for the growing population. The answer is probably positive (see Chapters 1 and 4), without this meaning that constraints at the local level will not continue to limit the potential for eliminating hunger.

Box 2.2 **Countries with high population growth to 2050 and limited agricultural resources: an untenable combination?**

A characteristic of the demographic outlook, which is not so evident in medium term projections but leaps to the eye in longer term ones, is the prospect that a number of countries could have in 2050 populations which are large multiples of present ones. As shown in Table 2.4 world population is projected to be in 2050 39 percent above that of 2006 (our base year) and that of the developing countries 47 percent. However, several of the most food-insecure countries are projected to have much larger increases. As noted, the population of Niger, the country with the highest total fertility rate in the world, is projected to grow from 14 million in 2006 to 58 million in 2050, a 4.3-fold increase. In like manner, Yemen's population would grow from 22 million to 54 million by 2050 (revised to 62 million in the 2010 revision of the UN Population Projections – see below), Uganda's from 30 to 91 million, and so on for a number of other countries. Almost all of these countries have been in nearly perennial food insecurity for several decades. The issue is therefore raised if and to what extent significant progress in development and food security can be achieved under the rapidly mounting population pressure implied by the demographic projections. The issue is of paramount importance for those countries with large and growing rural populations and heavy dependence of their economies on their own agriculture for income, employment, food supplies and for providing the basis for their overall development. Countries falling in this category which also have agricultural resources that are limited in quantity and/or quality (e.g. predominantly semi-arid, little irrigation potential) and are not endowed with other resources (e.g. oil, mining) will find it much more difficult than other low-income countries to reduce poverty and make adequate progress in food security. The food and agriculture projections cannot avoid recognizing this prospect and highlight the possibility that food insecurity could continue to be a dominant characteristic in a number of countries for several decades to come. More generally, the demographic projections themselves (e.g. the underlying assumptions about fertility, mortality and migration) may have to be revisited and re-assessed in the light of findings demonstrating prima facie incompatibilities between population growth and agricultural potentials in countries where the latter are of crucial importance for development (a more complete discussion of the issues in this Box can be found in Alexandratos, 2005).

Before ending the presentation of the demographic projections, a digression is in order: speaking of population projections, it is important to realize that they can vary significantly from one revision to the next. This bears witness to the uncertainties surrounding this variable, and hence the associated food projections. Differences are particularly large for countries of sub-Saharan Africa and the region as a whole. For example, in the previous exercise (FAO, 2006) we used the population data and projections of the 2002 round of the UN population revisions: sub-Saharan Africa (regional country coverage as in the UN population projections, i.e. including South Africa which in our definition is in the developed countries) had a projected population for 2050 of 1557 million. In the version we use now (the 2008 revision) the region has a 2050 projected population of 1753 million, 200 million more (Figure 2.5). The present food projections take into account the consequences of such population revisions. However, the 2010 Revision of the UN population projections (published after our food projections had been completed) has even higher population projections for sub-Saharan Africa: 1960 million in 2050, i.e. 200 million more than we used in the present exercise (of which 100 million comes from the drastic upward revision of Nigeria's projected population) and 400 million more than in our earlier projections in FAO (2006).

Projected world population is now 9.3 billion in 2050 vs. the 9.15 billion we have used in the present food projections. The difference in the global number is small and in principle it should not have a significant impact on the global projected food and agriculture variables. However, almost all the differences come from the higher projected population of sub-Saharan Africa, a region starting with high prevalence of undernourishment. It follows that even a small global difference can generate a significant impact on the projected per capita food consumption levels and the associated projections of undernourishment for the reasons explained in Box 2.3. It is likely that with the new population projections the attainment of the WFS target of halving the numbers undernourished would shift further into the future than shown in our current projections (Table 2.2).

Box 2. 3 Population growth and global food demand

The effects of global population growth on that of the demand for food are influenced by inter-country differences in population growth rates and in the levels of food consumption per capita. In the present projections, many countries with high food per capita (hence limited scope for further increases) also have low (eventually negative) population growth rates. In extreme cases of significant differences in per capita levels and in population growth rates, the effect could be that global demand could grow less fast than global population and the world average consumption may decline, even though it may increase in all countries. These characteristics will dampen the growth of global demand. The following example illustrates (calculations shown in table below) meat consumption per capita is 80 kg in the developed countries and 27.9 in the developing countries, for a world average of 38.7 kg, as shown in Table 2.5. For the sake of illustration, assume that both groups increase per capita consumption by 1 kg, between 2005/2007 and 2050. The net result is that global demand grows at a lower rate than population - 0.66 percent p.a. vs. 0.75 percent - and the world average falls to 37.2 kg, even though both country groups are better off[1]. It is just that the share of those with low food per capita in global population increases.

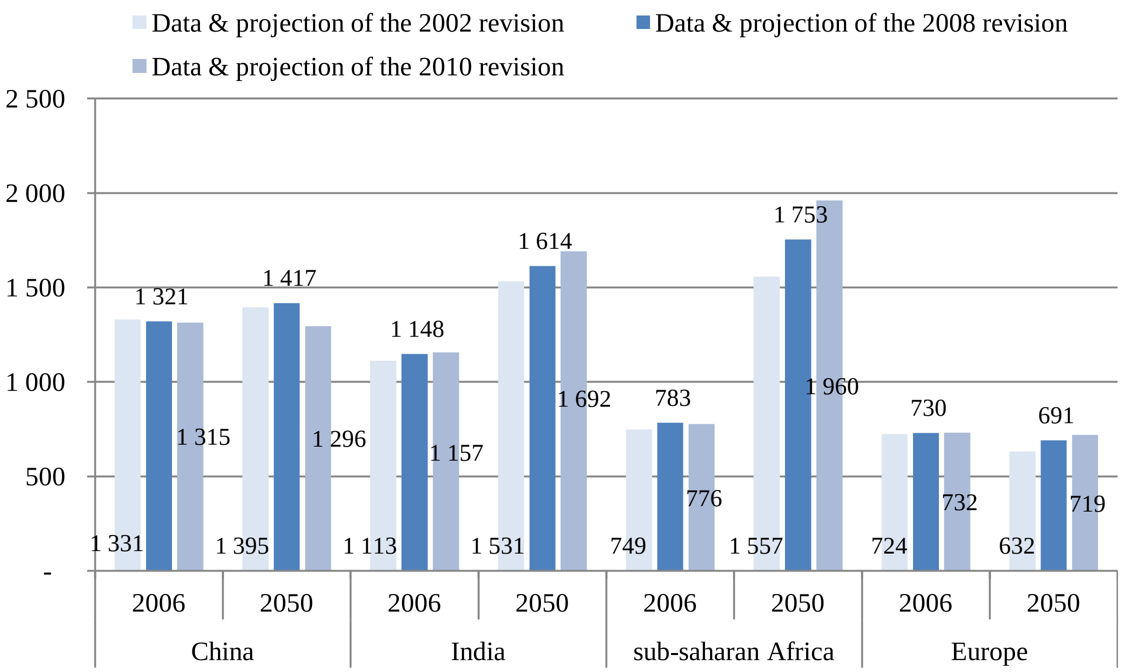
The fall in global per capita consumption does not happen in our projections of Table 2.5 because per capita consumption is projected to increase by more than required to keep the global average from falling. But the example illustrates that (a) the fact that countries with high food consumption per capita have lower or negative demographic growth than others, contributes to dampen the growth of global demand as discussed in Chapter 3; (b) carrying out the projections for individual countries, rather than large groups, can help form more reasoned views about where the world may be going concerning food futures; and (c) the notion that "global food production must grow as fast as global population just to keep the food security situation from becoming worse" can lead to fallacious reasoning. To take an extreme example, at current consumption of meat per capita, a reduction of the population by one person in the developed countries causes global meat demand to decline by 80 kg of meat, which offsets the impact caused by an increase of 18 persons in South Asia.

Table: Growth in Population vs. Growth in Meat Consumption (hypothetical projection of per capita and total demand)

	2005/2007	2050	2005/2007-2050
	Population (million)		% p.a.
Developed countries	1351	1439	0.14
Developing countries	5218	7671	0.88
World	6569	9111	0.75
	Meat (kg/capita)		
		+1 kg for each group	
Developed countries	80.0	81.0	
Developing countries	27.9	28.9	
World (derived)	38.7	37.2	
	Meat total demand (thousand tonnes)		% p.a.
Developed countries	108145	116598	0.17
Developing countries	145824	222076	0.96
World	253969	338674	0.66

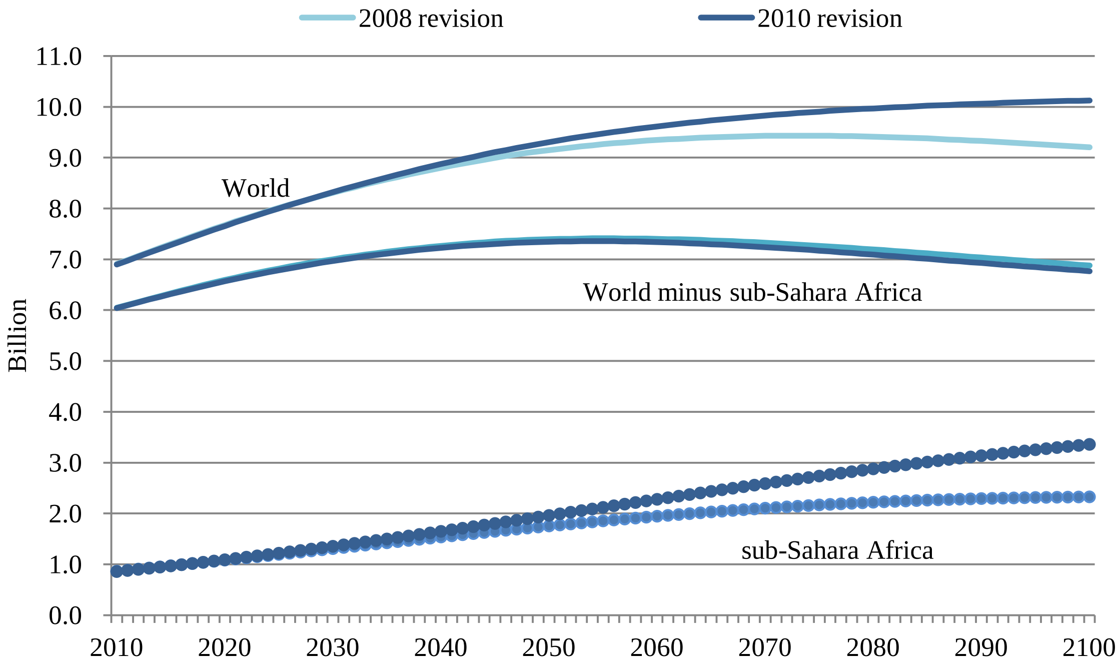
[1] Simpson paradox in statistics – see Alexandratos, 1997, 1999.

Figure 2.5 Comparison of population data and 2050 projections of three UN assessments



In the new projections, world population that was projected to peak at 9.4 billion in the second half of the 2070s, is now projected to keep growing and will reach 10.1 billion in 2100. Without sub-Saharan Africa, population in the rest of the world would peak in 2055 (Figure2.6), at 7.4 billion in both projections. In conclusion, world population growth will be increasingly dominated by that of sub-Saharan Africa. This will tend to make the goal of ending hunger more difficult to achieve.

Figure 2.6 Medium population projection to 2100: world total, sub-Saharan Africa and Rest-of-World



2.2.2 Overall economy

The long time horizon of the study means that the agricultural futures we shall be developing must be visualized in a world that would be significantly different from the present one and, according to some income projections to 2050, perhaps immensely richer and with less pronounced relative gaps between the per capita incomes of the developed and (the present day) developing countries. Here are some examples:

- van der Mensbrugghe *et al.*, (2011) show a GDP growth baseline implying a 3.6-fold increase in world economic activity from 2005 to 2050. The GDP of the developing countries would grow 9.8 times, corresponding to a 6.6-fold increase in average per capita income.
- Projections to 2050 for a large number of countries (including 73 of our 98 developing countries) have been published recently by the French Research Institute CEPII (Foure *et al.*, 2010). The global growth rates projected from 2005-50 are near those of the World Bank paper: a 3.3-fold increase for world GDP. For per capita GDPs, they have high multiples for some major developing countries, e.g. 16-fold for China and 11-fold for India and some extraordinarily high multiples for several countries, e.g. Mozambique's per capita GDP increases 47-fold or 22-fold for Mali and Nepal. In contrast, per capita incomes in the OECD area are projected to grow only 1.75-fold. They give projected per capita GDPs in Purchasing Power Parity (PPP) $ of 2005, but the projected absolute numbers are not very useful, since the PPP rates will change. For example, a dollar in China has 2.3 times the purchasing power of a dollar in the United States of America, but this relationship is bound to be much smaller in the future: the ratio between the incomes measured in PPP rates and those in market exchange rates

tends to converge towards unity as incomes of the low-income countries rise faster than those of the high-income countries and the distance between the two narrows[23].

- A set of projections by the Goldman Sachs Global Economics Group (Goldman Sachs, 2007) covering the G-7, the BRICS and 11 other major countries, imply a 6.5-fold increase in their aggregate GDP from 2006-50.
- A paper by Price-Waterhouse-Coopers (Hacksworth, 2006) explores several carbon emissions scenarios to 2050 of global GDP growth rates in the range 2.6 percent to 3.2 percent p.a., implying global GDP increases 3.3 to 4.1-fold from 2004-50.
- There are more scenarios in the literature. For example, a wide range of world GDP growth scenarios are explored for analyzing climate change issues in the IPCC 4th Assessment Report. From 2000-2050 the increases in world GDP range from 2.2-fold to 7.1-fold; for 2000-2100 the range is from 7.4-fold to 20.8-fold (IPCC, 2007a: Table 1).

Considering the projections that imply more than 3-fold increase in world economic activity in just 45 years, one cannot but pose the issue of limits imposed by natural resource constraints and the environment. The fact that those that make these projections consider them as possible outcomes, even in a scenario sense, suggests either of two things: (a) that such constraints will not prove binding in the 45-year projection period, or (b) more likely, they make the implicit assumption that, in time-honoured fashion, a more prosperous world will be finding ways around such constraints, as and when they arise – a Julian Simon concept of economic progress (Simon, 1996).

We cannot possibly examine these aspects here, but certainly we shall have to address the issue whether agricultural resources, together with prospective developments in technology and investments in the sector, are sufficient to meet the demands placed upon them by a growing population and the growth of incomes and changes in diets towards more livestock products. The saving grace in the case of food is that consumption per capita is a largely bounded variable: incomes may continue growing but, beyond certain levels (when per capita food consumption approaches saturation) such income growth becomes largely irrelevant as it will not be generating additional pressures, at least not significant ones, on agricultural resources for increasing food production. Considering also that population growth will be slowing down, we can be more sanguine about absence of constraints to development arising from global agricultural resource scarcities for producing food than from other resources, e.g. energy and the environment. However, growth of total GDP becomes very relevant for pressures exerted on agricultural resources if, as is likely, it increases competition among agriculture and alternative (non-food production) uses of land and water, e.g. diversion to biofuels production, or to urban, industrial and infrastructure development.

GDP projections used in this study

Our projections of food demand are derived, as a first step, as functions of projected per capita GDPs, using different Engel functions for the different commodities and countries. The projected per capita GDPs are exogenous variables to our agricultural projections exercise and come from other sources that specialize in economy-wide analyses and modelling. The demand projections are subsequently modified, sometimes substantially, in the context of

[23] As shown in Table 2.4, currently the average GDP per capita of the developing countries valued at PPP rates is twice as high as that valued in market exchange rates. For the developed countries the two measures are nearly equal.

successive rounds of revisions for nutritional consistency and compatibility with "feasible" projected levels of production and trade for each commodity.

We have traditionally depended on external sources for the GDP projections, usually from the World Bank. For the present study, the staff of the Development Prospects Group of the World Bank kindly made available one set of GDP projections related to their above mentioned work, though much more conservative than the one used in their paper for the 2009 Expert Group (van der Mensbrugghe *et al.*, 2011). They are shown in Table 2.4: world GDP grows at 2.1 percent p.a., from 2005/2007-2050; that of the developing countries (our definition used in this study) at 3.6 percent p.a. The differential growth rates will contribute towards convergence between per capita incomes in the developed and the developing countries. At present the average of the developed countries is nearly 12 times as high as that of the developing countries when GDP is measured in dollars at market exchange rates of 2005/2007. The ratio may be nearly halved by 2050, i.e. decline to 6.3. The initial gap between developed and developing countries is much smaller if GDP is measured in dollars at PPP exchange rates. This we can measure for the historical data: the ratio of incomes in 2005/2007 is 5.9 rather than 11.9 (Table 2.4). However, as noted PPPs change as incomes of the low income countries grow faster than those of the high income countries and the distance between the two narrows: it follows that the ratio of incomes may be less than halved by 2050 if incomes are measured at the PPPs that would prevail in 2050.

Table 2.4 GDP assumptions and implied convergence indicators

	Growth rates (percent p.a.)				GDP per capita $ at prices of 2005/2007			Developed countries Multiples of the other groups		
	Total GDP		Per capita GDP		at intern PPP$	at 2005/2007 exchange rates		Intern PPP$	at 2005/2007 exchange rates	
	2005/ 2007-2030	2005/ 2007-2050	2005/ 2007-2030	2005/ 2007-2050	2005/ 2007	2005/ 2007	2050	2005/ 2007	2005/ 2007	2050
World	2.47	**2.11**	1.49	**1.36**	**9 510**	**7 603**	**13 758**			
Developing countries	4.47	3.58	3.30	2.67	4 704	2 350	7 499	6.0	11.9	6.3
Sub-Saharan Africa	4.64	4.17	2.34	2.20	1 363	666	1 736	20.6	41.9	27.1
Near East/North Africa	3.54	2.92	2.03	1.72	7 696	3 858	8 160	3.6	7.2	5.8
Latin America and the Caribbean	2.45	2.09	1.58	1.49	9 539	5 726	10 966	2.9	4.9	4.3
South Asia	4.90	4.05	3.67	3.14	2 316	814	3 169	12.1	34.3	14.9
East Asia	5.51	4.18	4.90	3.85	5 406	2 738	14 428	5.2	10.2	3.3
Developed countries	1.56	1.34	1.30	1.20	28 056	27 880	47 121			
memo item										
45 Developing with GDP/cap under $1000 in 2005/2007	4.73	*4.02*	3.15	*2.73*		*721*	*2 361*		*38.7*	*20.0*
Other Developing	4.43	*3.49*	3.65	*2.98*		*3 763*	*13 698*		*7.4*	*3.4*

Sources: Data for 2005/2007: World Bank, WDI, Accessed June 2011; Projections: World Bank, personal communication with staff from Development Prospects Group.

What matters for food and nutrition is the extent to which the incomes of the low-income countries attain levels that generate food consumption compatible with absence or significant reduction of undernourishment, as the latter is measured by the FAO method used here (see Box 2.1). On this aspect we cannot be very optimistic. As shown in Table 2.4, 45 of the 98 developing countries have presently incomes per capita of less than $1,000, an average of $721. This average may grow to $2,361 by 2050 but 15 of them may still have incomes under $1,000 in 2050 (dollars at prices and market exch. rates of 2005/2007). This is a rough indication that significant poverty will continue to prevail in 2050 in a world that, according to these GDP projections, will be over 80 percent richer in terms of average per capita incomes. This does not augur well for the elimination of hunger, as is shown in the following sections of this Chapter.

2.2.3 Food security outcomes

Higher per capita food consumption in the future, but with significant exceptions

As noted earlier, the key variable we use to track and project developments in food security is the per capita food consumption as defined above. For the developing countries the base year 2005/2007 stands at 2620 kcal/person/day (Table 2.1). By itself this level is not too low, as it is well above the weighted average MDER of 1820. Should all countries have reached it, undernourishment would be much lower than it is, even after accounting for inequalities in distribution. However, there are wide differences among countries and several of them have very low kcal/person/day and a high incidence of undernourishment: as noted, 2.3 billion or 44 percent of their population live in countries with less than 2500 kcal/person/day, of which 227 million in countries with under 2000 kcal/person/day. Hence the average of the developing countries must rise significantly if undernourishment is to be reduced. Our projections suggest that the average of the developing countries could rise from the 2620 at present to 2740 kcal by 2015. This will certainly not be sufficient to achieve the halving target by that year, not even to make significant progress towards it.

In the earlier report (FAO, 2006) we projected a rise from 2654 in 1999/01 to 2860 kcal by 2015 which, although far from sufficient to achieve the halving target, would represent significant progress. So why are we more pessimistic this time? The answer is that the 1999/01 data that formed the basis of the earlier study (including those of the base-year 1999/01) were drastically revised downwards. The average developing countries' consumption is now estimated to have been in 1999/01 2572 kcal while it was estimated at 2654 at the time of the earlier study (Table 2.1). Even the new base year (2005/2007) at 2620 kcal is still lower than the old base year 1999/01.

The new revised FBS data indicate that the average did rise from 2572 to 2620 kcal during the period 99/01-2005/2007. The numbers undernourished should have fallen as a consequence on the path from 1999/01-2015, as projected in the earlier report; yet they are estimated to have increased (Table 2.2). This anomaly is due to (a) the revisions in the other parameters used to estimate undernourishment, in particular the MDER (Box 2.1) which increased from 1781 to 1796 kcal from 2000 to 2006[24], and (b) to the fact that the population of the developing countries is now estimated to be 85 million higher in 2005/2007 than embodied in the population projections used in the earlier study (FAO, 2006). These differences in the historical data and initial conditions and population make a lot of difference on how one views the future. Preliminary revised projections (Alexandratos, 2011a) anticipated that the outlook of the earlier report needed to be revised towards a more pessimistic outcome.

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[24] The projections of undernourishment in the earlier report had factored in a much slower increase in the MDER (from 1842 to 1864 kcal from 2000-2015 – simple average of the developing countries) than the new revised estimates (used in the new projections from 1781 to 1814 kcal).

Notwithstanding the revisions, the message of the earlier report stands. The average kcal/person/day of the world and the regions will likely continue to rise (Table 2.1). Expected changes in world averages reflect above all the rising consumption in developing countries. More and more people will live in countries with medium to high levels of per capita food consumption. For example, in 1990/1992 (the base year for the WFS target) 55 percent of developing countries' population of lived in countries with less than 2500 kcal/person/year. As noted, the proportion had fallen to 44 percent in 2005/2007. It is projected to continue to fall to 42 percent by 2015 and to only 3 percent by 2050, with 44 percent of their population living in countries with over 3000 kcal, up from 14 percent at present (Figure 2.2).

These rises are not always an unmixed blessing, as shown by transitions experienced by many countries towards energy-dense diets, high in saturated fat, sugar and salt and low in unrefined carbohydrates. In combination with lifestyle changes associated with rapid urbanization, such transitions, while beneficent in many countries with still inadequate diets, are often accompanied by a corresponding increase in diet-related chronic Non-Communicable Diseases (NCDs –WHO, 2003; Schmidhuber and Shetty, 2005; Alexandratos, 2006). In many countries undergoing this transition, obesity-related NCDs appear when health problems related to undernutrition of significant parts of their populations are still widely prevalent. The two problems co-exist and present these countries with novel challenges and strains in their health systems.

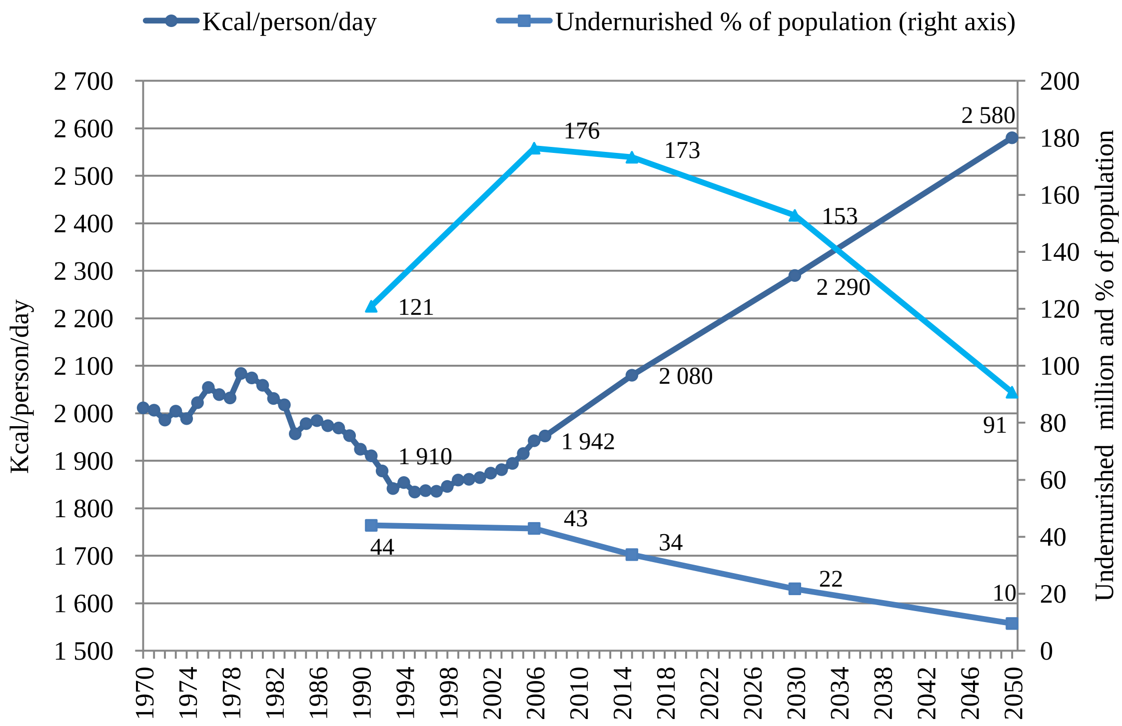
Modest reductions in the numbers undernourished

The relatively high average consumption levels that the developing countries may attain in the future (Table 2.1) could lead one to expect that numbers undernourished should show significant declines. However, due to adverse initial conditions and large population growth in several countries, their per capita consumption will not increase to levels allowing significant reductions in the numbers undernourished: their reduction will be a very slow process (Table 2.2 and Figure 1.4). Developing countries may have to wait until after 2040 before the numbers of undernourished are reduced to the target set for 2015 by the WFS, i.e. one half of the 810 million estimated for the base period of 1990/1992.

There are two main reasons why several countries will likely fail to reduce significantly the numbers undernourished in the medium term. The first reason is the very adverse initial conditions, i.e. the very low levels of food consumption several countries start with. Secondly, high population growth keeps the numbers undernourished high even though they decline as a share of population. For these countries to attain the medium-high per capita food consumption levels that would be required for them to halve undernourishment in the next 10-15 years, their aggregate food consumption would need to grow at rates that would exceed even optimistic assumptions about growth in domestic production and food imports.

The following example illustrates: as noted, 20 developing countries start with estimated base year (2005/2007) undernourishment of over 30 percent. The group's average per capita food consumption is 1940 kcal in 2005/2007 and the undernourished are 176 million (or 43 percent) out of a total population of 411 million. The food consumption projections (2075 kcal for 2015) imply (according to the method used here) that the proportion of the population affected will fall to 34 percent by 2015. This is a significant decline. However, the absolute numbers affected will be in 2015 virtually the same, because of the relatively high growth rate of the group's population (2.5 percent p.a. in 2006-2015) which will have increased to 513 million by 2015. The undernourished may still be some 150 million by 2030 (22 percent) of the population which is projected to grow to 700 million (2.1 percent p.a. from 2015-30), no matter that their food per capita may have grown to 2290 kcal. In short, it is a slow process in the presence of adverse initial conditions and rapid demographic growth.

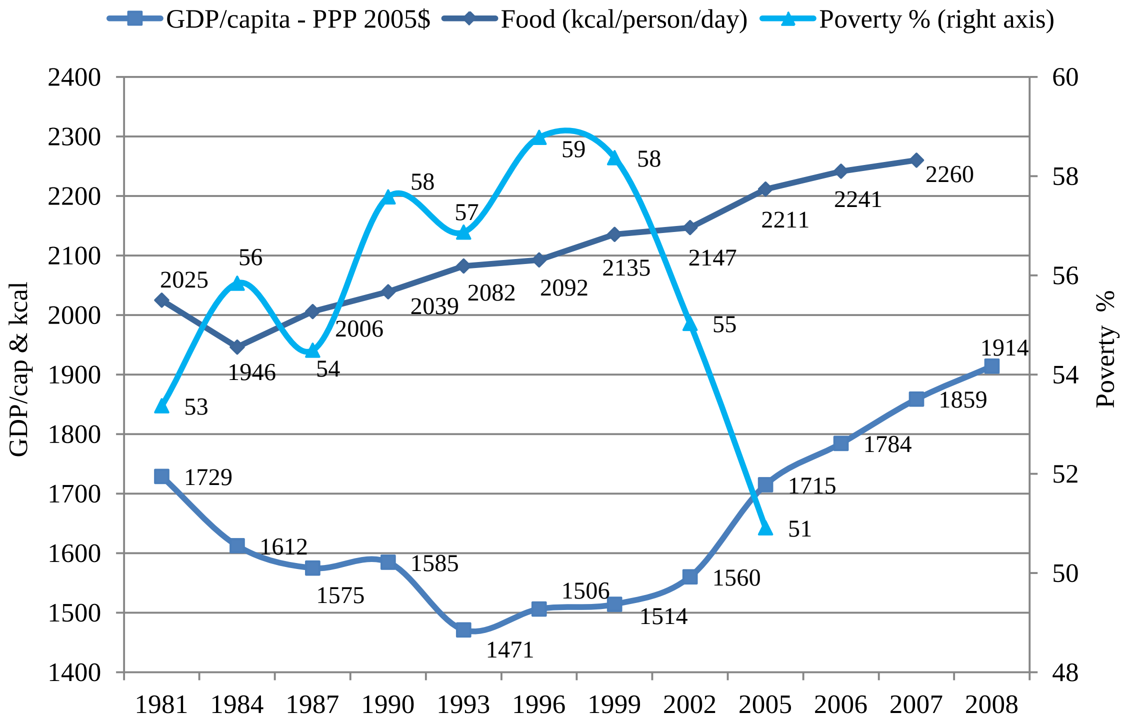
Figure 2.7 **20 countries with undernourishment over 30% in 2005/2007, data and projections**



Based on these projections, the numbers undernourished in this group of countries will not change much by 2015; they may fall significantly after 2030, when the population growth rate will have fallen to 1.5 percent p.a. There may still be some 10 percent of the population undernourished in 2050 (Figure 2.7). While this will still be a significant problem, it would represent a real break from the past history of stagnant food/capita and rising numbers undernourished. Overall, therefore, the projections of food consumption and those of the underlying production and trade, far from being pessimistic, embody a degree of optimism. There are three main reasons why this may be so: the trend of declining per capita food consumption seems to have reversed after the mid 1990s (Figure 2.7); eventually, population growth in this group of countries will decelerate from the high 2.5 percent p.a. in 2006-2015 to 1.5 percent in 2030-50; finally, sub-Saharan Africa (where most countries in this category are) has been experiencing accelerated economic growth and poverty reductions in recent years: the prospects are that such improvements will continue. A recent paper from the World Bank projects drastic falls in poverty in the region, from 51.7 percent of the population in 2005 to 2.8 percent in 2050 (van der Mensbrugghe *et al.*, 2011: Table 5.8)[25]. Figure 2.8 graphs the region's recent upturn in per capita GDP and declines in the poverty rates.

[25] A recent article in the *Economist* highlights sub-Saharan Africa's good economic growth record of the current decade and future prospects. See: "A more hopeful continent: The lion kings? Africa is now one of the world's fastest-growing regions", *Economist*, 08 January 2011.

Figure 2.8 Sub-Saharan Africa: GDP per capita (PPP 2005$), food per capita and poverty



Source: GDP and Poverty: WB, WDI Accessed Oct. 2010; kcal: FAOSTAT, accessed Dec. 2010.

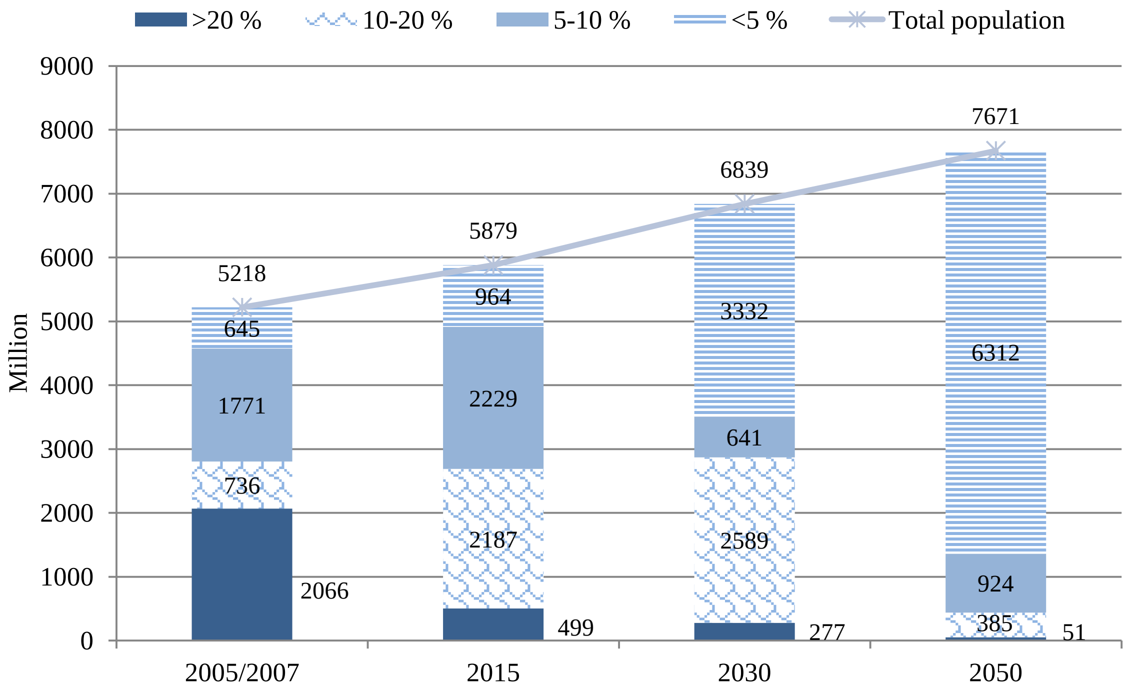
Such optimism notwithstanding, achieving significant declines in the numbers undernourished may prove to be a more arduous task than commonly thought. A combination of higher national average food consumption and reduced inequality[26] can have a significant impact on the proportion of the population undernourished. However, when population growth is added, such gains do not necessarily translate into commensurate declines in the absolute numbers. In this context, it is noted that WFS halving target, being set in absolute terms (numbers undernourished), is much more difficult to reach than the MDG1 target which is set in terms of halving the proportion of people who suffer from hunger, not the absolute numbers. Monitoring progress towards the WFS halving target will always show countries with high population growth rates as making less progress than countries with low population growth rates, even when both make the same progress towards the MDG1 target. Finally, an additional factor why progress may be slow is the increase in the share of adults in total

[26] Food consumption per capita, being a bounded variable (a rich person can eat/waste so much food and a poor person must consume a minimum amount in order to survive), does not offer as much scope for increase in inequality as income. The indices of inequality of access to food are generally well below those of income. For example, for 100 countries with Gini coefficient data from surveys for both income and food (admittedly of different years and qualities) the simple Gini average of the income is 0.39 and that of food 0.14 (data in http://www.fao.org/economic/ess/food-security-statistics/en/). For these reasons, the increase in national averages of food consumption beyond certain levels is bound to be accompanied by declines in inequality. We take this prospect on board by assuming that countries (with significantly higher projected kcal/person/day) will have lower food inequality in the future. How much lower depends on the progress they make in raising their average kcal/person/day, as follows: *Future CV=Present CV times (Present kcal/Future kcal), subject to future CV=> 0.20.*

population. This raises the average MDERs of the countries and, ceteris paribus, contributes to making the incidence of undernourishment higher that it would otherwise be.

In conclusion, in many countries the decline in the numbers undernourished will be slow. Where population growth rates are high the numbers undernourished may increase by 2015. This prospect notwithstanding, the significant improvements implied by the projections should not be underestimated: the part of the developing country population living in countries with relatively low incidence of undernourishment (under 5 percent) would increase from the present 645 million (13 percent of the total of the developing countries) to 3330 million (49 percent) in 2030; and the part living in countries with high incidence (over 20 percent) would fall drastically from 40 percent to 4 percent. The shift of China from the 5-10 percent class to the one of under 5 percent, and of India from the over 20 percent to the 10-20 percent class are instrumental in these prospective developments. More details are given in Figure 2.9.

Figure 2.9 Developing countries: population (million) in countries with x% undernourished



2.3 Structural changes in the commodity composition of food consumption

Food consumption growth is accompanied by changes in composition. A rapid increase takes place in livestock meat, milk, eggs and vegetable oils as sources of food calories (Tables 2.5 and 2.6). These two food groups together now provide 22 percent of total calories in the developing countries, up from 13 percent in the early 1970s. Their share is projected to rise to 26 percent in 2030 and 28 percent in 2050 (in the developed countries the share has been around 35 percent for several decades now). However, structural change was not universal and wide inter-country diversity remains in the share of different commodity groups in total food consumption. The major changes, past and projected, are briefly reviewed below.[27]

Cereals continue to be by far the most important source of total food consumption in the developing countries (their direct food consumption provides 53 percent of total calories) and the world as a whole (49 percent). There is, however, very wide inter-country diversity: direct food consumption of cereals provides only 20-30 percent of total calories in several countries ranging from those with diets based predominantly on roots and tubers (e.g. Rwanda, Burundi, the Congo, the Democratic Republic of the Congo, Uganda, Ghana, etc.) to several high income countries with predominantly livestock-based diets. At the other extreme are countries with rice-based diets like Bangladesh, Viet Nam, etc, or those with diets based on coarse grains (e.g. Lesotho, Burkina Faso) which continue to derive 70-80 percent of total food calories from cereals. The great diversity of diets in Africa must also be noted: countries in North Africa have high shares of direct consumption of cereals and very small ones of root crops. The opposite is true for several countries in sub-Saharan Africa, like those mentioned above. However, sub-Saharan Africa also has countries at the other extreme (e.g. Mali, Niger, Senegal, Burkina Faso, Lesotho, etc): over 60 percent of calories coming from cereals and only 2-3 percent from root crops. The role of the prevailing agro-ecological characteristics conditioning the production patterns is overwhelming as a key determinant of what people eat, particularly when incomes per capita and food consumption levels are low and high shares of the population depend on agriculture for a living.

Per capita *food* use of cereals[28] seems to have peaked in the mid-1990s and declined slowly thereafter. This is true for the world as a whole as well as for the aggregate of the developing countries. This of course raises the question why should the average of the developing countries be levelling off when so many of them are far from having reached adequate levels of food consumption. In practice, the peak and subsequent decline reflects primarily developments in China and, to a smaller extent, India. China's consumption of cereals declined while total calories and those derived from other foods were increasing. India's decline was accompanied by falls in total kcal/person/year which remained very low, a phenomenon often referred to in the literature as a "paradox" or "puzzle" (see Annex 2.1 for more details). These two countries account for 37 percent of world population and for 47 percent of that of the developing countries. Therefore trends in their values influence decisively the global totals. Excluding these two large countries, the average for the developing countries has continued to grow, albeit very slowly. Figure 2.10 illustrates.

This near constancy in the midst of still significant undernutrition is a composite of both positive and negative factors. On the negative side, there are the experiences of the many developing countries whose declines in food cereals consumption, while they still have very low kcal/person/day, are part of the a broader picture of failures in the food security area. Countries in this class include Zambia, the United Republic of Tanzania, Democratic People's Republic of Korea, Yemen and several others. On the positive side, there are the experiences of those countries whose declines in food cereals are part of a diet diversification away from staples. Countries in this class include several in the middle and upper middle income categories, e.g. China, the Republic of Korea, Turkey, Tunisia, the Syrian Arab Republic, etc.

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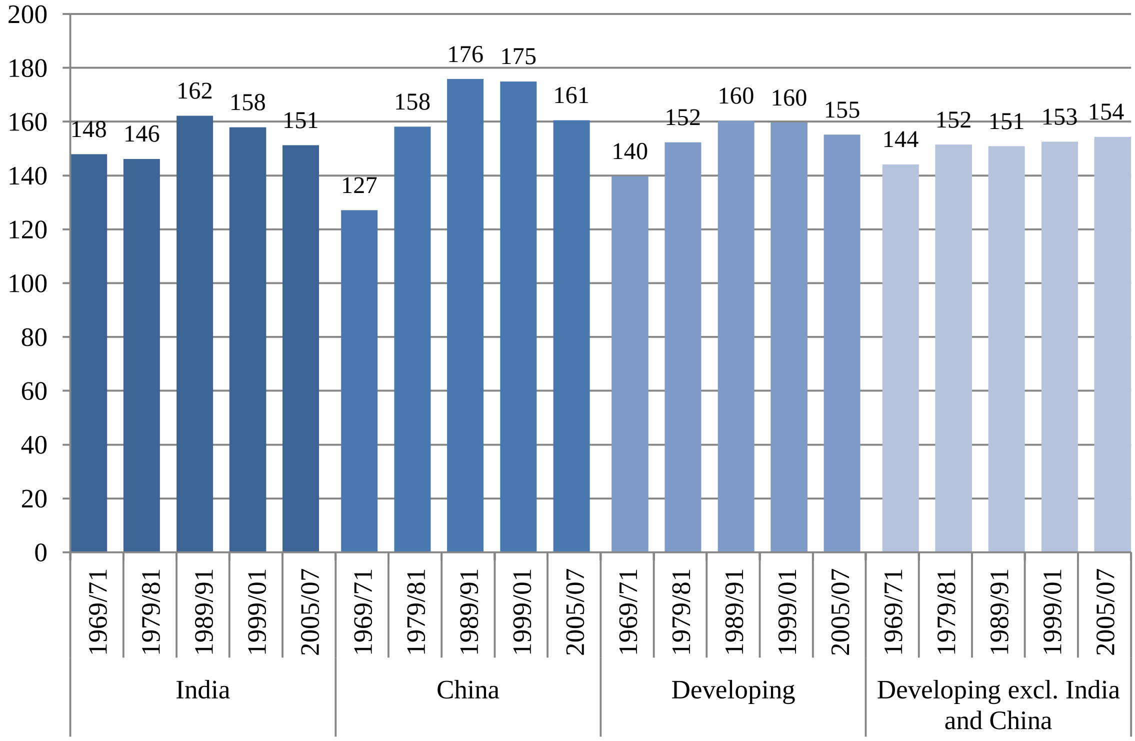
[27] As mentioned, these projections, like previous interim reports, do not separate fisheries products in the diets, but calories from fish are included in a 'other consumption' aggregate for commodities which are not analysed individually. Specific projections for fisheries products can be found in OECD-FAO Agricultural Outlook 2011-2020 (2011); the FAO Statistical Yearbook (2012) has fisheries data; and the FAO *The State of World Fisheries and Aquaculture* (2010) has data and analyses.

[28] Food use of cereals includes the grain equivalent of all cereals-based food products, including products like beer produced from barley and sugar-substitute sweeteners produced from maize, e.g. corn syrups.

Figure 2.10 Cereals consumption (direct food only) in kg/person/year



Concerning the future, the downward pressure on the direct food consumption of cereals per capita from developments in China (and to a smaller extent in the region Near East/North Africa) on the average of the developing countries will likely continue. This may, however, be more than compensated by a continuation of the recent upturn in sub-Saharan Africa and Latin America. Eventually South Asia may also raise its per capita cereals food if India's near stagnant and recently declining consumption per capita is halted or reversed in the medium term future before declining again in the longer term following diet diversification (see Annex 2.1). In the end, the world average and that of the developing countries may be in the future somewhat above present levels. This likely development will be the net effect of the contrasting trends of, on the one hand, diet diversification away from the direct consumption of cereals in those countries attaining medium-high levels of food consumption, and on the other hand, increases in per capita consumption in those countries remaining at low levels of food consumption and/or diversifying towards cereals and away from other staples, e.g. roots and tubers.

The share of cereals in total calories will continue to decline, but very slowly, falling for the developing countries from 53 percent at present to 49 percent in 2030 and to 47 percent in 2050. The wide inter-country differences in cereals food consumption will continue to persist, though not as pronounced as at present, for the reasons already mentioned: agro-ecological factors favouring dependence of diets on roots and tubers, bananas and plantains, in countries mainly in the humid tropics on the one hand; and prevalence of poverty and depressed levels of food consumption on the other hand. World average per capita consumption of cereals for all uses (including food, feed, and other non-food uses, e.g. for seed and the production of ethanol or starch for industrial uses should instead keep growing after the reversal of the sharp declines of the 1990s in the feed sector of the formerly centrally planned economies of Europe (Table 2.5).

Table 2.5 Changes in the commodity composition of food by major country groups

Kg / person / year	1969/ 1971	1979/ 1981	1989/ 1991	2005/ 2007	2030	2050	Comparison 1999/2001 New	Comparison 1999/2001 Old
World								
Cereals, food	144	153	161	158	160	160	158	165
Cereals, all uses	304	325	321	314	329	330	309	309
Roots and tubers	84	74	66	68	73	77	69	69
Sugar and sugar crops (raw sugar eq.)	22	23	22	22	24	25	23	24
Pulses, dry	7.6	6.5	6.2	6.1	6.6	7.0	6.0	5.9
Vegetable oils, oilseeds and products (oil eq.)	7	8	10	12	14	16	11	12
Meat (carcass weight)	26	30	33	39	45	49	37	37
Milk and dairy, excl. butter (fresh milk eq.)	76	77	77	83	92	99	78	78
Other food (kcal/person/day)	194	206	239	294	313	325	285	289
Total food (kcal/person/day)	**2 373**	**2 497**	**2 633**	**2 772**	**2 960**	**3 070**	**2 719**	**2 789**
Developing countries								
Cereals, food	140	152	160	155	159	158	157	166
Cereals, all uses	193	219	229	242	254	262	239	238
Roots and tubers	79	70	62	66	73	78	67	67
(Developing minus China)	62	59	58	64	74	81	62	63
Sugar and sugar crops (raw sugar eq.)	15	17	18	19	22	24	19	21
Pulses, dry	9.3	7.8	7.3	7.0	7.4	7.7	6.8	6.7
Vegetable oils, oilseeds and products (oil eq.)	4.9	6.4	8.4	10.1	13.1	15.4	9.4	10.4
Meat (carcass weight)	11	14	18	28	36	42	26	27
(Developing minus China and Brazil)	11	12	13	17	23	30	15.4	16
Milk and dairy, excl. butter (fresh milk eq.)	29	34	38	52	66	76	45	45
Other food (kcal/person/day)	115	130	177	253	279	293	242	242
Total food (kcal/person/day)	**2 056**	**2 236**	**2 429**	**2 619**	**2 860**	**3 000**	**2 572**	**2 654**
Developed countries								
Cereals, food	155	156	162	167	166	166	163	163
Cereals, all uses	571	620	618	591	682	695	564	565
Roots and tubers	96	84	78	77	73	72	78	78
Sugar and sugar crops (raw sugar eq.)	41	40	36	34	33	33	33.6	34
Pulses, dry	3.6	2.9	2.9	2.9	3.0	3.1	3.0	3.0
Vegetable oils, oilseeds and products (oil eq.)	11	14	16	19	20	21	18	18
Meat (carcass weight)	63	74	80	80	87	91	75.7	76
Milk and dairy, excl. butter (fresh milk eq.)	189	195	201	202	215	222	196	196
Other food (kcal/person/day)	492	508	498	458	488	509	472	458
Total food (kcal/person/day)	**3 138**	**3 222**	**3 288**	**3 360**	**3 430**	**3 490**	**3 251**	**3 257**

Note: Cereals food consumption includes the grain equivalent of beer consumption and of corn sweeteners; Vegetable oils do not include oils from crops other than oilseeds (rice bran oil and maize germ oil); Meat includes bovine, ovine, poultry and pig-meat.

Concerning the likely developments in the individual cereals (wheat, rice, coarse grains) much of the slowdown in per capita food consumption will continue to originate from *rice*. This is a well established trend in diets of some major rice-based countries, particularly those in the East Asia. South Asia is projected to follow this pattern in the medium term. Rice consumption per capita will however continue rising in the other regions, including the developed countries. *Wheat* food consumption per capita may see little growth for the world as a whole, but it will continue to rise in sub-Saharan Africa, South Asia, Latin America; while levelling off and eventually declining in the Near East/North Africa, East Asia – mainly in China – and the developed countries. Such growth in consumption in some of the developing regions will be accompanied by continued growth in their wheat imports, particularly in those countries that are non-producers or minor ones for agro-ecological reasons (see Chapter 3).

Food consumption of *coarse grains* has stagnated at 35-37 kg/capita as a world average as well as in the developing countries (30-32 kg). It continues to be important and rising slowly mainly in sub-Saharan Africa, where it accounts for 69 percent of food consumption of cereals, with some countries – e.g. Zimbabwe and Zambia – depending overwhelmingly on maize and others on millet and sorghum, mostly in the Sudano-Sahelian zone and to a smaller extent in Latin America (43 percent, mostly maize). Developments in barley use for beer (which in our data appears as food demand for barley) has been and will continue to be a factor in sustaining per capita consumption of coarse grains[29]. In like manner, the use of maize for the production of sweeteners has boosted the food consumption of coarse grains in the industrial countries, mainly in the United States of America, where HFCS has replaced a good part of sugar, though this trend has run its course and signs are that some reversal is in prospect[30]. In the future, a continuation of recovery in sub-Saharan Africa (already evident in the current decade), could raise the average of the developing countries.

Aggregate demand for coarse grains will be increasingly influenced by the demand for animal feed in developing countries: they now account for 42 percent of global feed use of coarse grains, up from 37 percent 10 years ago and 25 percent 20 years ago. They may account for some 56 percent of global feed use of coarse grains by 2050. Use of coarse grains for biofuels (mostly maize, some sorghum) is to play a growing role in world demand, at least for the next ten years, but the longer-term prospects are shrouded in uncertainty (see Chapter 3, Annex 3.1).

As noted, the diversification of diets in the developing countries has been most visible in the shift towards livestock products and vegetable oils. Here again there is very wide diversity among countries as regards both the levels of consumption achieved as well as the speed with which the transformation has been taking place. Concerning *meat*, several developing countries have traditionally had high consumption per capita, comparable to the levels of the industrial countries. They include the traditional meat exporters of Latin America (e.g. Argentina or Uruguay), but also the occasional country with predominantly pastoral economy, e.g. Mongolia. However, developments in these countries are not what caused the structural change in the diets of the average of the developing countries towards more meat consumption. If anything, they slowed it down as the per capita consumption in many of them either remained flat or actually declined. The real force behind the structural change has been rapid growth in consumption of livestock products in countries like China (including Hong Kong SAR), the Republic of Korea, Malaysia, Chile, Brazil and Saudi Arabia). Indeed, as discussed in Chapter 3, the increase of meat consumption of the developing countries from 14 to 28 kg from 1979/1981-2005/2007 was decisively influenced by the rapid growth in China and Brazil. Excluding them from the totals, the average of the other developing countries

[29] World beer consumption has grown from 21 kg to 25 kg/capita in the last ten years.
[30] See “High-fructose corn syrup: Sickly sweetener, Americans are losing their taste for a sugar substitute made from maize”, *Economist*, 29 May 2010.

grew much less over the same period, from 12 kg to only 17 kg[31] (Table 2.5). Given the uncertainty surrounding China's meat statistics[32], one may question whether a "livestock revolution" is really taking place in developing countries.

In the future we may witness a significant slowdown in the growth of demand for meat, as more and more countries attain medium/high levels of consumption per capita. For example, there are currently only 18 developing countries (out of 98) with over 50 kg, including China and Brazil which between themselves account for 56 percent of meat consumption in the developing countries (against their share of 28 percent in the population). Their number may rise to 28 countries by 2030 and 36 by 2050. The rising weight in world consumption of the developing countries attaining medium/high levels together with the large initial weight of the developed countries (in relation to their population – see Box 2.3) and the fall in the growth rate of population will lead to world meat consumption growing at a lower rate than in the past, e.g. 1.6 percent p.a. from 2005/2007-2030 compared with 2.6 in the comparable historical period 1980-2006 and already lower in the first 7 years of the current decade (2.1 percent).

The prospects are slim that other large developing countries such as India will emerge as major meat consumers, due to a continuation of low incomes for a significant part of the population and the influence of dietary preferences favouring meat less than in other societies. In India per capita meat consumption is currently minuscule (3.1 kg in the FBS data) and even lower than in the past. Its consumption may grow only slowly in the short to medium term, but the prospect of faster growth in the longer term cannot be excluded. The current study projects India's meat consumption (mostly poultry meat) rising to 18 kg in 2050. A recent World Bank paper projects an exploding size of the South Asia's middle class by 2050 – from under 1 million at present to some 660 million (29 percent of the population) in 2050 (van der Mensbrugghe *et al.*, 2011: Table 5.9). Such developments can be expected to have a significant impact on the region's demand for livestock products but, as noted, this is a prospect for the longer term (after 2030) of our projection period. Even so, India will still have very low meat consumption compared with other countries.

In contrast to the projected moderate consumption of meat, India's consumption of milk/dairy products rose very fast, with per capita consumption doubling to 67 kg from the levels of the early 70s. There is still scope for fast growth in the country's consumption. For the foreseeable future, India will play a significant role in the evolution of the world milk sector. It now accounts for 15 percent of world production and its share may rise to 21 percent by 2050.

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[31] These data for meat consumption refer only to the traditional meats constituting the great bulk of aggregate consumption, i.e. bovine, ovine, pig meat and poultry. Other meats (horse, camel, rabbit and game for which the FBS provide crude estimates) are not included in the data given here. They add to the world average of 39 kg another 3 kg. However, these other meats are significant food sources in a number of countries, e.g. they add 24 kg to the per capita meat consumption in Mongolia, an important 5-10 kg in several African (sub-Saharan) countries which significantly increases the meat consumption from the more traditional animals. For sub-Saharan Africa, this other meat increases the regional average from the 10.1 kg shown in Table 2.6 to 13.3 kg. Several European countries have also significant consumption, e.g. Italy and France (5-6 kg), and an EU27 average of 5 kg added to the traditional average of 83 kg.

[32] China's meat production data are thought to overstate the growth of livestock production because the implied consumption of meat is well above what other data (from the food consumption surveys) show (Ma *et al.*, 2004). If the data actually overstate China's meat production by a considerable margin, the country's impact on the world meat economy and particularly the aggregates of the developing countries would have been more modest, and its future impact on the livestock economy and the demand of cereals for feed would be larger, than suggested here.

In conclusion, the boost given in the past to world meat consumption by the surge in China, pending mentioned reservations on the data, is unlikely to be replicated by other countries in the medium term future. The major structural changes that characterized the historical evolution of the world livestock economy, particularly in the 1990s, are likely to continue, though in somewhat attenuated form. These changes are: the growing role of the developing countries in the world meat sector and that of the poultry sector in world meat production.

The other major commodity group with very high consumption growth in the developing countries has been *vegetable oils*. The rapid growth in consumption, in combination with the high calorie content of oils and other oilcrop products[33], have been instrumental in bringing about the increases in apparent food consumption (kcal/person/day) of the developing countries, that characterized the progress in food security achieved in the past. In the early 1970s, consumption of oilcrop products was 4.9 kg/person/year in oil equivalent; it is currently 10.1 kg. One out of every four calories added to the consumption of the developing countries over this period originated in this group of products. In the future, vegetable oils are likely to retain, and indeed strengthen, their primacy as major contributors to further increases in food consumption of the developing countries: they could provide 13 percent of total calories by 2050, up from 10 percent at present.

Consumption of *pulses* in the developing countries stagnated overall and registered drastic declines in several countries, mainly in Asia and sub-Saharan Africa. These trends reflected not just changing consumer preferences, but also, in several countries, failure to promote production of these crops. Often this was the result of preference for increasing production and self-sufficiency in cereals. As Evenson (2004), referring mostly to Latin America, puts it "Because of limited genetic improvements, beans have effectively been "crowded out" of productive areas by crops with greater genetic improvement, especially corn and soybeans". It is thought that where these declines in protein-rich pulses were not accompanied by increases in the consumption of livestock products, the result has been deterioration in the overall quality of diets, even where per capita dietary energy increased. In India pulses are an important source of protein for the vegetarian population (Hopper, 1999). For the future, no major changes are foreseen in per capita consumption of pulses, with the average of the developing countries remaining at 7-8 kg.

Roots, tubers and plantains have traditionally been the mainstay of food consumption in several countries with low-middle levels of overall food consumption, mainly in sub-Saharan Africa and Latin America. Ten countries depend on these products for over 30 percent of food consumption in terms of calories and another six for 20-30 percent, all 16 in sub-Saharan Africa. In the Democratic Republic of the Congo and Rwanda, the dependence is over 50 percent. These 16 countries account for 52 percent of the region's population. At the same time, the region contains countries at the other extreme of the spectrum with only minimal consumption of roots and tubers, e.g. Burkina Faso, Mauritania, Niger, Sudan, etc.

[33] The figures given here refer to the consumption of oils as well as that of oilcrops directly (soybeans, groundnuts, etc.) or in the form of derived products other than oil, all measured in oil equivalent. This consumption of oilcrops in forms other than oil is particularly important in some countries.

Table 2.6 Changes in the commodity composition of food, developing regions

Region	Kg / person / year	1969/ 1971	1979/ 1981	1989/ 1991	2005/ 2007	2030	2050	Comparison 1999/ 2001 New	Comparison 1999/ 2001 Old
Sub-Saharan Africa	Cereals, food	128	126	115	125	142	154	117	123
	Roots and tubers	190	174	184	184	189	186	192	191
	Sugar and sugar crops (raw sugar eq.)	7.5	9.5	8.2	10.7	13.0	15.0	9.3	10.0
	Pulses, dry	11.0	9.8	9.0	10.5	12.5	13.5	10.0	9.8
	Vegetable oils, oilseeds and products (oil eq.)	7.7	8.1	8.2	9.4	11.6	13.5	8.6	8.9
	Meat (carcass weight)	9.9	10.2	9.4	10.1	12.4	16.0	9.3	9.5
	Milk and dairy, excl. butter (fresh milk eq.)	29	33	29	31	33	37	28	28
	Other food (kcal/person/day)	n/a	n/a	119	126	132	148	126	128
	Total food (kcal/person/day)	**2 031**	**2 021**	**2 052**	**2 238**	**2 530**	**2 740**	**2 136**	**2 194**
Near East/North Africa	Cereals, food	181	205	213	203	203	200	206	204
	Roots and tubers	16	27	32	37	39	39	34	34
	Sugar and sugar crops (raw sugar eq.)	20.2	27.7	28.1	27.8	28.8	29.4	27.6	27.7
	Pulses, dry	6.2	6.2	7.9	7.1	6.5	6.2	7.0	6.6
	Vegetable oils, oilseeds and products (oil eq.)	7.0	10.3	12.3	12.3	13.7	14.5	12.1	12.1
	Meat (carcass weight)	12.3	16.6	19.0	23.7	31.6	38.5	21.0	21.7
	Milk and dairy, excl. butter (fresh milk eq.)	67	83	74	78	88	96	72	73
	Other food (kcal/person/day)	221	252	306	343	361	376	343	333
	Total food (kcal/person/day)	**2 355**	**2 804**	**3 003**	**3 007**	**3 130**	**3 200**	**2 975**	**2 974**
Latin America and the Caribbean	*Cereals, food*	*118*	*129*	*130*	*138*	*143*	*145*	*133*	*133*
	Roots and tubers	*93*	*73*	*64*	*63*	*63*	*64*	*63*	*63*
	Sugar and sugar crops (raw sugar eq.)	*39*	*47*	*44*	*42*	*42*	*41*	*41*	*49*
	Pulses, dry	14.2	12.6	10.5	11.3	11.0	10.5	11.3	11.2
	Vegetable oils, oilseeds and products (oil eq.)	6.7	10.1	12.0	13.6	15.5	16.4	13.0	11.8
	Meat (carcass weight)	33	40	42	61	74.6	84.0	58	59
	Milk and dairy, excl. butter (fresh milk eq.)	83	96	94	111	128	139	110	109
	Other food (kcal/person/day)	262	250	251	264	293	311	274	272
	Total food (kcal/person/day)	**2 442**	**2 675**	**2 664**	**2 898**	**3 090**	**3 200**	**2 802**	**2 836**
South Asia	Cereals, food	151	147	161	152	157	154	154	157
	Roots and tubers	17	20	18	25	33	38	22	24
	Sugar and sugar crops (raw sugar eq.)	20.7	19.4	20.6	19.1	23.7	28.2	25	26
	Pulses, dry	14.5	11.1	12.0	10.3	9.6	9.1	10	10
	Vegetable oils, oilseeds and products (oil eq.)	4.6	5.7	7.1	8.9	12.4	16.7	8.5	9.7
	Meat (carcass weight)	3.9	4.0	4.6	4.4	9.6	18.0	4.4	5.5
	Milk and dairy, excl. butter (fresh milk eq.)	38	42	54	71	94	116	66	68
	Other food (kcal/person/day)	90	87	98	137	168	195	122	141
	Total food (kcal/person/day)	**2 071**	**2 025**	**2 254**	**2 293**	**2 590**	**2 820**	**2 303**	**2 392**
East Asia	Cereals, food	135	160	172	163	162	157	170	187
	Roots and tubers	97	82	61	60	57	53	66	66
	Sugar and sugar crops (raw sugar eq.)	5.7	8.3	10.6	13.4	16.6	18.8	11.3	11.6
	Pulses, dry	4.9	4.3	2.6	1.9	1.8	1.7	1.9	2.0
	Vegetable oils, oilseeds and products (oil eq.)	3.5	4.8	7.6	9.9	13.8	15.3	8.7	10.6
	Meat (carcass weight)	9.3	13.4	22.8	44.3	61.2	71.1	39.6	39.8
	Milk and dairy, excl. butter (fresh milk eq.)	3.7	5.0	7.4	23.3	34.6	39.2	11.6	11.3
	Other food (kcal/person/day)	109	140	202	367	422	455	334	322
	Total food (kcal/person/day)	**1 908**	**2 217**	**2 487**	**2 850**	**3 130**	**3 220**	**2 770**	**2 872**

Note: Cereals food consumption includes the grain equivalent of beer consumption and of corn sweeteners; Vegetable oils do not include oils from crops other than oilseeds (rice bran oil and maize germ oil); Meat includes bovine, ovine, poultry and pigmeat.

The Food Balance Sheets data show that in several of the countries with high dietary dependence on roots and tubers, production and consumption of these crops go in tandem, given the minor role of trade and often their nature as subsistence crops. Changes in their production/consumption are an important determinant of changes in the national average food consumption in terms kcal/person/day. In countries such as Ghana, Malawi, Sierra Leone and Peru, whatever improvements in national average kcal/person/day occurred from the early 1990s to the present originated predominantly in the increased production/consumption of roots and tubers. The same is true for countries that experienced falls in the national averages, e.g. the Democratic Republic of the Congo, Madagascar, the United Republic of Tanzania and Uganda: most of the fall originated in the decline of roots and tubers.

The general trend in recent years has been for average per capita food consumption of these products in developing countries to increase, but to decline if potatoes are excluded. Increases in some countries were compensated by declines in others. The drastic decline in food consumption of sweet potatoes in China had a decisive influence up to the early 1990s after which strong growth in potato consumption in China and in several other countries, contributed to reversing the earlier declines in the per capita consumption of all roots (Table 2.5). Overall, potatoes were the one commodity in this group with consistent increases in per capita consumption in the developing countries.

The high dependence of several developing countries on roots and tubers as a major source of food calories is expected to continue. Six countries of sub-Saharan Africa may still depend on them for over 30 percent of total food consumption (calories) in 2050. Potato consumption per capita will continue to grow fairly rapidly. There is scope for the declining trend in the other roots, tubers and plantains to be reversed now that much of the decline in China's per capita food consumption of sweet potatoes has already occurred and in the future it will not have the depressing effect it had in the past on the average of the developing countries. Another factor that could raise consumption is the potential for productivity increases in the root crops (cassava, yams). It will be possible for more countries in sub-Saharan Africa to replicate the experiences of countries like Nigeria, Ghana, Benin and Malawi, and increase their food consumption based on rapid production improvements in these crops (Nweke, 2004; Babaleye, 2005).

World average sugar consumption per capita has been nearly constant over several decades, but rising in the developing countries and falling in the developed ones (Table 2.5). Sugar shares some of the characteristics of vegetable oils in that it is an important source of total calories in the developing countries and it is a major export commodity of several of them such as Brazil, Thailand, Guatemala and Colombia – with Brazil dominating by far total exports. In addition, several developing countries are becoming large and growing net importers: this is the case of Indonesia, Nigeria, Algeria, Pakistan, Iran and the Republic of Korea, making up for the lack of growth of net imports into the developed countries. The developing countries' average consumption is 19 kg/person year, but it is 22 kg if China is excluded from the calculation. China has only 10 kg, partly because it uses saccharine as a sweetener. About one quarter of the developing countries consume less than 10 kg/year. The scope for consumption growth is still considerable and we project that in 2050 only one in ten developing countries would be in the under 10 kg/year category. China's contribution to total growth should be more than in the past since the country could be discouraging the use of saccharine.

2.4 Concluding remarks

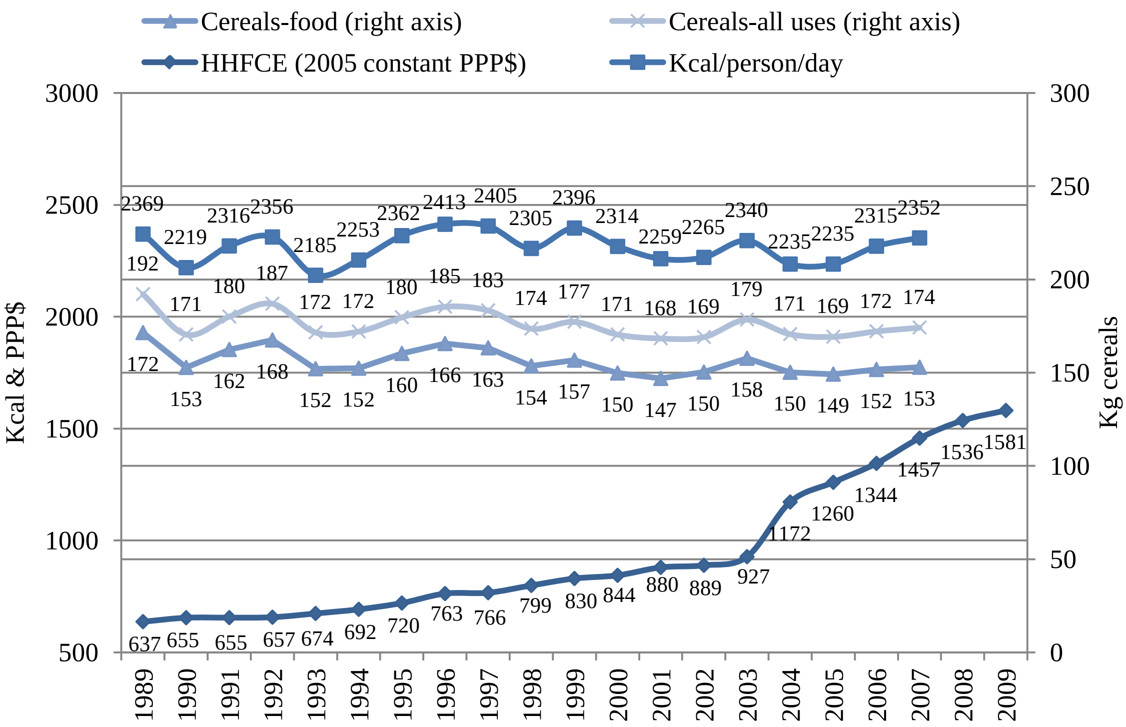
Some brief conclusions may be drawn, as follows:

- Over the longer term significant progress can be made in raising food consumption levels and reducing the percentage of the population undernourished. However the progress in reducing the absolute numbers will be a very slow process, mainly because the countries that have high incidence of undernourishment now have also high population growth rates. This means that improvements in per capita food consumption and reduction in the percent of the population undernourished will not be translated into commensurate reductions in absolute numbers affected. A contributing factor will be the growing share of adults in the population that will raise the average minimum food requirements.
- The number of undernourished in developing countries stood at 810 million in 1990/1992 (the 3-year average used as the basis for defining the World Food Summit target of halving the absolute numbers by 2015). This number, far from declining, had actually increased a little by 2005/2007, i.e. before the food price surges of 2008. Provisional estimates suggest that it increased further after 2007 (FAO, 2010: Figure 1). It is not likely to be halved by 2015 as per target. We may have to wait until after 2040 for the halving target to be attained. However, if the target is redefined (as per MDG1) as halving the proportion of the population undernourished by 2015, then it could be attained shortly after 2015 (Figure 1.4 and Table 2.2).
- Despite this slow pace of progress in reducing the numbers undernourished, the projections imply a considerable overall improvement. In many countries, including some of the more populous ones, the relative incidence of undernourishment (percent of the population) will decline significantly. Fewer countries than at present will have high incidence of undernourishment, none of them in the most populous class. Many more will transit to the category of low incidence (under 5 percent undernourished). That would be no mean achievement. The problem of undernourishment will tend to become smaller in terms of both absolute numbers affected and, even more, in relative terms, hence it will become more tractable through policy interventions, both national and international.
- Structural change in the diets will continue reducing the relative weight of staples in direct food consumption like roots and cereals, in favour of livestock products, vegetable oils and fruits and vegetables. However, the so-called “livestock revolution” in the developing countries, driven in the past by the rapid growth of meat consumption in countries like China and Brazil, cannot continue at the same pace. The two countries produced 10 percent of world meat in the early 70s: they now produce 34 percent. India’s possible transformation into a moderate meat-eating country will be very slow and longer term. Even if it increased per capita consumption six-fold by 2050 (to 18 kg) it would only account for 6.5 percent of world meat output in 2050.

India's food demand projections in a global context

In our earlier report on global food and agriculture projections we had noted the diversity of country experiences as concerns the apparent relationship between income growth (as measured in the National Accounts) and changes in per capita food consumption as depicted in the trajectories of kcal/person/day in the FAO Food Balance Sheets (FBS), using the then available data going to 2002 (FAO 2006: 9). In particular we had noted that, unlike the experiences of other countries, the income growth of India was not accompanied by increases in per capita food consumption: this was a puzzle given the low levels of food consumption and the high prevalence of undernourishment. More recent data from the FBS and the national accounts confirm the puzzle. If anything, they strengthen it. They are shown in Figure A.2.1.1: kcal/person/day remained flat at low levels, and so did cereals (all uses, kg/person/year) while cereals for direct food declined somewhat. In short, food demand in India has not been growing at anything near the rates one would expect from the high economic growth and the high prevalence of unsatisfied food needs. This puts paid to the frequent assertions that growth in the demand on the part of the emerging countries, particularly in India and China, was among the major causes of the food price surges of 2007-08 (on this see Mitchell, 2008; Alexandratos, 2008).

Figure A.2.1.1 India: per capita HHCE (PPP2005$), cereals (kg) and kcal/person/day

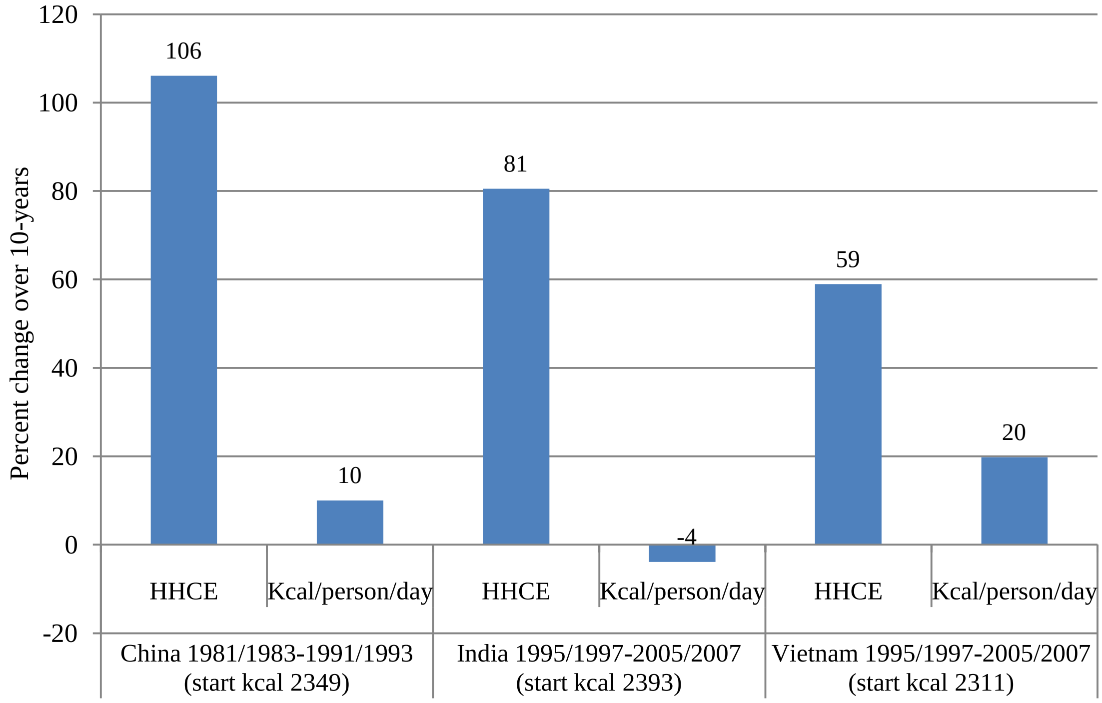


Sources: kcal and Cereals from FAO Food Balance Sheets; HHCE (Household Consumption Expenditure) from World Bank, World Development Indicators.

For our long term projections India plays a pivotal role because of its size and the significant potential for increasing food demand given its low consumption levels, high undernourishment and the prospect of continuation of sustained income growth. Developments in India will influence in major way the future outcomes of global magnitudes of food and agriculture and those of the developing countries.

The first question to ask is whether India is unique in this behaviour of combining high income growth with non-increasing food per capita. Other countries (e.g. China, Viet Nam), starting from per capita food consumption about the same level of India (2300-2400 kcal), experienced fast growth in per capita incomes for a period of about ten years. What happened to their food consumption? As shown in Figure A.2.1.2 both countries increased food consumption per capita. For China, the relevant period is the decade 81/83-91/93: it started with 2350 kcal and ended the ten-year period with 2585 kcal, a 10 percent increase (it has grown further since, to the present 2970 kcal). Viet Nam started with 2370 kcal in 1995/1997 and ended with 2770 kcal in 2005/2007. India seems to be the exception rather than the rule. In a recent article, Jean Dreze and Amartya Sen (2011) state that: “There is probably no other example in the history of world development of an economy growing so fast for so long with such limited results in terms of broad-based social progress”. The all important question for our work is: will it continue to be so in the future?

Figure A.2.1.2 Changes in kcal/person/day in ten-year periods of high growth in per capita HHCE

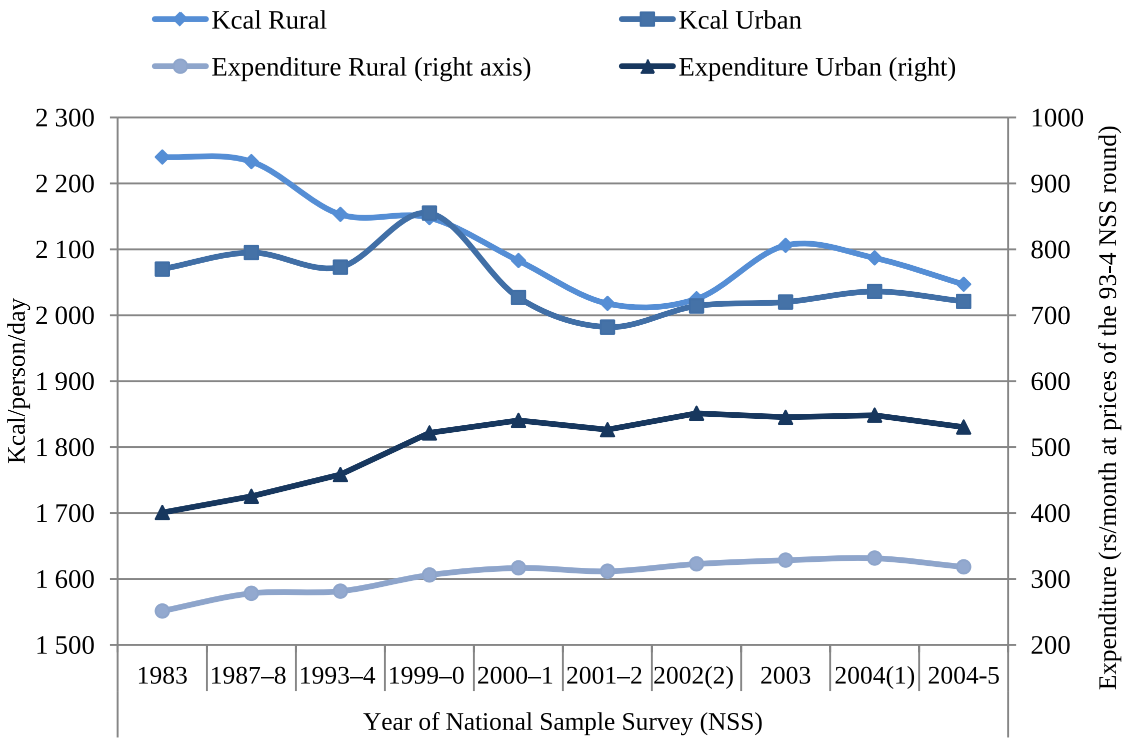


Sources: kcal/person/day, FAOSTAT FBS data; Expenditure: World Bank, WDI/GDF data base.

This brings us to pose the question whether the data (both of the FBS and the National accounts) may not reflect reality. Deaton and Dreze (2008, 2009) carried out a meticulous inspection and analysis of the food consumption and expenditure data from Indian sources, mainly the National Sample Surveys – (NSS)(Figure A.2.1.3). They conclude that “the per capita consumption of calories and of protein is falling in rural India, and shows no trend in urban India; this is occurring against the increase in real household per capita expenditures”. The contrast between rising incomes and falling food consumption is even more pronounced if we consider that the NSS expenditure data are likely to underestimate rather than overestimate real income growth, as evidenced by the large differences with the National

Accounts, something which the authors accept in part: "the NSS is almost certainly missing some of the growth, and the NAS is almost certainly overstating it". The authors explore several reasons why food consumption per capita is falling rather than increasing, e.g. changes in real relative prices, in household age composition, in food habits, reduction in dietary energy requirements because of reduced physical activity level and improved health environment. Such reduction is thought to be an important explanatory factor why average calorie consumption has declined. An additional often cited explanation is the shift in consumption towards more high-value foods, such as milk, vegetables, meat, etc[34].

Figure A.2.1.3 Indian data: kcal/person/day and consumption expenditure per capita (Rs/month)



Source: Deaton and Dreze (2008): Tables 1 and 2.

Lisa Smith (2011) considers that data underestimate the improvements in food consumption in recent years. She considers that "There are many signs that the food and nutrition situation has improved during India's rapid economic growth (minus obesity and NCDs)" and puts forward the hypothesis that "The single most important measurement issue is that data on foods consumed away from home and of prepared/processed foods consumed at home are not being adequately measured". If this hypothesis were to prove true it would raise the problem of how to reconcile the resulting higher consumption data with the food availabilities coming from the food balance sheets. The additional food consumed must come from production or imports or by reducing the estimates for non-food uses of food commodities and waste. Figure A.2.1.1 shows that at least for cereals such estimates (the gap between food use and total disappearance) offer limited scope for downward revision since

[34] "… as income rises, households generally diversify their food consumption pattern by shifting towards high-value and high-quality food items" (Kumar *et al.*, 2007).

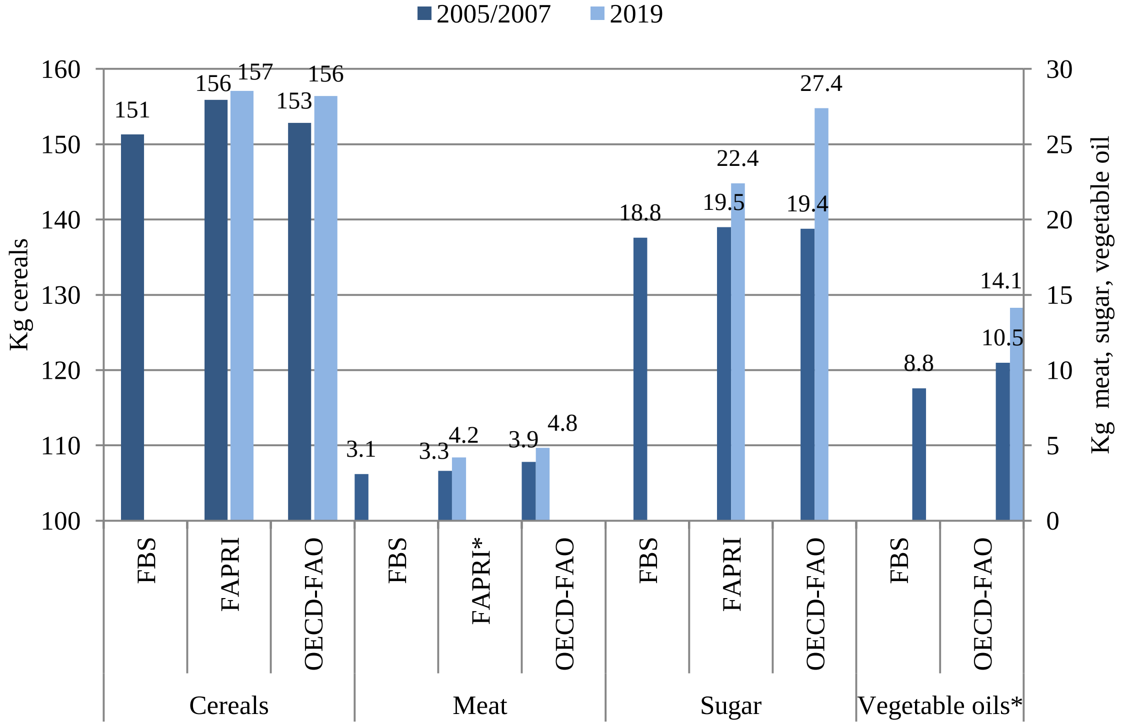
the gap has not been increasing. This leaves the production data as candidate for possible upward revisions (see discussion below on the meat, particularly poultry, production data).

A recent study undertaken for the United Kingdom *Foresight* report (The Government Office for Science, 2011, hereafter referred to as Foresight), by Gaiha *et al.* (2010) highlights the importance of reduced energy requirements but also emphasizes that their analyses of changes in calories show consistently robust food price and expenditure effects. Some observers (Patnaik, 2010a,b) note that the explanation why per capita food consumption has been declining is more mundane and conventional and there is no paradox to explain: using alternative deflators to calculate real per capita expenditure it is argued that it has been falling for almost all income groups; this explains why food consumption has declined. Deaton and Dreze (2010a, b) reply: "we do find it difficult to believe that 90 percent of the urban population was worse off in 2004-05 than in 1993-94, and even more so, that average real spending declined in both rural and urban areas in that period, as if the economy's entire income growth had been stashed away in Swiss bank accounts". In addition, the World Bank estimates of poverty rates show significant declines over the period in question[35]. Apparently, the puzzle remains. The case for the possibility that India's experience is an example of how rapid economic fails to translate into improved nutrition should not be lightly dismissed: Dreze and Sen (2011) conclude that "We hope that the puzzle with which we began is a little clearer now. India's recent development experience includes both spectacular success as well as massive failure. The growth record is very impressive, but there has also been a failure to ensure that rapid growth translates into better living conditions"

In an attempt to survey other views on how food consumption per capita may develop in the future, we examine briefly existing *recent* projections of demand in India. Figure A.2.1.4 shows two 10-year projections to 2019 made in 2010 with models of world demand, supply and trade of agricultural commodities, that of the OECD-FAO (OECD-FAO, 2010) and that of FAPRI (FAPRI, 2010). However, they cover only the main commodities (e.g. they do not include roots/tubers, fruit, vegetables, pulses, etc) and do not project nutrient indicators like calories. In general, they show in various degrees increases in the per capita food consumption of all commodities covered. In particular, and contrary to trends in the national data of India, they project no declines in the per capita food consumption of cereals but rather marginal increases over the period to 2019. Meat per capita is projected to increase but India will still have very low consumption in ten years time, nothing like the increases experienced by other countries with high income growth. Substantial increases are projected for vegetable oils and sugar, both high calorie-content foods. By implication, calories per capita should also increase, given that these three commodities (cereals, sugar and vegetable oils) provide some 80 percent of total calories. In conclusion, the Indian food projections derived from world models imply that, contrary to the trends in the historical data in the Indian sources, calories per capita would be increasing.

[35] http://iresearch.worldbank.org/PovcalNet/povcalSvy.html

Figure A.2.1.4 India: OECD-FAO and FAPRI projections of food (kg/person/year)



* FAPRI meat: only beef and poultry; OTHERS: beef, poultry, pork and ovine.

** FAPRI does not show FOOD consumption of vegetable oil, just consumption of oils from palm, soybeans, groundnuts and rapeseed, which increases 50 % in the projection period. Its implied food consumption growth should not be too different from that of OECD-FAO.

Gaiha *et al.* (2010) surveyed a number of projections, all except one India-specific and using data from Indian sources. They conclude that "the discrepancies between different estimates are much too large in a few cases to be useful for policy purposes". Some of these projections are outright outlandish. For example, the latest of them (Mittal, 2008) projects sugar demand to rise from 12 kg/capita in the base year 1999/2000 to 51 kg in 2026 (assuming 8 percent GDP growth rate) or to 71 kg (9 percent GDP growth rate). The latter figure would certainly not be a nutritionally tenable proposition. This is the problem with demand projections applying high income elasticities that remain constant over the longer term. Few countries have high per capita sugar consumption (in the range 50-57 kg in the FBS data, more likely of availability rather than actual consumption), mainly sugar producing/exporting ones like Barbados, Trinidad and Tobago and Cuba.

Livestock products projections including some detail are rarer. The latest one by Dastagiri (2004) has projections of meat demand to 2020 under three GDP growth assumptions (4 percent, 5 percent and 7 percent). Per capita demand could grow little under the low GDP growth to reach 3.4 kg in 2020; but it is projected to explode to 37 kg under the high GDP growth, most of it ovine meat (an unlikely 35 kg in 2020, up from 1.7 kg in 2000), while poultry meat remains under 1 kg. Demand for ovine meat would grow 20 percent p.a., impossible to meet from domestic production and most unlikely from imports. It is poultry meat that is growing rapidly according to some fragmentary evidence and has the potential to continue growing. Such projections are a poor guide as to what may be in store for India's food sector.

Where does this leave us on the projections? Economic growth in India is projected to continue at fairly sustained rates, at least over the medium term[36]. One scenario projects an exploding size of the South Asia's middle class by 2050 – from under 1 million at present to some 660 million or 29 percent of the population in 2050, and a drastic fall in poverty rates based on a the PPP$ 1.25/day poverty line from 40 percent to zero (van der Mensbrugghe *et al.*, 2011: Tables 6.2, 6.3 – no India projections given). The key question is: will India, if and when it attains reduced poverty and a sizable middle class, behave like other countries, e.g. China, concerning food expenditure and change in dietary habits towards more livestock products, essentially meat since preference for milk is already evident in the historical data[37]? One is tempted to say "much less than other countries": the country has a strong vegetarian tradition given that around 40 percent of the population are vegetarians (Yadav and Kumar, 2006), and consumption of beef and pork is against religious cultures of significant parts of the population. At the same time, poultry production and consumption seems, according to some reports, to be growing rapidly, though this is not evidenced in the official statistics[38]. Some national data indicate meat consumption per capita of 5.3 kg in 1999-2000 (Kumar *et al.*, 2007), i.e. higher than the 3.5 kg of the FBS. Also, a recent report of ICAR (Indian Council of Agricultural Research, 2011:4) has a figure of meat consumption of 4.5 million tonnes in 2000, i.e. 4.3 kg per capita. Whatever the truth, the long-term projections cannot ignore the fact that the poultry meat production statistics used in the FAO Food Balance Sheets are underestimates, and the prospect that things may change and that per capita consumption of meat may eventually take off from the minuscule quantities reported in the FBS.

In the light of uncertainties and the inconsequential nature of projection exercises applying elasticities over long periods, the following principles are used for generating a set of food demand projections for India to use in this global study:

- We first generate a projection of calories in 2050. This is 2825 kcal/person/day, up from 2300 in 2005/2007. This projected number is derived from the cross-country relationship for 62 developing countries with Household Consumption Expenditure (HHCE) data between kcal from the FBS and HHCE per capita in 2005$ PPP from the World Bank data. The relationship is graphed in Figure A.2.1.5. We then project per capita HHCE in 2050, from the 6 percent GDP growth rate (5.4 percent per capita) from Foure *et al.* (2010), but reducing it to 4.4 percent for HHCE per capita in order to account for the probable overstatement of the HHCE growth in the national accounts, as

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[36] India's Eleventh 5-year Plan (2007-12) has a target of 9 percent annual growth rate of GDP (Mittal, 2008); a recently released set of GDP projections to 2050 from a French research centre have India growing at 6 percent p.a. from 2008-2050 (Foure *et al.*, 2010). We have already noted the apparent discrepancies between the growth rate of consumption expenditure from the National accounts data and that from the Indian national surveys. This is an aspect to keep in mind when we consider long-term food projections for India.

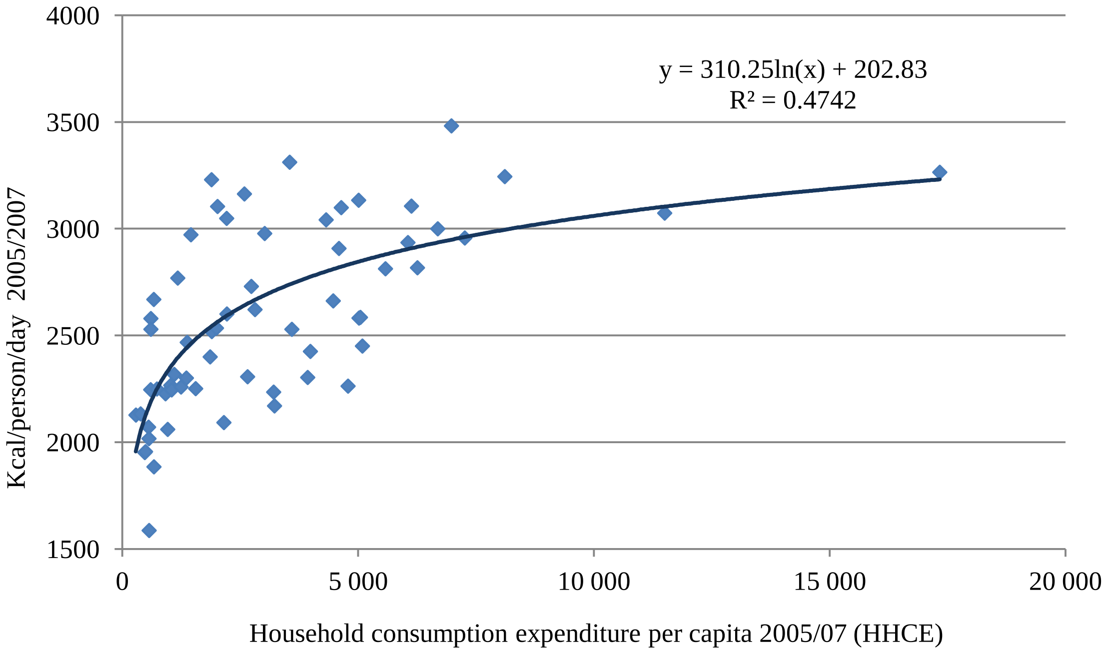
[37] The recent major UK government report (*Foresight*) lists among the uncertainties around future per capita consumption "whether regional differences in diet (particularly in India) persist into the future" (The Government Office for Science:54).

[38] "The current chicken consumption is under 3 kg per head a year and the poultry industry expects the consumption to double in the next five years" ("Consumption of chicken set to double by 2014", *Economic Times*, 8 June 2010). Also: "Rapid poultry sector growth is being driven by an expanding middle class and the emergence of vertically integrated poultry producers" (Landes *et al*, 2004). The USDA PSD data base indicates poultry meat production grew from 1080 thousand tonnes in 2000 to 2550 thousand tonnes in 2009. The FAO official data are 455 and 727 thousand tonnes, respectively. Recently released official data from India confirm that poultry meat production is much higher than the one previously reported and used in the FAO Food Balance Sheets (see http://dahd.nic.in/dahd/statistics/animal-husbandry-statistics.aspx). By implication, our meat consumption projection is by no means too high, on the contrary.

hypothesized by Deaton and Dreze (2011). The projected per capita HHCE results as 9000 PPP$. The kcal corresponding to this level of HHCE is, according to the cross-country relationship, 2825.

- The next step is to generate the food demand of the different commodities that go with this projected level of kcal. This is done as follows for main commodity groups:
- Direct food consumption of cereals is assumed to be lower in 2050 than in the base year: in 2050 they would provide 48 percent of total kcal, down from the 60 percent at present.
- Meat increases considerably to 9 kg in 2030 and to 18 kg in 2050, of which 12.5 kg[39] poultry meat. This is well below the levels consumed by other countries which attained the per capita HHCE India is projected to attain in 2050. In brief, the vegetarian tradition is largely preserved while recognizing that the rise in incomes, the emergence of sizeable middle class and the accompanying change in food habits will have an impact on the average diet composition. Such prospect tallies with ICAR's Vision 2030 which projects per capita meat consumption to increase from 4.3 kg in 2000 to 10.1 kg in 2030 (Indian Council of Agricultural Research, 2011:4).
- Food use of dairy products in milk equivalent to increase 63 percent from 2005/2007 to 2050. ICAR projects total demand for milk – probably for all uses – to increase from 76 million tonnes in 2000 to 182 million tonnes in 2030 or 54 percent in per capita terms.
- Sugar, vegetable oils, fruit and vegetables all to increase considerably, but the first two ones to remain within nutritionally acceptable limits.

Figure A.2.1.5 Cross-country relationship between kcal/person/day and HHCE per capita (PPP2005$) for 62 developing countries

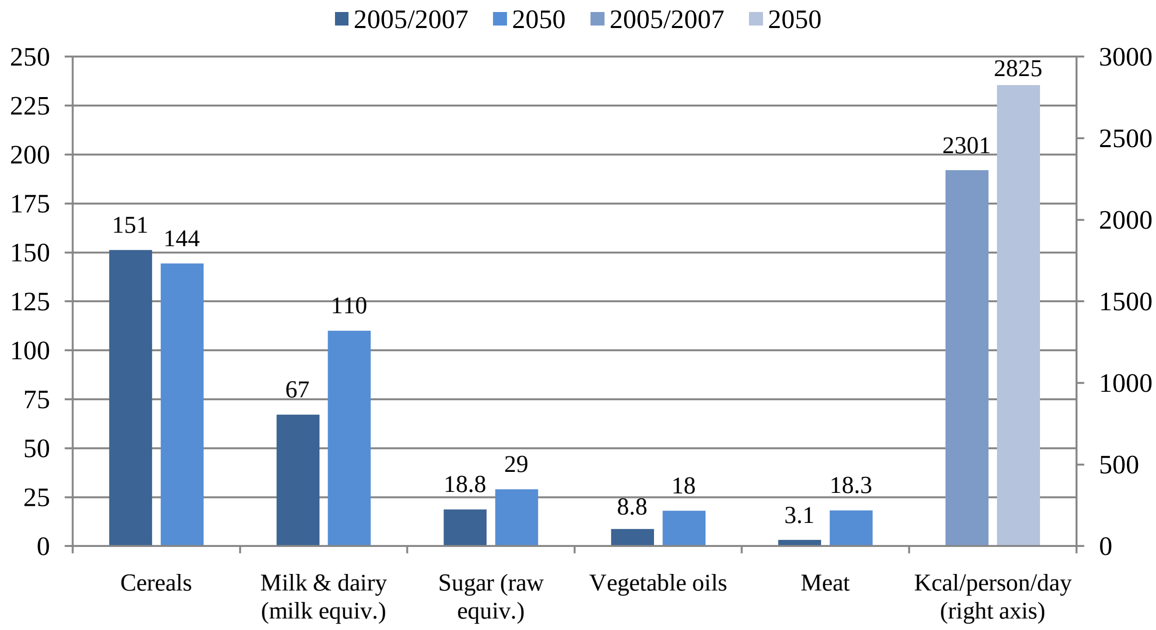


[39] the hefty increases projected for poultry meat reflect also the fact that the country's revised production data (see above) imply current per capita consumption much higher than the one we use here, which was based on the earlier lower data used in the FAO Food Balance Sheets to 2007.

Sources: kcal, FAO/FAOSTAT; HHCE, World Bank, WDI.

Figure A.2.1.6 shows these projections to 2050 for the main commodities or groups.

Figure A.2.1.6 India: food demand, base year and 2050



CHAPTER 3

PROSPECTS FOR AGRICULTURE AND MAJOR COMMODITY GROUPS

This Chapter deals with the trends and future outlook of world food and agriculture in terms of the main commodity sectors. A brief introduction to the subject is given first presenting trends and prospects for total agriculture (the aggregates of all crops and livestock products).

3.1 Aggregate agriculture: historical trends and prospects

Historical evidence suggests that growth of the productive potential of global agriculture has been sufficient to meet the growth of effective demand up to quite recently and before the emergence of biofuels as additional demand. This is what is suggested by the long-term term decline in the real price of food up to the mid-1980s and the near constancy afterwards up to about 2005. In practice, world agriculture had been operating for several decades in a demand-constrained environment. This situation has co-existed with hundreds of millions of the world population not having enough food to eat. Such un-met demand co-existing with actual or potential plenty is not, of course, specific to food and agriculture. It is found in other sectors as well, such as housing, sanitation, or health services.

Limits on the demand side at the global level reflect three main factors: (a) the slowdown in population growth from the late 1960s onwards; (b) the growing share of world population that has been attaining fairly high levels of per capita food consumption, beyond which the scope for further quantitative increases is limited (Figure 2.2), and (c) the fact that those who did not have enough to eat were too poor to afford more food and drive its production, or did not have means to produce it themselves. The first two factors will continue to operate also in the future. Their influence will be expressed in terms of lower growth rates of food and feed demand compared to the past and, at the global level, also of production. The third factor will also continue to play a role, given that the economic outlook indicates that poverty will continue to be widespread in the medium term. It follows that for a rather significant part of world population the *potential* demand for food will not be expressed fully as *effective* demand. Thus, past trends of decelerating growth of demand for food and feed will likely continue and perhaps intensify.

However, the trend may be halted or reversed for total demand if the intrusion of energy markets into those for agricultural produce for the production of biofuels were to continue at anything like the rates of the last few years. It is recalled that maize use for ethanol in the United States of America takes now 127 million tonnes[40] or 15.6 percent of world production, up from an insignificant 16 million tonnes or 2.7 percent ten years earlier; that 54 percent of sugar cane in Brazil is used for ethanol production which, counted as sugar equivalent, accounts for 23 percent of world sugar production[41]; and that some 9 million tonnes of vegetable oils are used in the EU for the production of biodiesel and an equal amount of cereals for ethanol[42]. In the present round of the projections we have assumed some expansion

[40] Data from www.ers.usda.gov/data/feedgrains/FeedGrainsQueriable.aspx.
[41] Estimates for 2010 from USDA/FAS and USDA/PSD.
[42] Data for 2009 from European Commission (2011).

of biofuels up to 2020 and no further increases in subsequent projection years. This "limited biofuels" scenario is explained in Annex 3.1.

The fact that there has been this additional demand for crops as biofuels feedstocks does not mean that equal amounts were subtracted from food and feed uses: most of the additional demand was met by additional production that would not have been there but for such use, certainly for sugar cane in Brazil and much of the rapeseed oil in the EU (the main feedstock for biodiesel production in the region). If anything, effects on the food-feed use have been indirect via the competition for resources that have raised the prices for these and other crop and livestock products for instance by raising the price of maize used for feed and the prices of livestock.

We present in this section a brief overview of what we can expect in terms of increases of aggregate demand for, and production of, agricultural products. The figures we use refer to the aggregate volumes of demand and production of the crop and livestock sectors. They are obtained by multiplying physical quantities of demand or production by price for each commodity and summing up over all commodities. Each commodity is valued at the same average international price in all countries in all years. The movement of these aggregates is rarely sufficient for us to analyze and understand the forces that shape the evolution of agricultural variables in their different dimensions. The commodities included (as listed in Appendix 1) are very diverse from the standpoint of what determines their production, demand and trade. Next sections analyze and present the historical experience and prospects for the main commodity groups.

Box 3.1 **Measuring change in agricultural aggregates**

An often posed question is by how much agricultural (or food) production must increase in the future to meet the demand generated by a growing population, income growth, etc. The figure 70 percent from average 2005/7 to 2050 has been widely quoted. It is important to realize what it means: when speaking of growth rates of aggregate agricultural production or consumption, it matters what units are used in the measurement of change, in particular whether quantities of the different commodities are just aggregated in physical units (e.g. tonnes – which can be done for commodity groups like cereals but not for summing up heterogeneous products such as cereals, meat, oranges, pumpkins, coffee, cotton, palm oil, etc) or aggregated after making them homogeneous by multiplying each quantity with an appropriate weighting factor and summing up. The weights often considered are food-specific calorie content of each commodity (e.g. kcal per kg.) or price. This study uses the international dollar prices of 2004/06 (the use of international dollar prices by FAO to compute the Production Index Numbers and the growth of aggregate production is explained in http://faostat.fao.org/site/375/default.aspx): the physical weight aggregation would not make sense and the same goes for calorie weights (non-food products have no food-specific calorie content, while high value commodities like tea, have virtually no calories – let alone raw materials like cotton, tobacco or rubber). Anyone interested in food and agriculture futures can use more meaningful metrics, e.g. tonnes of grain, of meat, food consumption per capita in terms of kg/person/year or kcal/person/day, yields, land use, etc.

With shifts in the commodity structure of production and consumption away from staples and towards higher value commodities, the price-based index of the volume of production or consumption grows faster than the aggregate in physical units, e.g. tonnes . For example, China's production of cereals grew from 1991-2007 at 0.4 percent p.a., that of meat at 4.9 percent. Both together in tonnage terms grew at 0.8 percent, but they grew at 2.4 percent when aggregated on the basis of their prices – given that the price of meat is almost ten times that of cereals in the price weights we use. Therefore, we should be aware that statements like "food production grew at x percent or that growth exceeded that of population or that production must increase by x percent in the future" do not necessarily imply that the quantities available for consumption increase by x percent but that the aggregate value of production increases. Similar considerations apply when food consumption quantities are aggregated with as weights their calorie content or, alternatively, prices. For example, China's food consumption per capita measured by the price-based volume index doubled from 1989/1991-2005/2007 but increased by only 16 percent in terms of calories. Analogous, though less pronounced, developments have characterized food consumption changes in other countries. In contrast, in countries or regions with little or virtually no diet diversification (e.g. sub-Saharan Africa), the volume of food consumption has grown at roughly the same rates in both measures.

At world level, demand growth for crop and livestock products is projected to be lower than in the past (Table 3.1), 1.1 percent p.a. in the period 2005/7-2050, half as large as in the historical period. The difference is in part due to the lower population growth of the future compared with the past (Table 2.3). This can be seen when the growth is expressed in terms the demand per capita (middle section of Table 3.1). It is mainly the slowing-down growth of demand in developing countries, and particularly in China, that accounts for a large part of the global deceleration. Why this should be so is shown in the more detailed regional numbers of Table 3.1. They show that the deceleration of the growth of demand per capita in the developing countries outside China is much less pronounced (from 0.8-0.9 percent p.a. in the past to 0.5 percent p.a. in the future – to 2050), an expected outcome given the operation of the factors mentioned earlier. The zero population growth rate of the developed countries from 2030-50 also contributes to the global slowdown of demand. The rather significant population declines of the Russian Federation and Japan, will impact international trade flows in commodities in which these countries are major importers, e.g. sugar and meat as indicated later in this Chapter.

A better idea about the roles of the above-mentioned factors making for deceleration, in particular the slowdown in the countries having attained higher consumption levels, can be obtained from the data and projections presented in Table 3.1. Countries with high per capita food consumption – over 2700 kcal/person/day in 2005/2007 face limited scope for increasing consumption. Those with less than 2700 kcal, instead, show higher potential. For the latter, very little decline in the growth rate of per capita consumption is expected: it is projected at 0.6 percent p.a., vs. 0.7-0.8 percent in the past. In contrast, there is a drastic decline in the growth rate of per capita consumption in the former group of countries. It is less pronounced, but still present, if China is excluded from this group.

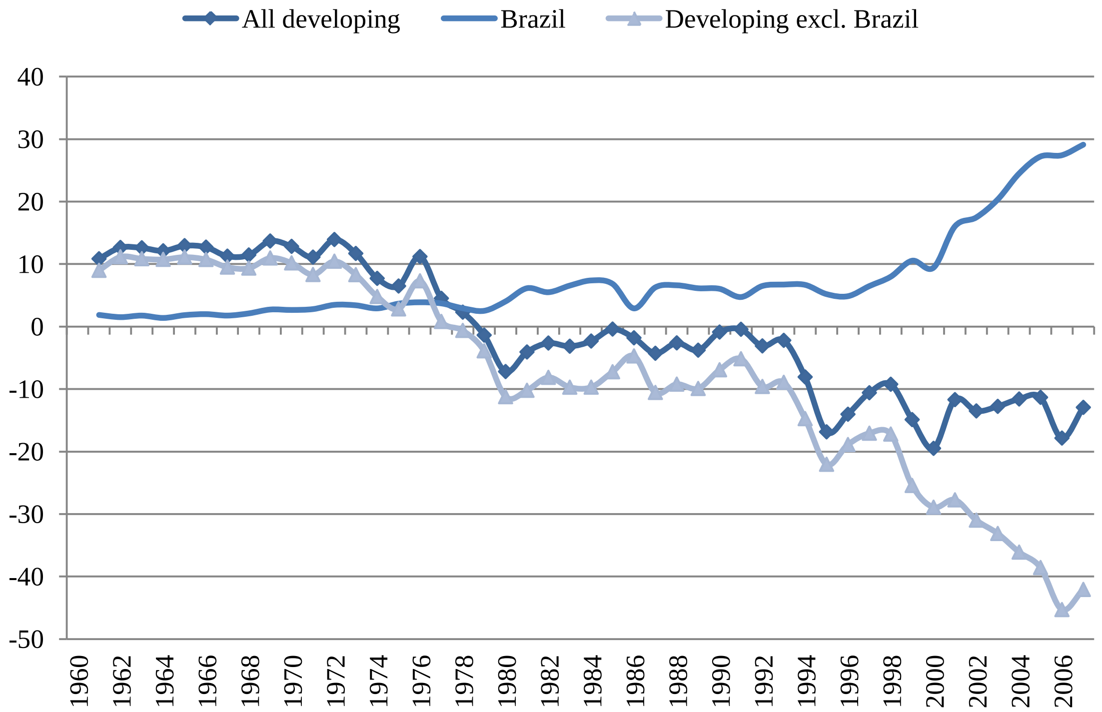
China's role is pivotal in the deceleration of demand compared with the past. Its star performance in increasing food consumption after the late 1970s meant that per capita consumption of the aggregate of all developing countries grew from 1980-07 at 1.7 percent p.a., but at only 0.8 percent if China is excluded. Such "China effect" disappears in the future as the country has already reached 2970 kcal/person/day in 2005/2007: there is much less scope for further growth compared with the past when the country had started with 2175 kcal in 1979/81. Likewise, there is much less scope for diet diversification towards the higher-value products (which increases the growth of the price weighted volume of consumption by more than it increases calories – see Box 3.1) compared with the early 1980s when China's food consumption was heavily concentrated in cereals and sweet potatoes and had little by way of livestock products. In conclusion, when such deceleration occurs in China and in a few other large developing countries, the whole aggregate of the developing countries, and indeed the world, will be affected downwards.

But would other developing countries experience similar spurts in consumption that counteract the deceleration caused by some major countries approaching saturation? There are many countries that have per capita food consumption similar or even lower than what China had in late 1970s before it started its take-off. As noted in Chapter 2 (Figure 2.7) several of these countries are projected to make significant gains. However, their weight in the aggregate of the developing countries is not large enough to change the aggregate result. India has the weight and the potential for fast growth in consumption: it starts with low per capita consumption and has good prospects of income growth. However, as seen (Annex 2.1) the country does not seem to play the role of prime mover as China did in the past. In conclusion, the prospect that China's influence will be much weaker in the future and that it will not be replaced by a similar boom in other large countries, is one of the major factors making for the projected deceleration in the aggregate demand of the developing countries and the world.

Production and Trade: At the world level production equals consumption, so the preceding discussion about global demand growth prospects applies also to that of global production. For the individual countries and country groups, however, the two growth rates can differ depending on movements in their net agricultural trade positions. In general, the growth rates of production in the developing regions have been a little below those of consumption (Table 3.1), as their agricultural imports have been growing faster than their exports, leading to gradual erosion of their traditional surplus in agricultural trade – this is the case for crop and livestock products, primary and processed, not including fishery and forestry products. The surplus has diminished and turned into a net deficit since the late 1970s. The deficit has levelled off after the mid-1990s. This reflected above all the extraordinary performance of Brazil's exports, mainly of oilseeds, livestock products and sugar, which generated a net agricultural surplus of $47 billion in 2008 at current prices, up from an average of $9-$10 billion ten years earlier. Excluding Brazil, the net balance of the other developing countries as a whole continued to precipitate (Figure 3.1). In the future, these trends may be attenuated, given that the slowdown in the growth of demand will lead to the net import needs of the developing countries growing less fast than in the past in the longer term, as shown in Figure 3.2. The growth rate of their production may no longer be lower than that of demand (Table 3.1). The commodity composition of such developments in trade is discussed in the subsequent sections of this Chapter for the major commodity groups.

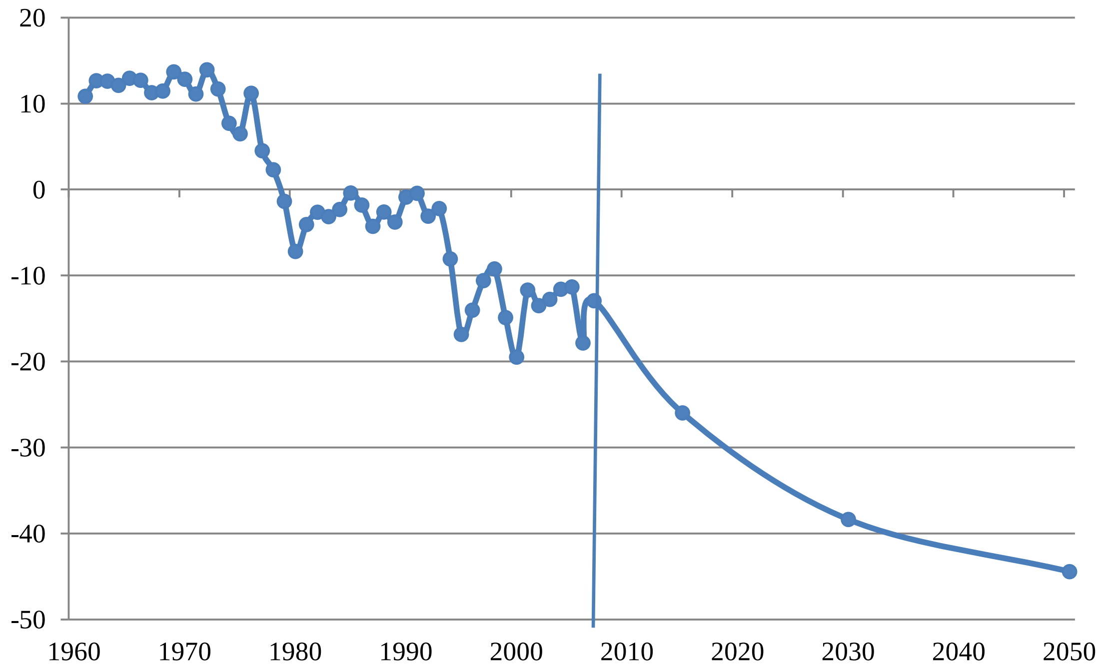
The net agricultural trade balance of developing countries is not an indicator of economic development. The aggregate of the developing countries is a composite of widely differing country and commodity situations. A growing deficit may indicate progress of non-agricultural activities and growing food consumption. The declining overall balance also reflects the rapid growth in such things as growing imports of vegetable oils (a positive development overall as they contribute to improve food consumption) or cotton imports into several developing countries, which sustain their growing exports of textiles. The same declining agricultural balance is a negative developmental outcome in countries where non-agricultural activities and the economy as a whole are stagnating, and where scarce foreign exchange resources need to be diverted to pay for growing food imports, eventually contributing to build unsustainable foreign debts. It is an even more negative indicator from the standpoint of human welfare when such food imports are not associated with rising food consumption per capita and improved food security, but are necessary just to sustain minimum levels of food consumption.

Figure 3. 1 Net agricultural trade of developing countries, 1961-2007 (billion 2004-06 ICP$)



* Commodities covered in this study valued as indicated in Box 3.1.

Figure 3.2 Net agricultural trade of developing countries, data and projections (billion 2004-06 ICP$)



* Commodities covered in this study valued as indicated in Box 3.1.

Table 3.1 Growth rates of demand and production, percent p.a.

	1970-2007	1980-2007	1990-2007	2005/2007-2030	2030-2050	2005/2007-2050
Demand (all commodities - all uses), total						
World	2.2	2.2	2.3	1.4	0.8	1.1
Developing countries	3.6	3.6	3.5	1.7	0.9	1.3
idem, excl. China	*3.1*	*2.9*	*2.8*	*1.9*	*1.2*	*1.6*
Sub-Saharan Africa	3.1	3.4	3.5	2.6	2.1	2.4
Near East/North Africa	3.3	2.8	2.8	1.7	1.1	1.5
Latin America and the Caribbean	2.8	2.6	2.6	1.7	0.6	1.2
South Asia	3.0	3.0	2.7	2.0	1.3	1.7
East Asia	4.3	4.4	4.4	1.4	0.5	1.0
idem, excl. China	*3.2*	*2.9*	*2.7*	*1.6*	*0.9*	*1.3*
Developed countries	0.5	0.3	0.4	0.6	0.2	0.5
Demand (all commodities - all uses), per capita						
World	0.6	0.6	0.9	0.4	0.3	0.3
Developing countries	1.6	1.7	1.9	0.5	0.4	0.5
idem, excl. China	*0.8*	*0.8*	*0.9*	*0.5*	*0.5*	*0.5*
Sub-Saharan Africa	0.2	0.6	0.8	0.3	0.5	0.4
Near East/North Africa	0.9	0.5	0.7	0.2	0.3	0.3
Latin America and the Caribbean	0.8	0.9	1.1	0.8	0.4	0.6
South Asia	0.9	0.9	0.8	0.8	0.8	0.8
East Asia	2.8	3.1	3.3	0.8	0.5	0.6
idem, excl. China	*3.2*	*2.9*	*2.7*	*1.6*	*0.9*	*1.3*
Developed countries	-0.1	-0.3	0.0	0.4	0.2	0.3
Developing countries, with under 2700 kcal/person/day in 2005/2007	*0.7*	*0.7*	*0.8*	*0.6*	*0.6*	*0.6*
Developing countries, with over 2700 kcal/person/day in 2005/2007	*2.3*	*2.5*	*2.7*	*0.7*	*0.4*	*0.5*
idem, excl. China	*1.1*	*1.1*	*1.1*	*0.5*	*0.3*	*0.4*
Production (all food and non-food commodities)						
World	2.1	2.1	2.2	1.3	0.8	1.1
Developing countries	3.5	3.5	3.4	1.6	0.9	1.3
idem, excl. China	*2.9*	*2.9*	*2.9*	*1.8*	*1.2*	*1.5*
Sub-Saharan Africa	2.7	3.2	3.1	2.5	2.1	2.3
Near East/North Africa	3.0	2.8	2.6	1.6	1.2	1.4
Latin America and the Caribbean	2.9	2.9	3.5	1.7	0.8	1.3
South Asia	3.0	2.9	2.5	1.9	1.3	1.6
East Asia	4.2	4.2	4.1	1.3	0.5	0.9
idem, excl. China	*3.1*	*2.7*	*2.7*	*1.5*	*0.9*	*1.3*
Developed countries	0.6	0.2	0.3	0.7	0.3	0.5

Concerning production, at global level sufficient production potential can be developed for meeting the expected increases in effective demand in the course of the next five decades. As noted, the required growth rate of global production will be lower than in the past. Even this growth may not materialize unless promoted through active interventions. This requires continued support to agricultural research and policies and other conditions such as the provision of education, credit and infrastructure, to make it profitable for farmers to expand production capacity. That there is scope for increasing global production is not to say that all people will be food-secure in the future. Far from it, as Chapter 2 has shown.

The interaction between food security and food production potential is very much a local problem in poor and agriculturally-dependent societies. Many situations exist where production potential is limited and a good part of the population depends on such poor agricultural resources for food and more general livelihood. This is the case, for instance, of semi-arid areas with poor access to technologies and infrastructures. Unless local agriculture is developed and/or other income earning opportunities open up, the food insecurity determined by limited local production potential will persist, even in the middle of potential plenty at the world level. The need to develop local agriculture in such situations as the condition *sine qua non* for improved food security cannot be overemphasized.

3.2 Cereals

In our previous work we highlighted that the growth rate of global demand for cereals shows a progressive fall until 2007. Our earlier projections concluded that such deceleration would continue, but that the global expected absolute increases still represented a significant quantum jump to 3 billion tonnes by 2050.

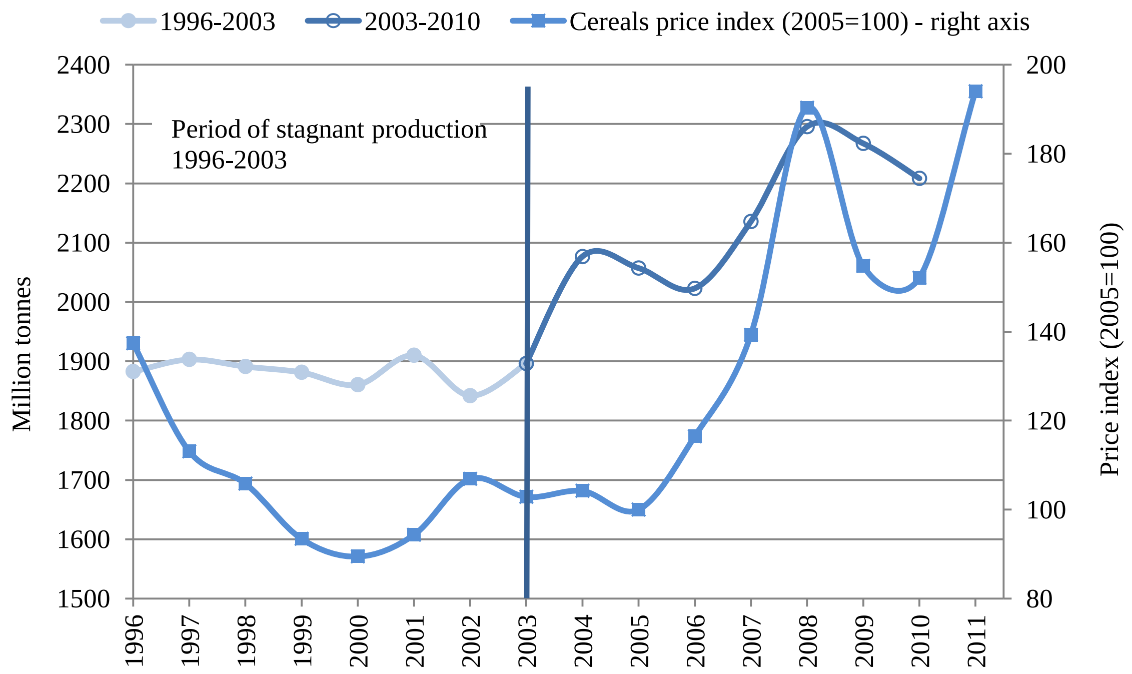
Our new projections confirm the 3 billion tonnes for 2050 – an increase of 940 million from the base year 2005/2007. Almost all the increases in the consumption of cereals will come from the developing countries, particularly after 2020 when use of cereals for biofuels is assumed to peak at 180 million tonnes.

The developing countries surpassed developed ones in total cereals consumption in the early 1980s and account now for 61 percent of world consumption, a share that will increase to 67 percent by 2050. They also surpassed them in total production in the early 1990s: they now account for 56 percent of world production and the share will increase to 60 percent in 2050.

It is noted, however, that the last few years (from 2003) have witnessed a reversal of trends in the growth rate of world cereals production: taking account of the latest estimates for 2010, the growth rate for the seven-year period 2003-10 was 2.3 percent p.a., up from -0.1 percent p.a. in the preceding equal period (1996-2003), during which world production was virtually stagnant as prices were low and major countries were running down stocks, with China playing a major role in these developments: the country started running down the huge stocks it had accumulated in the 1990s (closing stocks of 309 million tonnes in 1999, 84 percent of annual consumption, falling to 148 million tonnes by 2005, 40 percent of consumption[43]). The reduction of stocks, weather shocks, loose monetary policy, the decline in the dollar and the spurt in demand caused by the biofuels set the stage for the rising prices of 2007-08 (see Alexandratos, 2008) and the resumption of production growth – with a vengeance, in subsequent years. The acceleration of the most recent period was therefore largely a rebound from the long period of stagnation. (Figure 3.3).

[43] Problems associated with China's huge stocks accumulated by the late 1990s included overflowing granaries and losses due to quality deterioration as well as large financial losses from sales (domestic and export) at below-cost prices. These problems prompted policy reforms to reduce stocks. They included some relaxation of the policies that obliged farmers to produce cereals (OECD, 2005:37; see also USDA, 2001).

Figure 3.3 World cereal production 1996-2010 (million tonnes) and prices



Source: Production, FAOSTAT (March2012). Price Index: World Bank, Commodity Price Data (Index from prices at constant dollars of 2005).

The issue is whether the recent acceleration of world production growth requires that we revise our views that the world is set on a path of gradual slowdown. The answer is no, unless the biofuels sector experiences further significant spurts in the use of cereals as feedstocks well over and above what we have assumed for up to 2020. But the recent experience is a useful indication that, within certain limits and barring weather or other shocks, world production responds to the growth of demand

A digression is in order here: we said above that the projected 3 billion tonnes for 2050 of world cereals production we had in the earlier study is virtually the same as we obtain in the present country by country projections. However, the latter now include an allowance of 180 million tonnes for biofuels (Annex 3.1). The earlier projections did not make an explicit allowance, since biofuels were a minor item in the base year 1999/2001 (16 million tonnes of maize in the United States of America, now increased to 127 million tonnes in 2010). However, they did include an allowance for the generic non-food industrial uses based on historical data in which the use for biofuels was supposedly included. In conclusion, our reconfirmation of the 3 billion tonnes projection implies that food and non-food uses of cereals (other than for biofuels) are now projected to be lower than in the earlier projection. Why this is so, is explained below.

- Food use is virtually the same as in the previous projections, with the higher projected population for 2050 (9.1 billion vs. 8.9 billion used in FAO, 2006) compensating for the lower projected per capita consumption (160 kg vs. 162 kg – Table 3.1). The latter is now lower because it was drastically revised in the historical data for the base year 99/01 of the previous projections for the developing countries average from 166 kg to 157 kg (see Table 2.5).

- Feed use of cereals is projected to be lower in 2050 than projected previously, for two reasons: (a) lower meat production (see section on Livestock, below) and (b) part of the feed needs will be covered by by-products of the biofuels industry[44]. These are also the main reasons why projected net cereal import requirements of the developing countries (see below) are lower than in the earlier projections.

Table 3.2 Cereal balances, world and major country groups

	Demand						SSR[a] %	Growth rates percent p.a.			
	Per capita (kg)		Total (million tonnes)								
	Food	All uses	Food	All uses	Production	Net Trade		Period	Demand	Production	Population
	1	2	3	4	5	6	7	8	9	10	11
World											
1969/1971	144	304	530	1 117	1 118	-3	100	1961-2007	2.0	1.9	1.7
1979/1981	153	325	678	1 438	1 442	-4	100	1971-2007	1.6	1.5	1.6
1989/1991	161	321	848	1 695	1 732	6	102	1981-2007	1.3	1.2	1.5
2005/2007	158	314	1 035	2 060	2 068	1	100	1991-2007	1.3	1.2	1.3
2030	160	329	1 324	2 719	2 720	1	100	2005/2007-2030	1.2	1.2	1.0
2050	160	330	1 454	3 008	3 009	1	100	2005/2007-2050	0.9	0.9	0.7
Developing countries											
1969/1971	140	193	363	501	483	-25	96.4	1961-2007	2.9	2.7	2.1
1979/1981	152	219	496	713	649	-73	91.1	1971-2007	2.6	2.4	1.9
1989/1991	160	229	644	919	868	-86	94.5	1981-2007	2.1	2.0	1.8
2005/2007	155	242	809	1 262	1 164	-116	92.3	1991-2007	1.8	1.6	1.6
2030	159	254	1 085	1 740	1 572	-168	90.4	2005/2007-2030	1.3	1.3	1.1
2050	158	262	1 215	2 008	1 812	-196	90.2	2005/2007-2050	1.1	1.0	0.9
Developed countries											
1969/1971	155	571	167	616	635	22	103	1961-2007	1.0	1.2	0.7
1979/1981	156	620	183	725	793	69	109	1971-2007	0.5	0.7	0.6
1989/1991	162	618	204	777	864	93	111	1981-2007	0.2	0.3	0.5
2005/2007	167	591	226	798	904	118	113	1991-2007	0.5	0.6	0.4
2030	166	682	239	979	1 148	169	117	2005/2007-2030	0.9	1.0	0.3
2050	166	695	239	999	1 197	197	120	2005/2007-2050	0.5	0.6	0.1

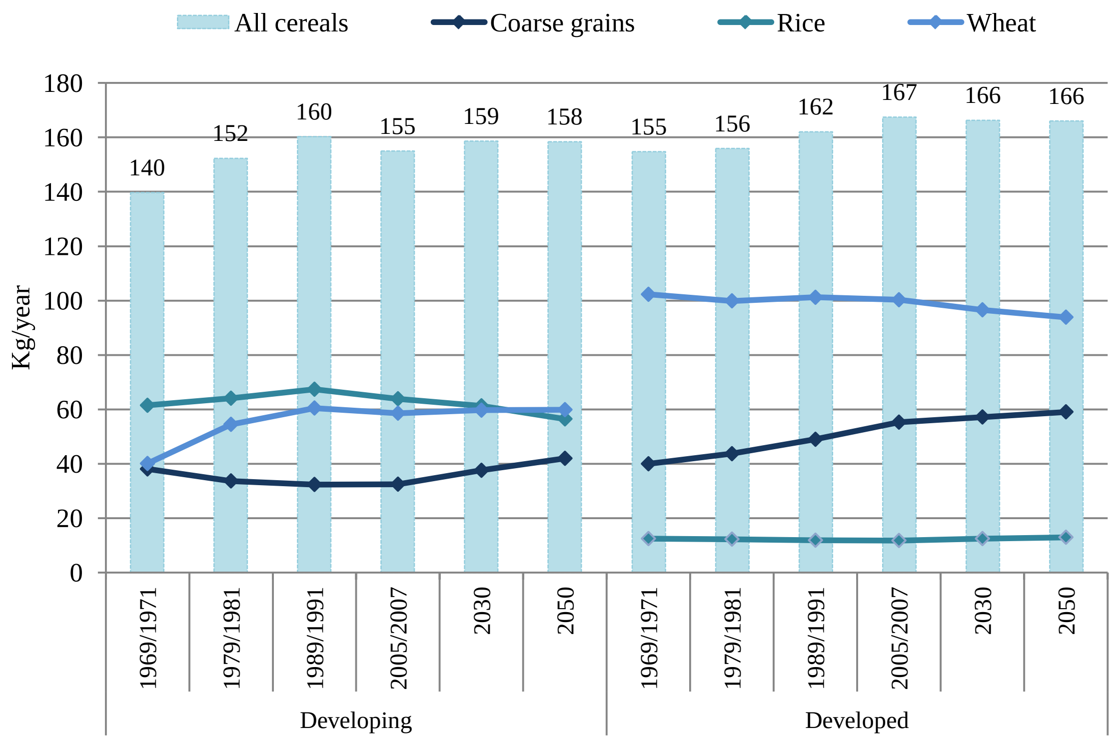
[a] SSR = Self Sufficiency Rate = production / demand.

[44] About 30 percent of the maize processed into ethanol is returned to feed sector in the form of by-products, mainly DDGs.

Individual cereal commodities and categories of use

For ***rice,*** world average per capita food consumption has levelled off after the late 1980s, following mild declines in several countries of East and South Asia and small increases in other regions. These trends are projected to continue and the average of the developing countries may fall from the present 64 kg to 57 kg in 2050 (Figure 3.4).

Figure 3.4 Per capita food consumption: wheat, rice, coarse grains and all cereals



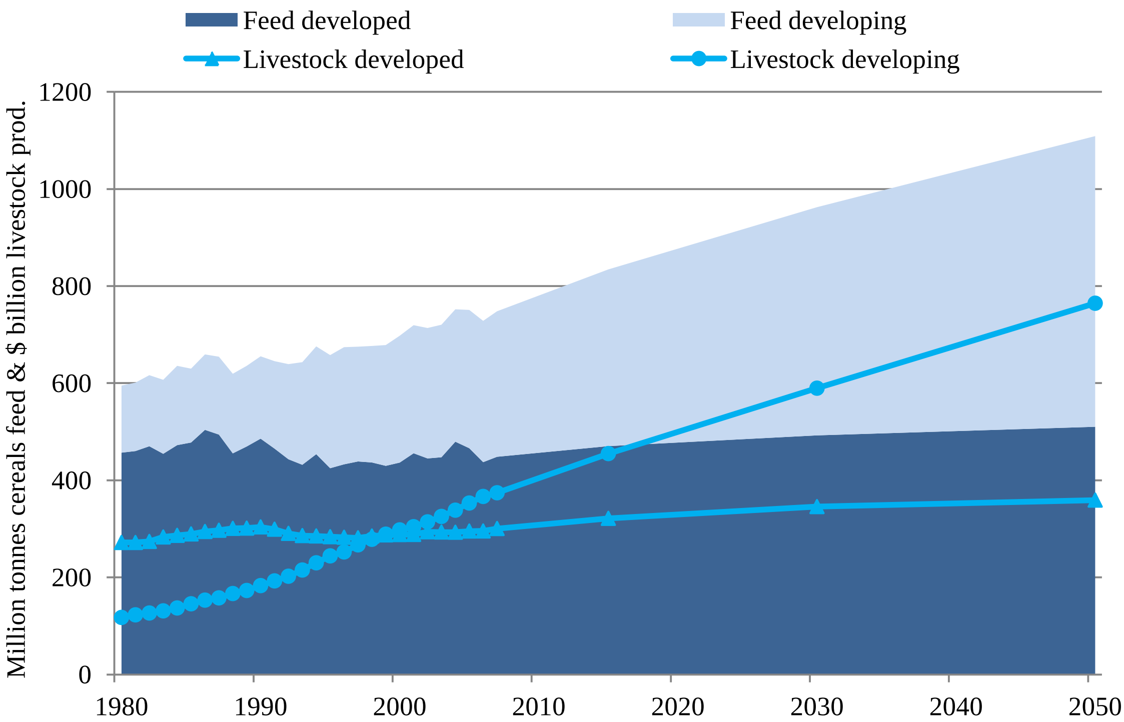
Concerning **wheat**, the per capita food consumption has also tended to level off in both the developing and the developed countries. Some decline in the world average is projected, reflecting small declines in the developed countries and only small increases in the developing ones. The latter would be the result of declines in China and the Near East/North Africa region which would compensate for the increases in most other developing countries.

Food consumption of **coarse grains** is the mainstay of diets in several countries, particularly in sub-Saharan Africa for products such as maize, millet, sorghum, but also teff in Ethiopia. The somewhat optimistic assessment of production prospects, already evident in the last few years, could lead to an increase in per capita food consumption of these grains in the region and lift the average for the developing countries. The developed countries may witness some increase in barley consumption in the form of beer, but not in maize, the other coarse grain consumed as food, including – mainly in the United States of America – in the form of corn syrup[45].

[45] Figure 3.4 shows an increase in the developed countries average food consumption of coarse grains, though all countries are projected to have some decline. This is another optical illusion of the Simpson paradox (see Box 2.3), because the USA which has the highest per capita food consumption of maize (including the part consumed as corn syrup) increases substantially its share in the group's population, from 23 percent to 28 percent over the projection period.

About 36 percent of world consumption of cereals goes to **feed**, the bulk of it **coarse grains**. The developed countries account for most of such use of coarse grains, but the developing ones are catching up: they now account for 42 percent of the world total, up from 30 percent ten years ago. They will continue to increase their share in world feed consumption of coarse grains, up to 56 percent by 2050, as their livestock sector grows; that of the developed countries, instead, will not increase much (Figure 3.5). The developing countries have already surpassed the developed countries in meat production and they will do so also for milk in the next decade or so. As a consequence, there is little growth in prospect for feed use in the developed countries, but non-food uses of coarse grains will likely grow as the biofuels sector expands. Our provisional projection for biofuels (Annex 3.1) indicates that some 180 million tonnes of cereals (mostly maize) may be so used in the developed countries by 2020, up from 61 million tonnes in the base year (average 2005/2007) and an estimated about 135 million tonnes in 2010.

Figure 3.5 Cereals feed (million tonnes) and livestock production ($ billion)



* Volume of production obtained as quantities times constant price of 2004/06 of individual livestock products, same price in all countries.

Cereals trade projections

Table 3.2 shows the projected net cereals imports of the developing countries and indicated that the self-sufficiency rates, measured as production in percent of domestic use, would fall marginally from 92 percent at present to 90 percent. The developing countries as a group would continue to be growing net importers, but the rate of expansion would be much smaller than in the past. Their net imports almost quintupled since the early 1970s: they may increase 70 percent by 2050. The slowdown in the growth of demand will make it easier for them to meet it from domestic production, which itself will be slowing down. The net import requirements of the net importer developing countries are partly compensated by net exporters. There are nine developing countries with over 1 million tonnes net exports each in 2005/2007.[46] Not all of them are likely to remain net exporters by 2050 (e.g. China, Turkey), but new ones would become net exporters (Brazil, Cambodia, Myanmar). For the developing countries as a whole, the slowdown in the growth of net imports and the near constancy of the self-sufficiency rate (graphed in Figure 3.6) is the net result of the varying performances of the two groups, net importers and net exporters (see also Figure 1.5).

Figure 3.6 Cereals self-sufficiency rates and net imports

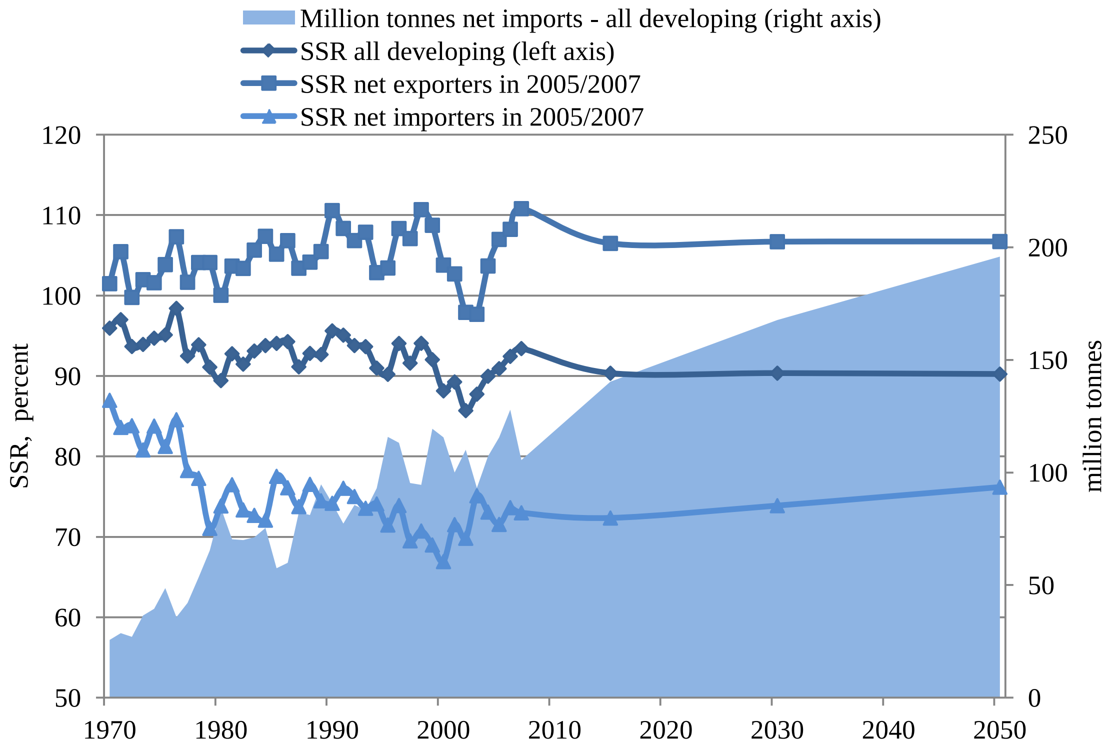


Table 3.3 shows the net trade balances of wheat, rice and coarse grains of the developing countries by region. Wheat will continue to account for about one half of total net imports and rice will continue to be a minor item, since much of the rice trade is between the developing countries (naturally, rice trade between the exporting and importing developing countries will continue to grow, no matter that the net balance of the developing countries will remain nearly constant).

The net cereals exports of the developed countries are the mirror image of the deficits of the developing countries, as shown in Table 3.3. The traditional developed exporters will continue to supply the required surplus with the major supplier (the United States of America) loosing share in favour of the new ones (Russian Federation, Other Eastern Europe), while the EU27 may maintain its status as net cereals exporter, but it is unlikely to revert to being the significant net exporter it was in the past. On the import side, Japan will remain the major player followed by Israel.

[46] They are in ascending order: Uruguay, Turkey, Paraguay, Viet Nam, Pakistan, India, China, Thailand and Argentina.

Table 3.3 Net trade balances, wheat, rice, coarse grains, developing countries by region (million tonnes)

	1969/ 1971	1979/ 1981	1989/ 1991	1999/ 2001	2005/ 2007	2030	2050
Developing countries*							
Wheat	-30.5	-55.9	-59.8	-63.4	-67.0	-95	-113
Rice	-0.9	-1.7	-0.1	1.6	4.0	5	5
Coarse grains	6.5	-15.8	-26.3	-50.0	-53.4	-78	-88
All cereals	**-25.0**	**-73.4**	**-86.2**	**-111.7**	**-116.4**	**-168**	**-196**
Sub-Saharan Africa							
Wheat	-6.6	-9.4	-4.5	-8.7	-12.7	-22	-33
Rice	-0.6	-2.3	-2.8	-4.7	-6.9	-12	-15
Coarse grains	-0.3	-1.8	-0.9	-2.3	-3.7	-7	-8
All cereals	**-7.5**	**-13.6**	**-8.2**	**-15.7**	**-23.4**	**-42**	**-56**
Near East/North Africa							
Wheat	-6.4	-17.1	-23.2	-27.0	-22.1	-37	-41
Rice	0.2	-1.3	-2.0	-3.4	-3.3	-6	-7
Coarse grains	-0.5	-5.9	-9.5	-21.9	-27.2	-48	-66
All cereals	**-6.6**	**-24.3**	**-34.6**	**-52.2**	**-52.6**	**-91**	**-114**
Latin America							
Wheat	-3.9	-7.1	-3.6	-7.4	-7.0	-4	-1
Rice	0.0	-0.5	-1.0	-1.0	-1.2	-0	1
Coarse grains	7.4	-0.6	-6.9	-9.8	-8.0	9	26
All cereals	**3.5**	**-8.2**	**-11.4**	**-18.2**	**-16.3**	**5**	**25**
South Asia							
Wheat	-4.4	-3.1	-3.9	-3.3	-5.8	-5	-6
Rice	-0.9	1.3	0.8	2.8	7.4	5	6
Coarse grains	-0.2	0.0	-0.1	-0.4	1.2	-1	-0
All cereals	**-5.5**	**-1.7**	**-3.2**	**-0.9**	**2.7**	**-0**	**0**
East Asia							
Wheat	-8.8	-18.3	-23.1	-14.9	-17.3	-23	-28
Rice	0.5	1.5	5.4	9.1	9.4	19	22
Coarse grains	0.2	-7.2	-8.5	-14.7	-14.5	-29	-35
All cereals	**-8.1**	**-23.9**	**-26.2**	**-20.5**	**-22.4**	**-33**	**-41**

* Includes net imports of other small developing countries with FBS data, not included in the regional totals.

3.3 Livestock commodities

3.3.1 Past and present

Livestock, a major factor in the growth of world agriculture. The world food economy is being increasingly driven by the shift of diets and food consumption patterns towards livestock products. Some use the term "livestock revolution" to refer to these trends (Delgado *et al.*, *2001*). In developing countries, where almost all world population increases take place, consumption of meat has grown at an average rate of 5.1 percent p.a. since 1970 (Table 3.4), that of milk and dairy products at 3.6 percent p.a. (Table 3.5). However, growth rates have been on the decline: meat was growing at 2.9 percent between 1997 and 2007, down from 6.1 percent in the preceding ten years. Aggregate agricultural output is being affected by these trends, not only through the growth of livestock production proper, but also through the linkages of livestock production to the crop sector which supplies the feeding stuffs, mainly cereals and oilseed products.

On the negative side, and in association with policy distortions or market failures, there are environmental implications associated with the expansion of livestock production. For example, through the expansion of land for livestock development, livestock sector growth has been a prime force in deforestation in some countries such as Brazil, and in overgrazing in other countries. Intensive livestock operations on industrial scale, mostly in the industrial countries but increasingly in the developing ones, are a major source of environmental problems through the production of point-source pollution such as effluents. In parallel, growth in the ruminant sector contributes to greenhouse gas concentrations in the atmosphere through methane emissions and nitrous oxide from the waste of grazing animals[47].

Important exceptions and qualifications. The strength of the livestock sector as the major driving force of global agriculture can be easily exaggerated. Many developing countries and regions, where the need to increase protein consumption is the greatest, are not participating in the process. There are 23 developing countries (out of the 98 analysed individually) having under 10 kg per capita consumption of meat and another 24 with between 10 and 20 kg. Of these 47 countries 17 (including India – but see Chapter 2, Annex 2.1) have currently consumption levels lower than at the beginning of the 1990s. Therefore, the phenomenon of rising meat consumption in the world is less widespread than first impressions from the aggregates would lead one to believe. It is just that per capita consumption has been growing rapidly in a number of large countries, China and Brazil among them, and this has pulled up the average of the developing countries and the world (see Table 2.5 and discussion in Chapter 2). Thus, the growth rate of meat consumption of 4.9 percent p.a. in the developing countries in the last three decades is reduced to 3.3 percent p.a. if China and Brazil are excluded from the developing country totals (Table 3.4). This is not to deny that meat and other livestock products are preferred foods in most countries and that demand grows rapidly when incomes increase, at least in most countries. It is just that there is less of a meat revolution than commonly asserted, mainly because of lack of development and income growth in many countries. In addition, cultural and religious factors have also stood in the way of wider diffusion of consumption of meat in general in some countries (India) or of particular meats (beef in India, pork in the Muslim countries).

For milk and dairy products, there has also been a mild ‘China effect’, but only in the last few years as the country’s per capita consumption almost quadrupled in the last ten years, though it remains modest at 26 kg in 2005/2007. Rapid growth in per capita consumption will continue for some time.

Rapid growth has instead taken place, in poultry**.** Perhaps the perception of revolutionary change in the meat sector reflects the extraordinary performance of world production and consumption of poultry meat. Production grew at 5.0 percent p.a. since 1970 vs. 2.8 percent for total meat (Table 3.4) and its share in world meat production increased from 15 percent to 32 percent currently. Per capita consumption increased three-fold over the

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[47] A study puts the problem as follows: “In 1964, half of all beef cows in the United States were on lots of fewer than 50 animals. By 1996, nearly 90 percent of direct cattle feeding was occurring on lots of 1,000 head or more, with some 300 lots averaging 16,000-20,000 head and nearly 100 lots in excess of 30 thousand head. These feedlots represent waste management challenges equal to small cities, and most are regulated as point-source pollution sites under the authority of the US Environmental Protection Agency (EPA)” (Commission for Environmental Cooperation-NAFTA, 1999: 202). See also de Haan *et al.* (2006) and, for the thesis that environmental impact has been declining if measured per unit of output, though not for the sector as a whole, see Capper *et al.* (2009).

same period. That of pork also increased from 9.7 kg to 15 kg (China's statistics helping, but hardly at all for the world without China). In contrast, per capita consumption of ruminant meat (from cattle, sheep and goats) actually declined a little. The growth of the poultry meat sector reflected, in addition to the more favourable expansion possibilities of industrial production and the lower feed requirements per kg of meat, also the substitution for other meats in consumption, essentially beef, in the countries with already medium-high levels of total meat consumption, e.g. several major producers and often exporters of beef in Latin America, North America, Oceania and the EU. For other countries, it was part of the more general thrust towards rapidly growing consumption of meat, e.g. several countries in the regions East Asia and Near East/North Africa. Brazil is an example of fast growth in all aspects of the meat economy, with significant increases in production, consumption and exports of beef, poultry and pork.

Buoyancy of meat trade in recent years. The rapid growth in consumption of several countries was supported by even faster growth in trade. Some drastic changes occurred in the sources of exports and destination of imports. For example, Japan increased per capita meat consumption from 29 kg in 1979/81 to 45 kg in 2005/2007, an increase of 2.3 million tonnes. All this increase was met by imports, which grew almost 6-fold over the period, while production remained essentially constant. Another major developed importer is the Russian Federation. On the side of the developing countries, the major importers are Mexico, Hong Kong, Saudi Arabia and the Republic of Korea. The major developing exporters include Brazil which has become the largest world exporter by increasing net exports more than 10-fold since the early 1990s; followed by Argentina. The major developed exporters are the United States of America, Australia, Canada, New Zealand and the EU.

Dairy products. The growth of world milk production and consumption[48] has been less buoyant than that of meat. World per capita consumption is currently 83 kg, up from 77 kg 30 years ago. All of the increase in per capita consumption came from the developing countries (from 37 kg to 52 kg), with China playing a major role in the last few years. The developing countries continue to have per capita consumption well below that of the industrial countries (partly reflecting the consumption habits of East Asia, though this is changing rather rapidly, as well as low incomes and poverty in many other countries), but they are gradually reducing the distance, although not all countries/regions are participating in these increases (Table 2.5). Consumption in Asia (both South and East Asia) grew the fastest and accounts for a good part of the gains in the developing countries (Table 3.5). The lack of progress in continuing to raise per capita consumption and reversal of past gains in many countries, particularly in sub-Saharan Africa and the Near East/ North Africa region, is partly associated with the levelling off in the 1980s and subsequent reduction of subsidized exports from the EU.

[48] In our data system all dairy products (e.g. cheese, milk powder, etc, but excluding butter which is part of the animal fats in the food balance sheets) are converted into liquid milk equivalent. Perhaps these conversions of data for so many final products are partly responsible for the fact that the world trade shows a large statistical discrepancy for 2005/2007 (Table 3.5), with world exports being 91000 thousand tons and imports 85000.

Table 3.4 Meat: aggregate production and demand

	Production							Consumption						
	2005/ 2007	1961-2007	1971-2007	1981-2007	1991-2007	2005/ 2007-2030	2005/2007-2050	2005/ 2007	1961-2007	1971-2007	1981-2007	1991-2007	2005/ 2007-2030	2005/ 2007-2050
	'000 t	Growth rates, % p.a.						'000 t	Growth rates, % p.a.					
World														
Bovine	63 583	1.5	1.2	1.0	0.9	1.3	1.2	62 321	1.5	1.1	1.0	0.9	1.3	1.2
Ovine	12 876	1.7	2.0	1.9	1.6	1.6	1.5	12 670	1.7	2.0	2.0	1.8	1.7	1.5
Pig meat	99 917	3.1	2.9	2.6	2.3	1.2	0.8	99 644	3.1	2.9	2.6	2.3	1.2	0.8
Poultry meat	81 994	5.2	5.0	4.8	4.4	2.1	1.8	81 545	5.1	4.9	4.7	4.4	2.1	1.8
Total meat	258 370	2.9	2.8	2.7	2.4	1.5	1.3	256 179	2.9	2.7	2.6	2.5	1.6	1.3
Developing countries														
Bovine	34 122	2.9	3.1	3.2	3.0	2.0	1.8	31 975	3.1	3.2	3.1	2.7	2.2	1.9
Ovine	9 462	3.1	3.5	3.6	3.4	1.9	1.7	9 695	3.3	3.5	3.5	3.3	2.0	1.8
Pig meat	60 483	5.7	5.6	5.0	3.7	1.5	1.1	60 584	5.6	5.6	5.0	3.7	1.6	1.1
-excl. China	15 504	3.9	3.8	3.7	3.5	2.0	1.7	16 053	3.8	3.8	3.7	3.6	2.1	1.8
Poultry meat	44 880	7.4	7.6	7.6	6.4	2.8	2.4	44 543	7.3	7.4	7.2	6.2	2.9	2.4
Total meat	148 946	4.8	5.1	5.0	4.2	2.1	1.7	146 797	4.9	5.1	4.9	4.1	2.2	1.8
-excl. China	80 660	3.7	3.9	3.8	3.7	2.3	2.1	78 958	3.8	3.9	3.6	3.4	2.5	2.2
-excl. China and Brazil	59 957	3.3	3.4	3.2	3.0	2.6	2.4	64 357	3.6	3.6	3.3	3.3	2.7	2.4
Total meat by region														
Sub-Saharan Africa	6 802	2.5	2.4	2.5	3.0	2.9	2.9	7 334	2.8	2.8	2.7	3.4	3.2	3.0
Near East/ North Africa	8 918	4.5	4.7	4.3	3.9	2.4	2.2	10 292	4.3	4.1	3.1	3.7	2.7	2.3
Lat. Amer. and Caribbean	40 585	3.7	3.9	4.1	4.5	1.7	1.3	34 557	3.8	3.9	3.9	3.6	1.7	1.3
-excl. Brazil	19 882	2.6	2.7	2.7	3.1	1.9	1.6	19 955	3.1	3.1	3.1	3.4	2.0	1.6
South Asia	7 180	2.8	2.8	2.3	1.6	4.4	4.0	6 685	2.6	2.6	2.1	1.2	4.5	4.2
East Asia	85 121	6.5	6.6	6.3	4.5	1.9	1.4	86 806	6.5	6.6	6.4	4.7	1.9	1.4
-excl. China	16 834	4.7	4.7	4.3	3.2	2.3	2.1	18 967	4.8	4.9	4.6	3.7	2.4	2.0
Developed countries	109 424	1.6	1.1	0.7	0.6	0.7	0.5	109 382	1.5	1.0	0.7	0.7	0.6	0.4

Memo items: cereals feed use vs. livestock production	2005/ 2007	1961-2007	1971 -2007	1981-2007	1991-2007	2005/ 2007-2030	2005/ 2007-2050
World livestock production[1]		2.2	2.1	2.0	2.1	1.4	1.2
- cereals feed (million tonnes)	742	1.8	1.1	0.8	1.0	1.1	0.9
Developing countries livestock production)[1]		4.3	4.6	4.6	4.1	2.0	1.7
- cereals feed (million tonnes)	292	4.2	3.6	3.1	2.7	2.0	1.6
Developed countries livestock production)[1]		1.0	0.5	0.1	0.2	0.6	0.4
-cereals feed (million tonnes)	450	1.0	0.1	-0.3	0.2	0.4	0.3

[1] Growth rates of aggregate production derived by valuing all products (meat, milk, eggs) at 2004/06 international prices (see Box 3.1).

Table 3.5 Milk and dairy products (liquid milk equivalent)

	Production						
	2005/ 2007	1961-2007	1971-2007	1981-2007	1991-2007	2005/ 2007-2030	2005/ 2007-2050
	Million	Growth rates, % p.a.					
World	664	1.4	1.3	1.1	1.6	1.3	1.1
Developing countries	305	3.5	3.7	3.9	4.2	2.1	1.8
Sub-Saharan Africa	22	2.7	2.9	2.7	3.5	2.4	2.3
Near East/North Africa	36	2.3	2.4	2.6	3.1	1.9	1.7
Latin America and the Caribbean	71	2.9	2.7	3.0	3.3	1.7	1.3
South Asia	135	4.0	4.4	4.4	4.1	2.3	2.0
East Asia	42	6.6	7.7	7.9	9.5	2.2	1.5
Developed countries	358	0.5	0.2	-0.3	0.0	0.5	0.3
Consumption (all uses)							
World	657	1.4	1.3	1.1	1.6	1.3	1.1
Developing	324	3.5	3.6	3.6	3.9	2.1	1.7
Sub-Saharan Africa	24	2.8	2.6	2.3	3.5	2.5	2.3
Near East/North Africa	41	2.6	2.4	2.0	2.8	1.9	1.6
Latin America and the Caribbean	72	2.8	2.6	2.6	2.6	1.5	1.1
South Asia	135	4.0	4.4	4.3	4.1	2.3	2.0
East Asia	50	5.9	6.5	6.7	7.9	2.2	1.5
idem excl. China	*14*	*5.0*	*4.6*	*4.0*	*3.0*	*2.3*	*1.8*
Developed countries	333	0.4	0.1	-0.4	-0.1	0.5	0.3
Net trade (thousand tonnes)							
		1969/ 1971	1979/ 1981	1989/ 1991	2005/ 2007	2030	2050
World (stat. discrepancy)		2 408	1 666	-1 638	5 765	5 750	5 800
Developing		-7 357	-17 686	-18 130	-19 357	-26 160	-25 320
Sub-Saharan Africa		-913	-2 493	-1 787	-2 605	-5 680	-7 270
Near East/North Africa		-1 078	-4 801	-5 523	-5 070	-7 870	-7 120
Latin America and the Caribbean		-2 313	-4 938	-4 976	-1 793	3 880	6 640
South Asia		-610	-1 052	-870	-153	-1 020	-620
East Asia		-2 129	-3 653	-4 173	-8 026	-13 670	-14 810
Developed countries		9 765	19 351	16 492	25 122	31 910	31 120

3.3.2 Prospects for the livestock sector

Slower growth in world meat consumption. The forces that shaped the rapid growth of meat demand in the past are expected to weaken considerably in the future. Slower population growth is an important factor. Perhaps more important is the natural deceleration of growth because fairly high consumption levels have already been attained in the few major countries that dominated past increases. As noted, China went from 14 kg/year in the early 1970s to the 52 kg currently, according to its production statistics which form the basis of the Food Balance Sheets. If it were to continue at the same rate, it would soon surpass the developed countries in per capita consumption of meat, an unreasonable prospect given that China will still be a middle income country with significant parts of its population rural and in the low-income category for some time to come. As another example, Brazil's went from 40 kg to 78 kg over the same period: the scope is rather limited for the rapid increases of the past to continue unabated through the coming decades.

The next question is whether any new major developing countries with presently low meat consumption will emerge as major growth poles in the world meat economy. *India* with its huge population and very low meat consumption could in theory dominate developments if it shifted massively to consuming meat. It is recalled that India is expected to rival China in population size by 2030 (both 1.47 billion) and surpass it by a good margin by 2050 (1.61 billion vs. 1.42 billion). India's meat consumption is very low –currently 3.1 kg per capita according to the food balance sheets (somewhat lower than in the past), but this could an underestimate.

Can India play the role China has had so far in raising world meat demand? In Chapter 2 (Annex 2.1) we have discussed the Indian "puzzle" of low and falling per capita food consumption in a period of high growth in incomes. We projected per capita meat consumption to increase to 18 kg by 2050, most of it poultry. This is on the assumption that India's participation in the global upsurge of the poultry sector, being at its incipient stage, has still a long way to go[49]. Consumption of other meats will probably grow by much less, with beef and pork being subject to cultural constraints for significant parts of the population of India and indeed the whole of South Asia. In parallel, consumption of the preferred mutton/goat meat faces production constraints, implying rising real relative prices compared with poultry meat[50]. This kind of growth in meat consumption will perhaps be viewed as revolutionary in a national context, since it would raise the very low intake of animal protein in the country's diet, though India would still be a predominantly vegetarian society by international standards[51]. However, it will be far from having an impact on world averages and those of the developing countries anywhere near that which was exerted in the historical period by developments in China.

In conclusion, the per capita meat consumption in the developing countries is likely to grow at much slower rates than in the past, mainly because the great push given in the past by China and Brazil to consumption growth will not be playing the same role in the future, with the result that the aggregate meat consumption of the developing countries may grow in the next thirty years half as rapidly as in the preceding three decades (Table 3.4). However, per capita consumption in the rest of the developing countries should continue rising and even accelerate, as shown in Table 2.5.

Per capita meat consumption in the *Developed countries* suffered a sharp decline in the 1990s following the systemic change in the formerly centrally planned economies of Europe. It was 81 kg in 1990, fell to 75 kg in the mid-90s and then gradually recovered to the 80 kg at present. The average of the developed countries is made up of very diverse country situations. A few countries with high fish consumption (Japan, Norway) have much lower levels and so do some others, mainly reflecting economic conditions, e.g. the Central Asian countries of the former Soviet Union[52]. At the other extreme, there are countries with over 100 kg, e.g., the United States of America, Australia), or high, levels (most EU countries – the EU27 has an average of 80 kg). In principle, the achievement of near-saturation levels of overall food

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[49] "Information from industry sources suggests that production and consumption of poultry meat in India has grown by as much as 15 percent annually since the mid-1990s, far faster than indicated by official data. Poultry will likely grow in importance to the Indian diet" (Landes *et al.*, 2004).

[50] "Mutton is generally the most expensive meat to buy, and available data suggest that both production and consumption are growing relatively slowly" (Landes *et al.*, 2004).

[51] "Fortunately, ours is largely a vegetarian society and thus dependence on meat as a source of protein is much less compared to other nations including China. Hence, comparatively, our food-feed competition will always be moderate" (Paroda, 2001).

[52] The countries of Central Asia are included in the group of developed countries in our classification in order to ensure comparability for the group between historical data and the projections.

consumption and high meat levels, as well as health concerns, suggest that there is little scope for further increases. Yet the data indicate that such increases do take place even in countries which have passed the 100-kg mark, probably reflecting a mix of over-consumption and growing post-retail waste or feeding of pets. For example, the latest USDA baseline projections to 2021 indicate an increase in per capita meat consumption of 2 percent from the 208.7 pounds of 2010 (retail weight, a small decline in red meat and an increase in poultry – USDA, 2012, Table 29). The latest projections of the EU foresee a 3 percent increase in the per capita meat consumption to 85 kg in 2020, carcass weight– small declines in bovine and small increases in poultry and pork (European Commission, 2011, Table A16). These trends have to be taken into account, even if nutritional and health considerations would suggest otherwise. As shown in Table 2.5, our projection of per capita meat consumption in the developed countries grows 14 percent in the four decades to 2050, but this includes all the countries with relatively still low consumption (countries of the former Soviet Union).

These prospects for changes in the per capita consumption of meat, in combination with slower population growth, suggest that the strength of the meat sector as a driving force of the world food economy will be much weaker than in the past. Thus, world aggregate demand for meat is projected to grow at 1.3 percent p.a. in the period to 2050, one half of the growth rate of the comparable historical period (Table 3.4). The reduction is even more drastic for the developing countries. Much of this reduction is due to the projected slower growth of aggregate consumption in China and Brazil. If these two countries are removed from the developing countries aggregate, the reduction in the growth of aggregate demand for meat is much smaller, indeed smaller than the reduction in the growth rate of their population, as their per capita consumption grows even faster than in the past (Table 2.5).

In conclusion, the projected slowdown in the world meat economy is based on the following assumptions: (a) relatively modest further increases in per capita consumption in the developed countries combined with near stationary population. In particular, the population of Russian Federation and Japan, the major importers will be lower in 2050 than at present, by 52 million or 19 percent[53], with the consequence that their aggregate meat consumption may stop increasing in the medium term future, eventually leading to a shrinkage of the import requirements of these two largest meat importers (see below); (b) growth rates in per capita consumption in China and Brazil well below those of the past, (c) persistence of relatively low levels of per capita consumption in India, and (d) persistence of low incomes and poverty in many developing countries. If these assumptions are accepted, the projected slowdown follows inevitably. Naturally, a slower growth rate applied to a large base year world consumption (258 million tonnes in 2005/2007, of which 149 million in the developing countries – Table 3.4) will still produce large absolute increases in world production (some 200 million tonnes by 2050, the great bulk of which in the developing countries). These increases will tend to accentuate environmental and other problems associated with such large livestock sectors (the sector's production aspects are discussed in Chapter 4).

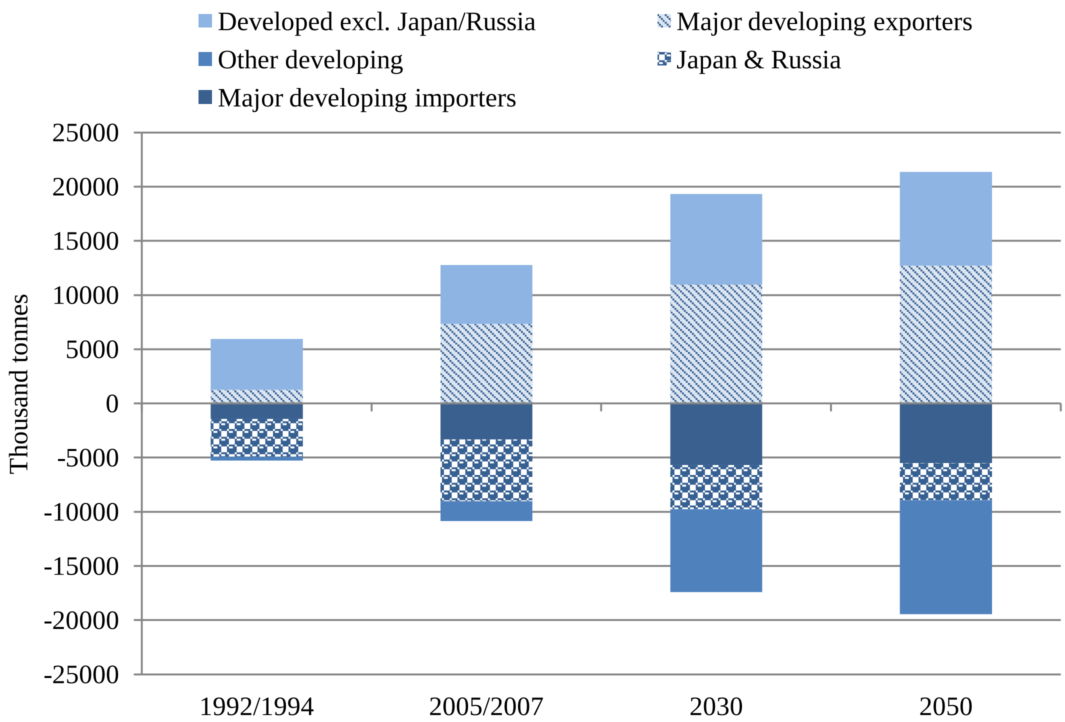
Little decline in the growth of demand for dairy products. Given the still low consumption levels in the developing countries, the potential for growth is there. Few developing countries have per capita consumption exceeding 150 kg (Argentina, Uruguay, some pastoral countries in the Sudano-Sahelian zone of Africa). Among the most populous countries, only Pakistan has such a level. In South Asia, where milk and dairy products are preferred foods, India has only 67 kg and Bangladesh 16 kg. East Asia has only 23 kg. In this latter region, however, food preferences do not favour milk and dairy products, but the

[53] 32 million in the revised UN population projections of 2010 (UN, 2011).

potential for growth is still there: with growing urbanization the per capita consumption has been rising fast and should continue to do so (Table 2.5). Overall, therefore, there is considerable scope for further growth in consumption of milk and dairy products. In the projections, demand in the developed countries grows faster than in the past (Table 3.5) because of the cessation of declines and recovery in the formerly centrally planned economies of Europe.

Meat trade expansion will likely continue, at least to 2050, but more of the exports may be supplied by the developing exporters: Despite the projected slowdown in meat demand growth, some of the forces that made for the above discussed buoyancy in world meat trade in the recent past are likely to continue to operate. The net trade positions are shown in Figure 3.7.

Figure 3.7 Meat: net trade of major importer/exporter country groups



* Country groups defined in text. Historical data go back only to 1992, because of the unavailability of data for Russia before 1992.

Overall, the trend for the developing countries as a whole to become growing net importers of meat from the mid-70s onwards has been reversed in recent years as Brazil's exports soared. Thus, an ever growing share of the imports of the importing developing countries may be supplied by other developing countries and this will eventually reduce the weight of the industrial country exporters as the main export suppliers.

Trade in dairy products will also likely recover, with the net imports of the developing countries resuming moderate growth after a period of stagnation from the mid-80s onwards (Table 3.5). This would reflect continuation of the growth of imports of East Asia and sub-Saharan Africa, as well as some resumption of import growth in the Near East/North Africa region partly compensated by growing net exports from Latin America.

Livestock Production and the Use of Cereals and Oilseed Cakes for Animal Feed. Estimates put the world feed use of cereals at 742 million tonnes, or 36 percent of world total cereal use. The bottom part of Table 3.4 compares the growth rates of total livestock production with those of cereals feed use. The latter have been generally lower than the former, suggesting a *prima facie* case of productivity gains in livestock production in the limited sense of more meat per kg of cereals feed. No doubt, there have been such productivity gains reflecting in part the above mentioned growing share of the poultry sector in total meat production (poultry requires much smaller quantities of cereals feed per kg of meat than beef). However other forces have also been at work leading to the reduced grain/meat ratios. Principal among them is the relative shift of world livestock production out of the regions that use grain-intensive feeding systems to the developing countries that have lower grain/meat ratios on average. The relative shift in the geographical distribution of world livestock production and cereals feed use towards the developing countries reflected not only their faster growth of consumption but also the drastic decline in the 1990s in the livestock production and feed use of the formerly centrally planned economies of Europe, which had high and often inefficient use of cereals feed per unit of output.

An additional factor that contributed to the slowdown in the use of cereals as feed has been the shift towards more balanced feed rations which favoured the use of protein-rich oilcakes. Indeed, such use has grown four times as fast as that of cereals from 1980-2007 or from 1990-2007 (Figure 3.8). The process was very pronounced in China, fuelled by rapid expansion of its imports of soybeans: the country now accounts for some 50 percent of world imports of soybeans, up from 10 percent in the mid-1990s.

The growth rate of cereals feed use (Figure 3.8) will likely continue to be lower than that of livestock production (Figure 3.5)[54]. Differences, however, will not be as pronounced as in the past: the depressing effect of the reforms in the formerly centrally planned economies of Europe has been exhausted and the increase of the share of poultry in total meat production will be less pronounced than in the past. The increase in developing countries' share of world livestock production will also contribute, as developing countries show lower cereals feed/livestock ratios[55]. All these factors will reduce the gap in growth rates of cereals feed use and livestock production.

An additional factor working in the same direction will be the gradual shift of livestock production in the developing countries from grazing and 'backyard' systems to industrial units and stall-fed systems using concentrate feedstuffs. Such structural change in production systems will raise the average grain-meat ratios in developing countries and perhaps compensate partly for opposite trends resulting from the other factors mentioned above. A strong case for this prospect is made in an analysis by the Dutch Centre for World Food Studies (Keyzer *et al.*, 2001).

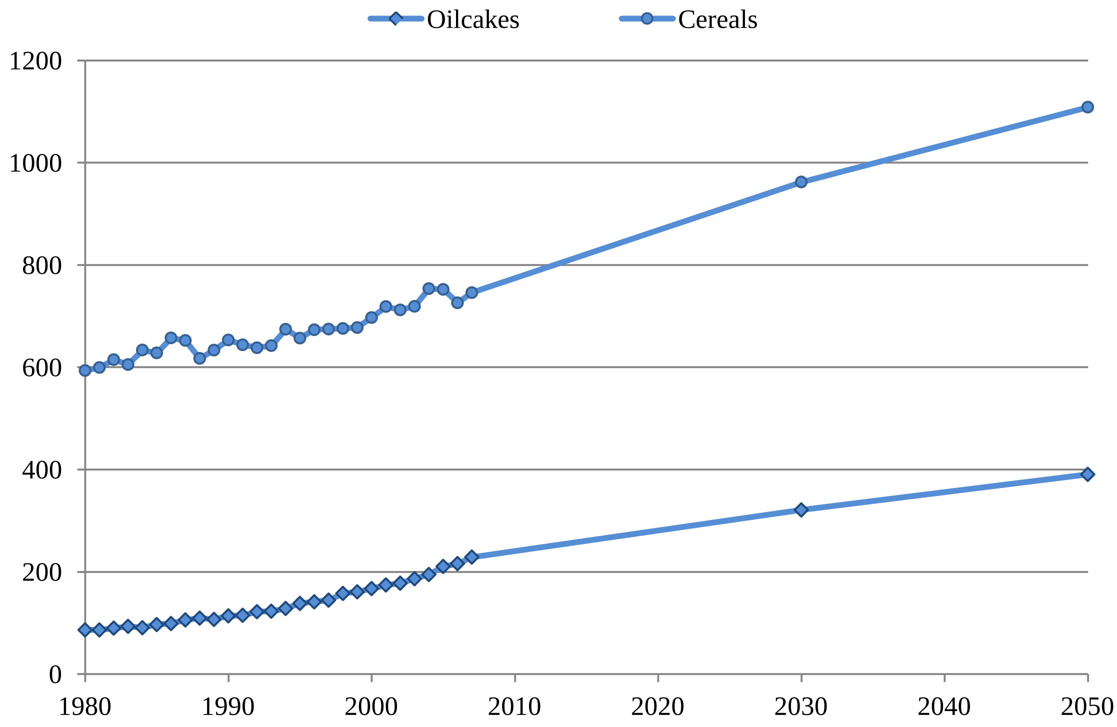
At the same time, a significant increase of cereals-based biofuels may produce by-products that can substitute for cereals in feed rations; this, together with the rise in cereal prices caused by an eventual substantial diversion of supplies to biofuels, will tend to depress the growth rate of cereals use for feed. As explained elsewhere (Annex 3.1), in the present projections the biofuels factor plays a role, albeit a minor one.

In the opposite direction, i.e. continuing to depress the growth of cereals feed use, will be the further increase of the share of protein-rich oilcakes in feed rations, a process that will be supported by the continued expansion of the oilseeds sector faster than that of cereals –see next section. This effect may be reinforced if vegetable oils uses for biofuels were to continue expanding, as oil cakes are produced as joint products with oils, particularly in the case of

[54] Our world cereals feed use projection of 1.1 percent p.a. from 2005/2007-2030 (Table 3.4) compares with the just released FAPRI projection of 1.2 percent p.a. from 2005/2007-2025. FAPRI, however, shows world feed use of wheat and coarse grains, but not world production of livestock products, only major producers (FAPRI, 2011).
[55] Their share may increase to 68 percent in 2050, up from 55 percent at present and the 26 percent of 1970.

soybean oil. Figure 3.8 shows the world production of oilcakes (assumed to be used for feed) derived as joint products with the vegetable oils. It rises by 80 percent to 2050, i.e. faster the 50 percent increase in the cereals feed use.

Figure 3.8 World feed use of cereals and oilcakes (million tonnes)



Historical data 1980-2007 from FAOSTAT; Projections: World feed use of Cereals: sum of the country feed projections; World projections of oilcakes feed use: world oilcakes production derived as joint products from the summation of the country production projection of oilcrops.

3.4 Oilcrops, vegetable oils and products

3.4.1 Past and present

Fastest growth of all sub-sectors of global agriculture. The oilcrops sector has been one of the most dynamic parts of world agriculture in recent decades. In the three decades to 2007 it grew at 4.3 percent p.a. (Table 3.6) [56], compared with an average of 2.1 percent p.a. for all agriculture, including livestock (Table 3.1). A major driving force on the demand side for vegetable oils has been their use for non-food purposes. As noted (Chapter 2, Table 2.5), food demand in the developing countries has also been a fast growing item (4.1 percent p.a. since 1970). The strong growth of demand for protein products for animal feed was also a major supporting factor in the buoyancy of the oilcrops sector. The rapid growth of the oilcrops sector reflects, in addition to the growth of non-food industrial uses, the synergy of these fast rising components of the demand for food –food demand for oils favouring all edible oilcrops that had the potential for rapid expansion of production, e.g. the oil palm, and that for livestock products favouring oilcrops with high protein content oilmeals for feed, e.g. soybeans (see below).

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[56] For the derivation of the growth rates of the entire oilcrops sector, the different crops are added together with weights equal to their oil content. This is what the expression 'oil equivalent', used in this study, means.

Growing contribution to food supplies and food security. World production, consumption and trade in this sector have been increasingly dominated by a small number of crops (Table 3.6) and countries. The oilpalm, soybeans and rapeseed provided 82 percent of the total increment in world oilcrop production since 1990 (in oil equivalent), with the former gaining share. However, the more traditional and less glamorous oilcrops continue to be very important as major elements in the food supply and food security situation in many countries as they account for a major part of their total oilcrop production, e.g. sesame seed in the Sudan, Uganda, Ethiopia and Myanmar; groundnuts in the Sudan, Ghana, Myanmar, Viet Nam, Senegal, the Democratic Republic of the Congo, the United Republic of Tanzania and Benin; coconuts in the Philippines, Sri Lanka, Viet Nam and Mexico; olive oil in the Mediterranean countries; and cottonseed oil in the countries of Central Asia and those in the Sahel, Pakistan, Turkey and the Syrian Arab Republic.

The rapid growth of food consumption in the developing countries, in conjunction with the high calorie content of oil products, has been a major component of the increases achieved in their total food consumption (national averages kcal/person/day, see Chapter 2). This trend is set to continue, although at slower rates than in the past, as vegetable oils still have significant scope for consumption increases in most developing countries.

Non-food uses. As noted, the major driving force on the demand side in recent years has been the non-food use of vegetable oils, with China and the EU being major contributors to this growth. The data do not indicate what such use is, though the bulk of it should be the non-food industrial uses (“other utilizations” in FBS terminology) –paints, detergents, lubricants, oleochemicals in general and, increasingly, biodiesel[57]. In terms of actual oil produced and used (rather than of oil equivalent of oilcrops) the world is apparently using some 51 million tonnes for these “other utilizations”, 41 percent a total use of some 125 million tonnes. The increase was particularly rapid in the last ten years or so: in the mid-1990s such use was 21 million tonnes, 28 percent of total use of 77 million tonnes.

The production of biodiesel played a primary role in boosting such use, though historical data are scarce: n the EU, mainly from rapeseed oil and to a smaller extent from soybean oil and sunflowerseed oil; in the United States of America, Argentina and Brazil from soybean oil; and in Indonesia and Malaysia for palm oil. As a basis for the projections in this “limited biofuels” scenario we use the OECD-FAO estimate of some 7 million tonnes global use for our base year 2005/2007 and the projection of 29 million tonnes in 2019 (Annex 3.1). The latest EU study has an estimate of vegetable oils use for bioenergy of 9 million tonnes in 2010 and projects it to increase to 12 million tonnes by 2020 (European Commission, 2011, Table A10). The other main industrial products involved (paints, detergents, lubricants, oleochemicals in general) are commodities for which world demand can be expected to grow much faster than the demand for food.

[57] One should be careful with these numbers as statisticians often use this category of demand as the dumping ground for unexplained residuals of domestic disappearance. There is no doubt, however, that non-food industrial uses are a dynamic element of demand.

Table 3.6 Major oilcrops, world production

	Actual oil production				Oilcrops in oil equivalent			
	Million tonnes				Growth rates (percent p.a.)			
	2005/	2005/	1970-	1980-	1990-	2005/	2030-	2005/
Soybeans	35.3	41.6	4.1	4	4.8	1.6	1.0	1.3
Oil palm	41.2	41.7	8.1	7.7	7.6	2.5	0.7	1.7
Rapeseed	17.5	20.0	6	5.2	4.1	2.1	0.9	1.6
Sunflower seed	11.2	12.5	3.1	2.4	1.6	1.4	0.8	1.1
Groundnuts	5.3	10.0	2.4	3	2.8	1.5	1.4	1.4
Coconuts	3.5	7.5	2.2	2.4	2	1.6	0.9	1.2
Cotton seed	4.9	7.4	1.7	1.5	1.7	1.0	0.6	0.8
Sesame seed	0.9	1.5	1.8	2.2	2.6	2.2	1.5	1.9
Other oilcrops	7.0	6.6	1.6	1.9	2.3	1.2	1.0	1.1
Total	**126.7**	**148.6**	**4.2**	**4.3**	**4.4**	**1.9**	**0.9**	**1.4**
Oils from non-oilcrops (maize, rice bran)	3.3							

Concentration of production growth in a small number of crops and countries. The three oilcrops mentioned above (oilpalm, soybeans and rapeseed) account for 69 percent of world production (in oil equivalent – Table 3.6). Their share was only 39 percent in the early 1970s. Moreover, a good part of these increases came from a small number of countries: for soybeans, 60 percent of the entire increase from 1999/2001-2005/2007 came from Brazil and Argentina, followed by the United States of America and, to a much smaller extent, India and China; for palm oil 90 percent came from Malaysia and Indonesia; and for rapeseed 90 percent came from the EU, China, Canada and India.

Growing role of trade. The rapid growth of demand in the developing countries was accompanied by the emergence of several of them as major importers of oils and/or oilseeds, with net imports rising by leaps and bounds. Thus, in 2005/2007 there were nine developing countries, each importing net over 1 million tonnes (Table 3.7). Together they had net imports of 28 million tonnes, of which 13 in China alone, reflecting both imports of oils and, as noted, large imports of soybeans. This represents an increase from the 6 million in the early 1990s and only 3 million tonnes ten years earlier. Numerous other developing countries are smaller net importers, but still account for another 10 million tonnes of net imports, a five-fold increase since the early 1980s. This group includes a number of countries that turned from net exporters to net importers over this period, e.g. Senegal and Sri Lanka.

With these rates of increase of imports, the traditional net trade surplus in oils/oilseeds of the developing countries would have turned negative if it were not for the spectacular growth of exports of a few developing countries that came to dominate the world export scene, viz. Malaysia and Indonesia for palm oil and Brazil and Argentina for soybeans. This has led to the net exports of the developing countries as a whole being now twice as high as in the early 1990s, despite the rising imports of most of them. The mirror image is the growth of the net deficit of the developed countries increasing 3-fold over the same period, mostly because of increases of the net imports of the EU, partly compensated by modest increases in the exports of the two major net exporters, the United States of America and Canada, and the more substantial, but still relatively small, increase in those of the non-EU Eastern Europe.

Table 3.7 Net trade balances for oilseeds, oils and products (in oil equivalent)[1]

Million tonnes (oil equivalent)	1969/ 1971	1979/ 1981	1989/ 1991	2005/ 2007	2030	2050
Developing countries	2.3	1.5	4.1	10.3	15.9	14.2
Malaysia	0.5	2.6	6.4	16.1		
Indonesia	0.3	0.4	1.2	13.3		
Argentina	0.3	1.1	3.0	8.8		
Brazil	0.3	1.2	1.4	7.0		
Paraguay	0.0	0.1	0.3	0.8		
Sub-total, 5 major exporters	**1.4**	**5.4**	**12.4**	**46.1**	**74.2**	**85.5**
Other developing exporters	0.8	1.1	1.1	1.6	2.2	2.8
China	0.1	-0.1	-1.3	-12.9		
India	-0.1	-1.3	-0.2	-4.5		
Mexico	0.0	-0.3	-0.9	-2.1		
Pakistan	-0.1	-0.4	-1.0	-2.0		
Bangladesh	-0.1	-0.1	-0.3	-1.4		
Turkey	0.0	-0.1	-0.4	-1.3		
Iran	-0.1	-0.4	-0.7	-1.3		
Republic of Korea	0.0	-0.2	-0.5	-1.1		
Egypt	-0.1	-0.3	-0.7	-1.0		
Sub-total, 9 major importers	**-0.4**	**-3.1**	**-6.1**	**-27.7**	**-44.9**	**-54.2**
Other developing Importers	0.5	-1.9	-3.3	-9.7	-15.6	-19.9
Developed countries	-2.3	-1.3	-3.8	-6.7	-12.3	-10.6
United States of America	2.3	5.4	2.9	5.1		
Canada	0.3	0.9	1.0	3.3		
Japan	-1.0	-1.7	-2.3	-2.8		
EU-27	-4.0	-4.7	-3.8	-11.3		
Other Developed	0.1	-1.2	-1.6	-1.0		
World balance (stat. discrep.)	0.0	0.2	0.2	3.6	3.6	3.6

[1] Trade numbers (in oil equivalent) are derived from trade data in oils, derived products and oilseeds; trade in oilmeals not included in order to avoid double counting in the equation: production + net trade = consumption expressed in oil equivalent.

Oilcrops responsible foremost agricultural land expansion. On the production side, oilcrops expanded mainly in land-abundant countries such as Brazil, Argentina, Indonesia, Malaysia, the United States of America, Canada, the Russian Federation and Ukraine. The oil palm and the two fast growing annual oilcrops, soybeans and rapeseed account for most of the expansion of cultivated land under all crops in the developing countries and the world as a whole. Globally, the harvested area[58] in oilcrops expanded by 65 million ha (mha) between

[58] The increase of harvested area implies not only expansion of the cultivated land in a physical sense (elsewhere in this report referred to as arable area) but also expansion of the land under multiple cropping (in the harvested or sown area definition, a hectare of arable land is counted as two if it is cropped twice in a year). Therefore, the harvested area expansion under the different crops discussed here could overstate the extent to which physical area in cultivation has increased. This overstatement is likely to be more pronounced for cereals and other annuals than for oilcrops, as the latter include also tree crops (oil and coconut palms, olive trees).

1989/1991 and 2005/2007, of which 48 mha in the developing countries and 17 mha in the developed ones. The area in other main crops (cereals, roots and tubers, pulses, fibres and sugar crops) declined by 8 mha (56 mha decline in the developed countries and 48 mha increase in the developing ones).

These numbers clearly demonstrate that land expansion continues to play an important role in the growth of crop production. The near doubling of oilcrop production in oil equivalent between 1989/1991 and 2005/2007 in developing countries was brought about by a 47 percent or 48 million ha expansion of land under these crops, at the same time as land under the above mentioned other main crops also increased by an equal amount.

3.4.2 Prospects for the oilcrops sector

Food demand. As noted, the growth of food demand in the developing countries was a major driving force behind the rapid growth of the oilcrops sector in the historical period. The most populous countries, China and India, played a major role in these developments. Will these trends continue in the future? In the first place, slower population growth, particularly in the developing countries, will be reflected in slower growth rates of their aggregate demand for food, *ceteris paribus*. But other things will not be equal: in particular, the per capita consumption of vegetable oils in the developing countries was only 4.9 kg in the early 1970s. This afforded great scope for the increases in consumption which took place. However, in the process per capita consumption grew to 10.1 kg in 2005/2007 (Table 2.5). Within this average, India increased its per capita consumption 76 percent and China 3.3-fold. The growth of food demand in these two countries accounted for 43 percent of the increment in the food demand of the developing countries. While oils will remain a food item with high income elasticity in most developing countries in the short and medium term-future, the higher levels that will be achieved gradually will lead to slower growth in the longer term future. Thus, per capita consumption will likely rise at much slower rates compared with the past (Tables 2.5-2.6). This slowdown must be seen in the context of rising food demand for all commodities and the implied levels of per capita kcal. We noted in Chapter 2 (Figure 2.2) that 44 percent of the population of the developing countries will be in countries with over 3000 kcal/person/day in 2050. Inevitably, consumption of these calorie-rich foods (oils and products) cannot continue growing at the fast rates of the past. This prospect notwithstanding, there will still be many low income countries which in 2050 will have per capita consumption of fats and oils totally inadequate for good nutrition, the result of persistent low incomes and poverty.

Non-food industrial uses. We noted earlier the inadequacy of the statistics on vegetable oils used for non-food industrial purposes. We also noted that some of the industrial products resulting from such use have high income elasticities of demand. In addition, vegetable oils are increasingly used as feedstocks for production of biofuels. There is, therefore, a *prima facie* case to believe that the share of total vegetable oil production going to non-food industrial uses will continue to grow fairly rapidly. In this "limited biofuels" scenario (Annex 3.1), the above mentioned 7 million tonnes estimated to be used for biofuels in the base year are increased to 29 million tonnes in 2020 and remain constant for the remaining projection years.

Overall, the demand for industrial non-food uses of vegetable oils is projected to grow at rates above those of the demand for food (1.7 percent p.a., versus 1.4 percent p.a. over the projection period to 2050). A glimpse on prospects beyond 2019 can be obtained from the recently released biofuels projections of FAPRI (2011) going to 2025: it has an increase of world vegetable oils use for biodiesel for 2019 lower than that of OECD-FAO (2010: Figure 4.8) used here and it projects a slowdown for the remaining period to 2025 (14 percent increase from 2019-2025). According to these projections, the boost to the oilseeds sector coming from biofuels may be weakening over time. However, the uncertainty surrounding these projections must be emphasized, as much depends on energy sector developments and policies.

Trade. The projected fairly buoyant growth in demand and the still considerable potential for expansion of production in some of the major exporters, suggest that past trade patterns will continue for some time. That is, imports in most developing countries will continue to grow at a fast pace, matched by continued export growth of the main exporters (Table 3.7). The potential for further production and export increases of several developing countries and the continued growth of demand for non-food uses in developed countries together imply that the net export surplus of the developing countries will keep growing over the medium term. However, this trend may be halted in the longer term under our scenario assumptions of biofuels use levelling off after 2020. The developing net exporter countries may come to depend increasingly for their exports on the growth of imports into the importing developing countries (Table 3.7).

Production. Production issues are discussed in Chapter 4in terms of individual crops listed in Table 3.6. Cotton is included among these crops because it contributes some 4 percent of world oil production, though projected production is determined in the context of world demand-supply balance of cotton fibre rather than oil. Production growth rates for the major oilcrops are shown in Table 3.6. As noted, oilcrop production has been responsible for a good part of the area expansion under crops in the developing countries. This will continue in the future: some 50 percent of the harvested area expansion in the developing countries under the main crops listed above will be due to the expansion of the oilcrops between 2005/2007 and 2050. Such expansion denotes the relatively land-intensive nature of oilcrop production. Oilcrops are in fact predominantly rainfed, with only 12 percent of the land irrigated, compared to about 40 percent for cereals in developing countries.

Given such land-intensive nature of oilcrops, the question whether there is enough land for such expansion without seriously threatening forest or other ecologically valuable areas must be posed. Expansion of soybeans in Brazil and the oilpalm in Southeast Asia are often cited as major contributors to deforestation and habitat disturbance. Land use issues are discussed in Chapter 4 Suffice to say here that early enthusiasm with the environmental or energy security benefits of biofuels are increasingly being questioned. The latest evaluation is vividly set out in the 2011 report of the Nuffield Council on Bioethics (2011).

3.5 Roots, tubers and plantains

3.5.1 Past and present

Food consumption of roots, tubers and plantains: As noted in Chapter 2, these products represent the mainstay of diets in several countries, many of which are characterized by low overall food consumption levels and food insecurity. The great majority of these countries are in sub-Saharan Africa. The high dependence on roots, tubers and plantains reflects the agro-ecological conditions of these countries, which make these products suitable subsistence crops, and to a large extent also the persistence of poverty and lack of progress towards diet diversification. There are significant differences as to which of these starchy foods provide the mainstay of diets in the countries dependent on this family of products. Cassava predominates in most of them but some have high shares of sweet potatoes or plantains.

Potatoes are the one product in this group with higher income elasticity of demand in several developing countries, the majority of which have very low levels of per capita consumption to start with[59]. Their per capita potato consumption has increased in recent years, with China having had a major role in this increase. This contrasts with the position of the other starchy foods (particularly sweet potatoes but also cassava), whose per capita food consumption in the developing countries has apparently stagnated or declined. However, caution is required in drawing firm inferences from these numbers because of the particularly poor quality of data as regards the production and consumption of several of these crops.

Efforts to improve the cassava data in Africa in the context of COSCA suggest that cassava is far from being the inferior good put forward in traditional thinking[60] [61]. "The COSCA study found that income elasticities of demand for cassava products were positive at all income levels" (Nweke *et al.*, 2002).

Feed uses of root crops. Significant quantities of roots are used as feed, mostly potatoes (11 percent of world production goes to feed), sweet potatoes (30 percent) and cassava (34 percent). A small number of countries or country groups account for the bulk of such use. For potatoes, it is mostly the countries of the former Soviet Union and Eastern Europe, China and the EU, though it has been declining in the latter two. Potato feed use has declined in recent years in absolute tonnage as well as percentage terms. For sweet potatoes, China accounts for some 80 percent of world feed use and for about one half of world production. Nigeria comes second with some 15 percent of world feed use.

For cassava, it is mostly Nigeria and Brazil (50 percent of their production goes to feed). China is also shown in the FBS as using most of its imported cassava supplies as feed, though this may be an error: press reports have it that China increased rapidly its cassava imports, mainly from Thailand and uses most of it for biofuels[62]. Use of imported cassava for feed had its heyday in the EU when internal prices of cereals were high and imported cassava provided a competitive substitute in feed rations. Such use reached a peak of some 25 million tonnes (fresh equivalent) in 1990. It then declined (to 2 million tonnes in 2005/2007) and so did exports to the EU from Thailand, as the price relation cereals/cassava changed in favour of the former following the EU policy reforms. However, for Thailand, new export outlets substituted for lost markets in the EU, as China promoted use of cassava for biofuels. China's net imports (from all sources) rose to 17 million tonnes in 2005/2007 from just 2 million tonnes ten years earlier. These changes are graphed in Figure 3.9: Thailand's exports track closely the combined imports of the EU and China.

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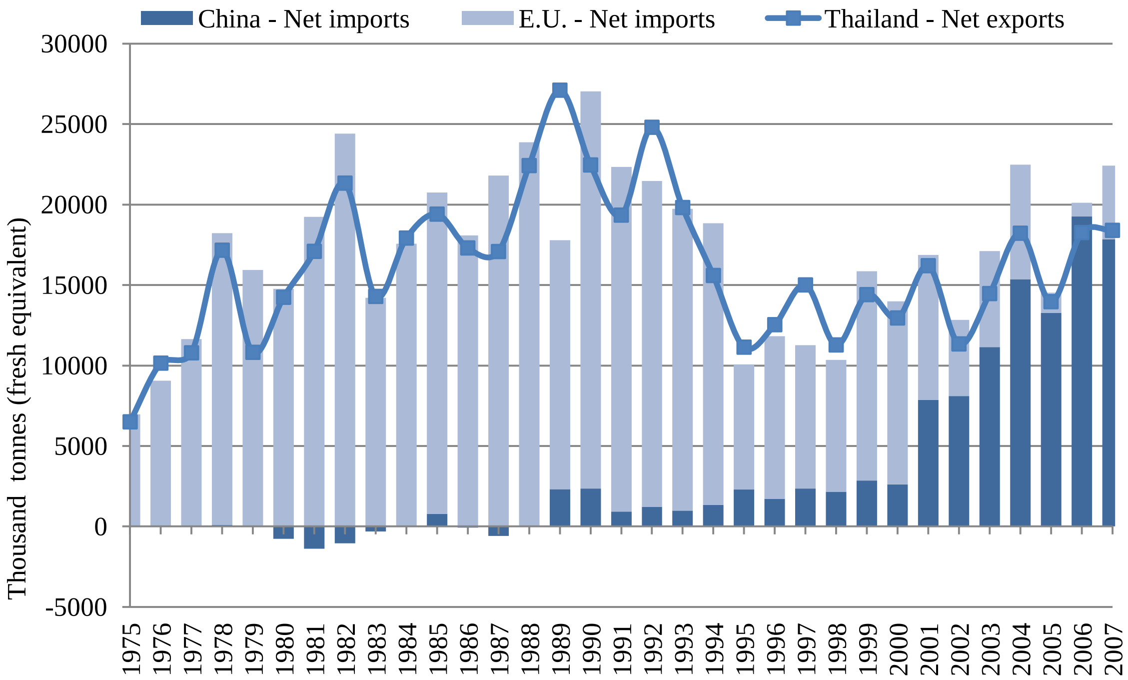
[59] "Whereas potatoes are typically considered a cheap, starchy staple in industrialized countries, they tend to be high-priced and sometimes are luxury vegetables in the developing world. Consumption of potato increases as income increases. The relationships for cassava and sweet potato are different. As per capita incomes increase, per capita consumption declines" (Scott *et al.*, 2000).

[60] Collaborative study of cassava in Africa (COSCA), initiated in 1989.

[61] "Outside of Kerala (India) and isolated mountain areas of Viet Nam and China, most cassava in Asia for direct food purposes is first processed. As incomes increase over time, also these areas will reduce their non-processed cassava intake in favour of the preferred rice. On-farm cassava flour consumption, seems to behave in a similar way to non-processed cassava in Asia, as it is also substituted for rice as economic conditions improve. Nonetheless, on-farm, in the poorer Asian rural areas (Indonesia, Viet Nam and China) cassava may remain as an emergency or buffer crop in times of rice scarcity. However, this is not the primary nor the preferred use" (Henry *et al.*, 1998). Also, "the general tendency is that cereals are preferred to root crops" (FAO, 1990, p.24) and "In general, cassava is not well regarded as a food, and in fact there is often a considerable stigma against it" (Plucknett *et al.*, 1998).

[62] "... last year, 98 percent of cassava chips exported from Thailand, the world's largest cassava exporter, went to just one place and almost all for one purpose: to China to make biofuel. Driven by new demand, Thai exports of cassava chips have increased nearly fourfold since 2008, and the price of cassava has roughly doubled", Rosenthal, E. (2011), "Rush to Use Crops as Fuel Raises Food Prices and Hunger Fears", New York Times, 7 April, 2011.

Figure 3.9 Cassava: Thailand net exports versus EU and China's net imports



3.5.2 Roots, tubers and plantains in the future

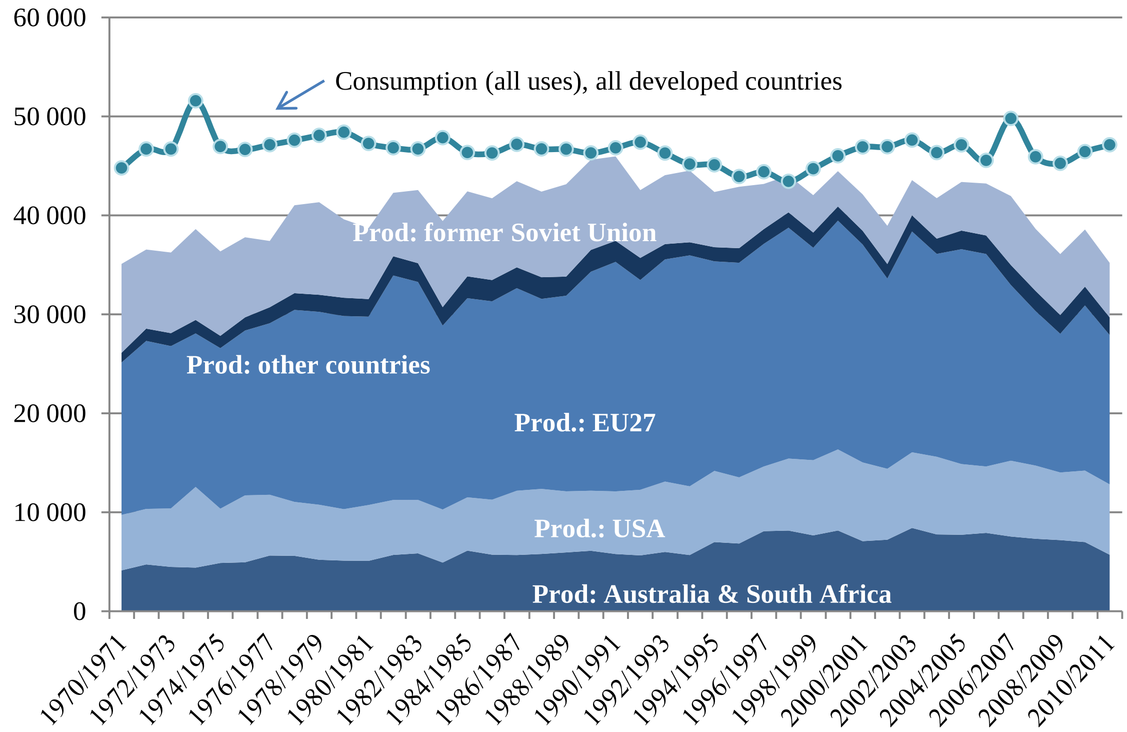
These products will continue to play an important role in sustaining food consumption levels in the many countries that have a high dependence on them and low food consumption levels overall. The possible evolution of food consumption per capita is shown in Tables 2.5-2.6. As noted in Chapter 2, the main factor that made for the decline in the average of the developing countries (precipitous decline of sweet potato food consumption in China) will be weaker in the future, as the scope for further declines is much more limited than in the past. In parallel, the two factors that make for increases in the average –the positive income elasticities of the demand for potatoes and the potential offered for Africa by productivity increases in the other roots (cassava, yams)– will continue to operate. It will be possible for more countries in sub-Saharan Africa to replicate the experiences of those that achieved higher food consumption levels based on improvements in the roots and tubers sector. Thus, the recent upturn in per capita consumption of the developing countries is projected to continue (Table 2.5), while the declining trend in sub-Saharan Africa (Table 2.6) may be reversed.

Concerning non-food uses, cassava has the potential of becoming an important feedstock for the production of biofuels. As noted, China is moving in that direction (Jansson *et al*, 2009) and so are some other countries, including Thailand. In the present projections under the "limited biofuels scenario", such use of cassava is projected to increase from 1 million tonnes to 8 million tonnes in 2019. However, the numbers could be much larger if China's data, after verification, are revised to recognise that much of the imported cassava goes to biofuels, not to fodder.

3.6 Sugar

Consumption has been growing fast in the developing countries, which now account for 73 percent of world consumption, up from 58 percent in the early 1980s, including the sugar equivalent of sugar crops used in non-food industrial uses[63] This is mainly Brazil's sugar cane used in ethanol production. The developing countries' consumption doubled, while that of the developed countries as a whole stagnated (Figure 3.10, 3.11). An important factor in the stagnation of sugar consumption in the developed countries has been the rapid expansion of corn-based sweeteners in the United States of America, where they now account for just over 50 percent of all caloric sweetener consumption, up from only 13 percent in 1970[64]. The fall in sugar consumption in the former centrally planned economies of Europe in the 1990s contributed to this trend. Sugar has been produced under heavy protection in many developed countries, with the exception of the traditional exporters among them (Australia, South Africa – OECD, 2002). Their aggregate production kept growing up to the early 1990s, while consumption did not. The result was that their net imports shrank from about 10 million tonnes in the early 1970s to almost zero in the late 1980s. The reforms in the former centrally planned economies of Europe interrupted this process in the early 1990s as their production and consumption declined, though both recovered later on in the decade. Policy reforms in the European Union led to declining production and turned the group into a net importer again in the second half of the 2010s, a status it had in the past until the late 1970s when it turned into a net exporter.

Figure 3.10 Sugar production and consumption, developed countries (thousand tonnes, raw equivalent)



Source: USDA, PSD (accessed 16 March 2012), incl. forecast for 2011/2012; data refer to actual sugar, not the sugar equivalent of sugar cane and beet. As such, they are not directly comparable with the data used in other parts of this study.

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[63] From 56 percent to 69 percent if only food consumption of sugar is taken into account.
[64] Data (loss-adjusted food availability in terms of calories) in http://www.ers.usda.gov/Data/FoodConsumption/FoodGuideSpreadsheets.htm.

Figure 3.11 Sugar and sugar crops food consumption (raw sugar equivalent)

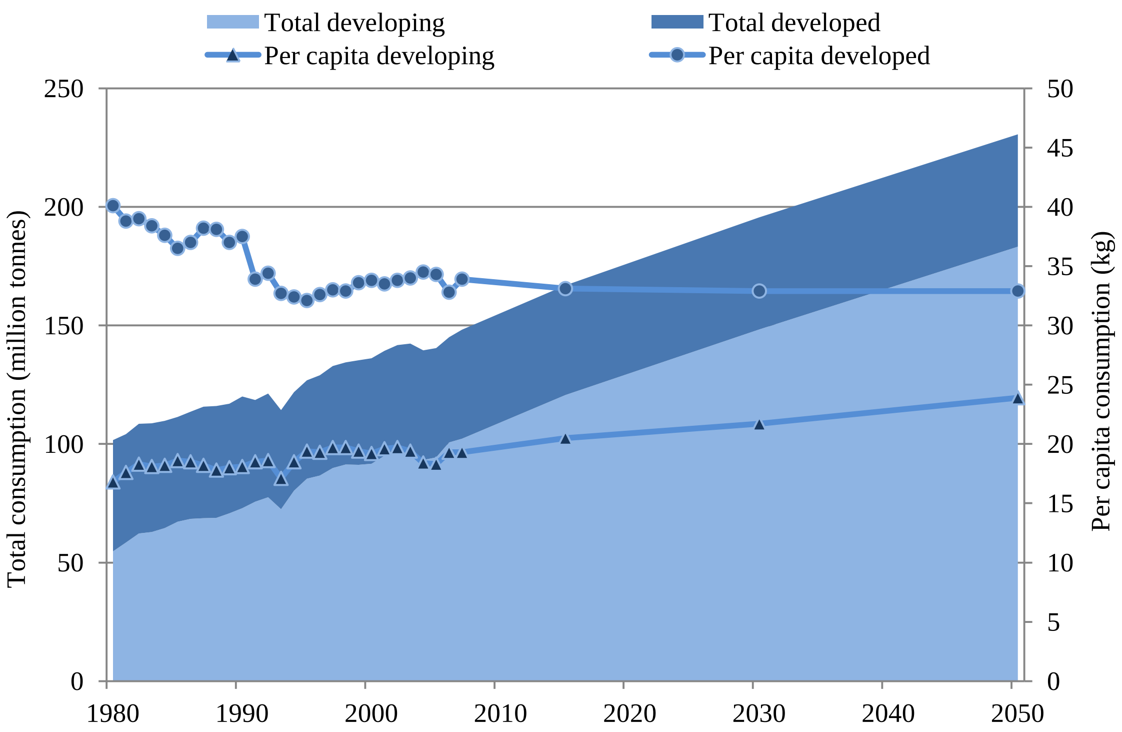
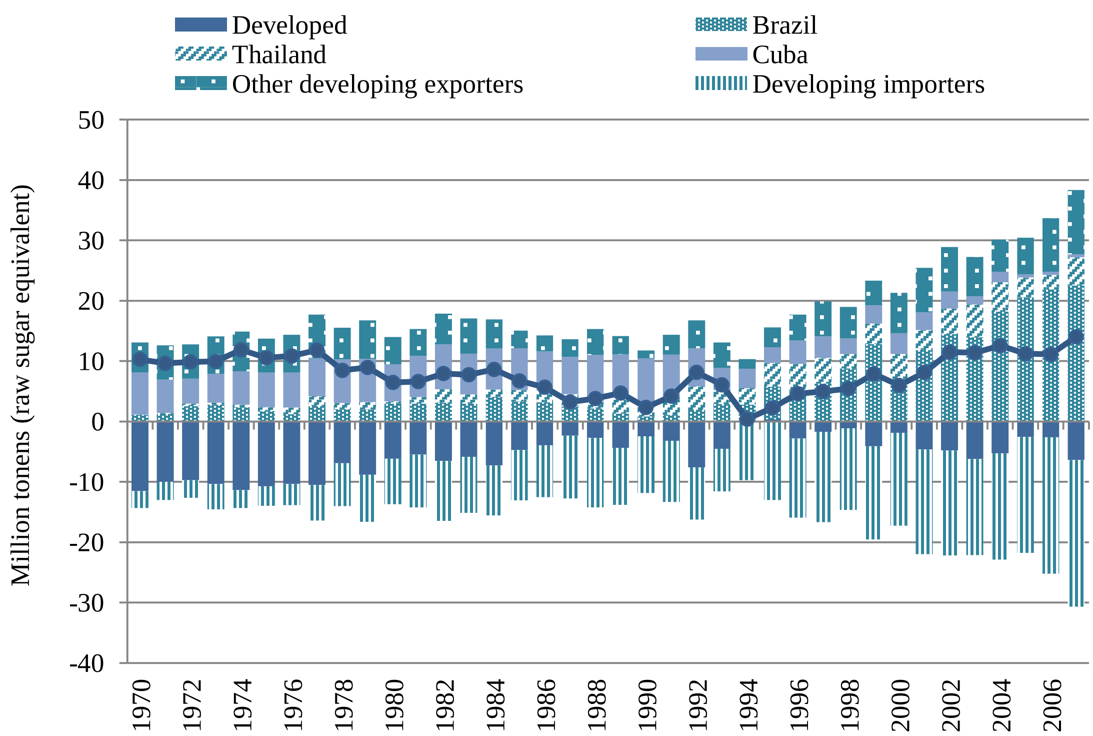


Figure 3.12 Sugar net trade positions, 1970-2007

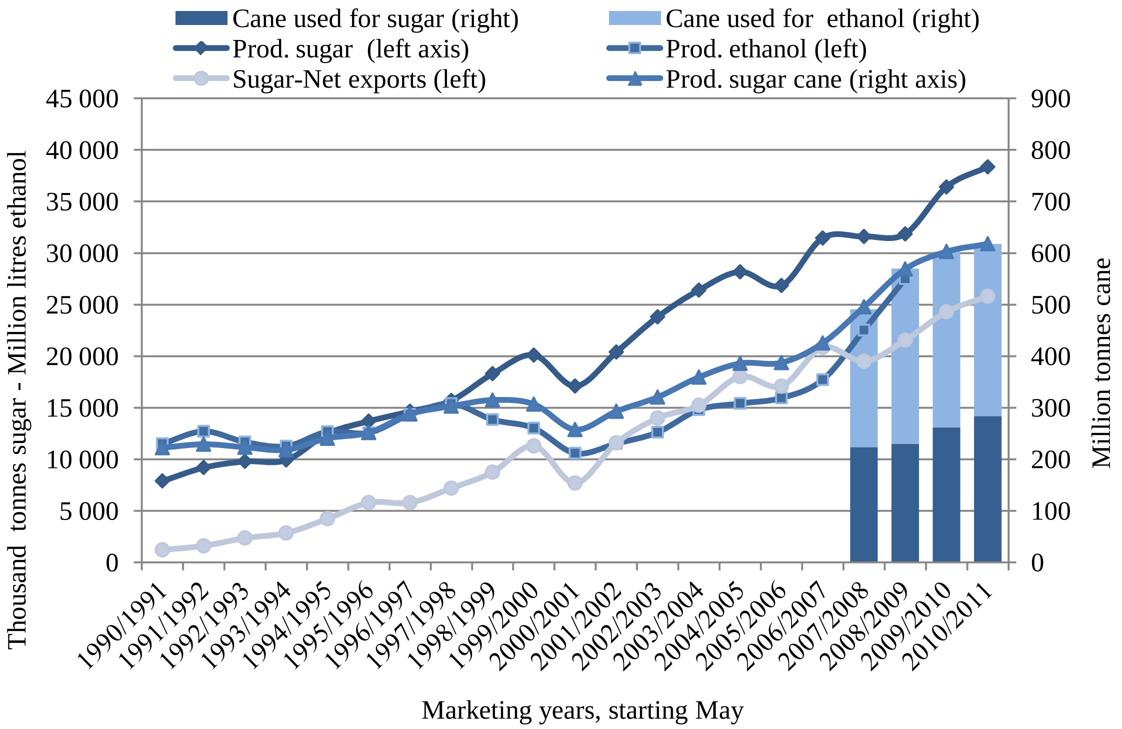


Net exporter/importer status of the developing countries as of average 2005/2007.

Net exports from developing countries did not decline because over the same period the decline of their exports to the industrial countries was offset by rising imports into developing countries. Several countries in the Near East/North Africa region and also countries like Indonesia, Nigeria, Malaysia, and the Republic of Korea played a major role in the expansion of world trade as their imports shot up. On the export side, Brazil has come to dominate world exports followed by Thailand, while Cuba turned from the leading world exporter it was up to the early 1990s to a minor one (Figure 3.12).

Beyond the turnaround of the developed countries from importers to exporters and back again and the emergence of Brazil as the major supplier to world markets, the last few years have been characterized by growing interaction between energy and sugar markets: an increasing part of world sugar cane and some sugar beet were used as feedstocks for the production of ethanol, with Brazil being by far the most important producer. Currently over one half of Brazil's sugar cane production is used for ethanol. Given the country's resource potential and technological prowess, this has not prevented the country from increasing in parallel sugar production and keep being the premier world exporter (Figure 3.13).

Figure 3.13 Brazil: sugar cane, sugar and ethanol

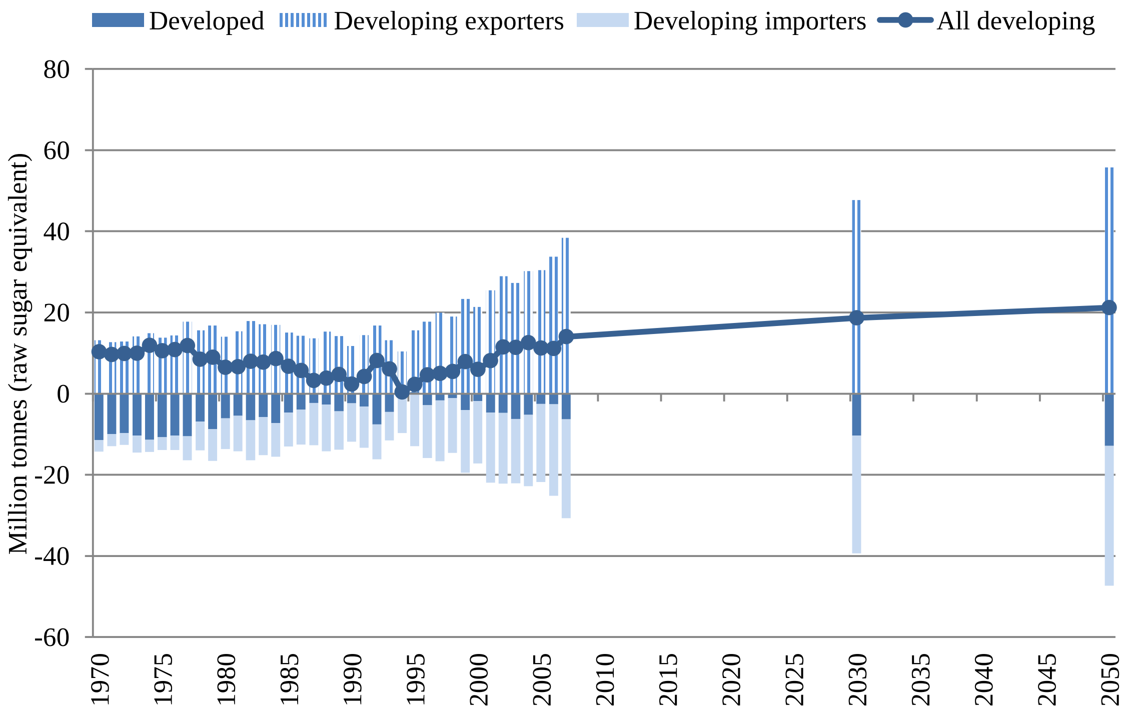


Sources: Production ethanol and sugar cane to 08/09: http://www.unica.com.br; Cane Production last two years and uses for Sugar/Ethanol: USDA/FAS/Sugar Annuals for Brazil; Sugar Production and Exports: USDA/PSD.

Food consumption of sugar in the developing countries is projected to continue to grow to 2050 (Table 2.5 and Figure 3.11). Much of the growth would occur in Asia, as Latin America and the Near East/ North Africa have already attained fairly high levels. Latin America may continue to experience some decline (Table 2.6). Per capita consumption in the developed countries will probably remain nearly constant, compared with declines in part of the historical period during which corn sweeteners were substituting for sugar in the United States of America. This process, very pronounced up to the mid-1980s, has by now run its course. In the 1990s the decline in the average of the developed countries continued as consumption fell in the formerly centrally planned economies of Europe during the reform period. These projected developments in per capita food consumption in combination with the lower population growth, suggest a further deceleration in the aggregate world food demand for sugar: from 1.9 percent p.a. in the past (1961-2007, or 1.3 percent from 1980-2007) to 1.1 percent in 2005/2007-2050.

As a result, developing exporters that benefited from the surge in demand of the importing developing countries and policy reforms in the developed ones may face more limited growth prospects in the long term. The growth of their net exports will increasingly depend on the growth of consumption in the importing developing countries which will be less buoyant than in the past, hence also the potential for export growth from the exporting countries (Figure 3.14).

Figure 3.14 Sugar net trade positions, 1970-2007 and projections



Net exporter/importer status of the developing countries as of average 2005/2007.

The impact of the lower food demand growth on the world sugar crops sector may be compensated by growing use for biofuel production. Under our "limited biofuels" scenario use of sugar crops in sugar equivalent will increase from 15 percent of world sugar output to 27 percent in 2030 and to 24 percent in 2050. As a consequence, world production should increase faster than world food demand, at 1.3 percent p.a. from 2005/2007-2050 vs.1.1 percent. A glimpse on prospects beyond 2019 can be obtained from the recently released projections to 2025 of FAPRI (2011) for ethanol production in Brazil (almost all the sugar cane-based ethanol of the world in the FAPRI projections): it has an increase from 2007/09-2019 of 122 percent, almost equal to that of OECD-FAO (2010: Table A.33) we use here, and projects a further 27 percent increase from 2019-2025. By implication, the boost to the sugar crops sector coming from biofuels may be weakening over time.

Annex 3.1
Biofuels and climate change in the projections

Biofuels

The projections presented in this study refer to a baseline scenario which is not meant to address explicitly biofuels. Given uncertainties surrounding the future of the use of crops as feedstocks for biofuels, doing justice to the issue would require the development of alternative scenarios taking into account, in the first place, possible developments in the energy sector and government policies.

However, biofuels cannot be entirely ignored, for the simple reason that considerable amounts of agricultural commodities are already used as feedstocks. Their presence in the starting values (base year) of the projections requires that the issue what numbers to put in the future years must be faced. We cannot put zeros because (a) we know that such use of crops has continued after 2007 (the last historical data we use) and (b) several countries have plans and policies that will ensure that such use of crops will continue, at least for some time. At the same time, we cannot generate our own numbers for fifty years ahead: that would be a time-consuming task requiring modelling of alternative energy futures and making many assumptions about policies. This task is reserved for the follow-up work.

We have opted for the following solution: use the baseline projections of other agricultural outlook studies to determine projected quantities for biofuels feedstocks for the medium term – in this case the 10-year projections to 2019 from the OECD-FAO *Agricultural Outlook* (OECD-FAO, 2010). These projections, at least for the OECD countries, have been reviewed/vetted by national authorities and therefore (at the time of publication of the Outlook – mid-2010) represent reasonable values of expected use of crops for biofuels up to 2019. For the years past 2019 we make the assumption that the levels reached by then will continue also in the subsequent projection years 2030 and 2050. This is why we have referred to this round of our projections as a "limited biofuels" scenario. The quantities of the main crops concerned projected to be used as biofuels feedstocks are shown in the following table.

Table A.3.1 World use of crops for biofuels

		2005/	2030	2050
Cereals	million tonnes	65	182	182
Cereals	percent of total use	3.2	6.7	6.1
Veg. oils	million tonnes	7	29	29
Veg. oils	percent of total use	4.8	12.6	10.3
Sugar (equiv. of sugar cane)	million tonnes	28	81	81
Sugar	percent of total use	15.1	27.4	24.3
Cassava (fresh)	million tonnes	1	8	8
Cassava	percent of total use	0.4	2.3	1.8

Climate change

In evaluating future production possibilities for each crop and country we use (a) estimates of land availability by category (very suitable, suitable, marginal, etc – see Chapters 1 and 4), (b) yield growth potentials and yield ceilings in relation to the presently prevailing ones, and (c) water availability and irrigation potential. In principle all these characteristics may be affected by climate changes (Alexandratos, 2011b). It follows that before we can say if our projections take into account climate change effects, we must make sure that we know the climatic variables used for generating the land suitability, etc we use. The latter come from the GAEZ. The water and irrigation potentials come from FAO's *Aquastat*. Both have been evaluated on the basis of the currently prevailing climate conditions (precipitation, temperature, etc).

Using them, as we actually do in this study, to set land, water and yield constraints for future years is equivalent to assuming that present conditions will prevail also in 2050. Thus we, as well as others doing scenarios under no climate change assumptions, are faced with a logical *non-sequitur* if present climatic conditions cannot exist in the future. This may well be the case if statements like the following are true: "a 2°C warming above pre-industrial temperatures –the minimum the world is likely to experience..." (World Bank, 2010). Apparently there is no possible future outcome with global average temperatures not above present ones. The IPCC (2007b) in its Fourth Assessment Report shows likely ranges and best estimates of rises in global average temperatures by the last decade of the century (over the average of 1980-1999) under its several scenarios. There is no scenario projection that does not include a rise in temperature. Temperature increases are inevitable even if GHG concentrations were not to increase further above the levels of 2000, a virtual impossibility since this has already happened (IPCC, 2007b, Table SPM.3).

In principle, a scenario that assumes no climate change has no place in the array of scenarios to be examined. It would entail the risk of generating results that are flawed if some of the assumed land, water and yield constraints become more binding (than they are found to be under the no change scenario) following inevitable climate change.

CHAPTER 4

AGRICULTURAL PRODUCTION AND NATURAL RESOURCE USE

This chapter discusses the main technical issues underlying the projections of agricultural production presented in Chapter 3. After a short discussion of overall production growth, crop production will be analyzed, the projections of which will be unfolded into land use and yield projections under rain-fed and irrigated conditions. Estimates will then be presented of the future expansion of arable rain-fed and irrigated land, fresh water use in irrigation and crop yields. The chapter concludes with projections of fertilizer use and a discussion of some of the parameters underlying the livestock production projections. Although the underlying analysis was carried out at the level of (105) individual countries and country groups, the discussion here is limited to a presentation of the results at the level of major regions which unavoidably masks wide inter-country differences.

4.1 Production growth in agriculture

The baseline projections presented in Chapter 2 and 3 show that by 2050 the world's average daily calorie availability could rise to 3070 kcal per person (Table 4.1), an 11 percent increase over its level in 2005/2007. As discussed in Chapter 2, this would by 2050 still leave some 4 percent of the developing countries' population (about 320 million persons) chronically undernourished.

Table 4.1 Increases in population, calorie supply and agricultural production

	Unit	1961/1963	2005/2007	2030	2050
World					
Population#	million persons	3 133	6 569	8 276	9 111
Daily energy supply (DES)	kcal/person/day	2 231	2 772	2 960	3 070
Total production*	index (2005/2007 = 100)	37	100	138	160
Cereals**	million tonnes	843	2 068	2 720	3 009
Meat production	million tonnes	72	258	374	455
Developing countries					
Population	million persons	2 140	5 218	6 839	7 671
Daily energy supply (DES)	kcal/person/day	1 884	2 619	2 860	3 000
Total production	index (2005/2007 = 100)	24	100	147	177
Cereals	million tonnes	353	1 164	1 572	1 812
Meat production	million tonnes	20	149	243	317
Developed countries					
Population	million persons	1 012	1 351	1 437	1 439
Daily energy supply (DES)	kcal/person/day	2 983	3 360	3 430	3 490
Total production	index (2005/2007 = 100)	64	100	118	124
Cereals	million tonnes	500	904	1 148	1 197
Meat production	million tonnes	52	109	130	138

UN 2008 Assessment (Medium-fertility variant); the countries included in this study cover in 2005/2007 99.7% of the world population.

* In value terms (2004/06 International Commodity Prices).

** Including rice in milled form.

For these projections to materialize, annual world agricultural production would need to increase by some 60 percent from 2005/2007 to 2050 (Table 4.1), consisting of a 77 percent increase in developing countries and a 24 percent increase in developed countries. Over the same period, world population is projected to rise by some 39 percent, meaning that per capita production would rise by some 15 percent. The fact that this would translate into a smaller (11 percent) increase of per capita calorie availability is mainly[65] due to the expected changes in diet, i.e. a shift to higher value foods of often lower calorie content (e.g. vegetables and fruits) and to livestock products which imply a less efficient conversion of calories of the crops used in livestock feeds. Meat consumption per capita for example would rise from 39 kg at present to 49 kg in 2050 (from 28 to 42 kg in the developing countries) implying that much of the additional crop (mainly coarse grains and oilseeds) production will be used for feeding purposes in livestock production.

At world level agricultural production increases are about equal to increases in demand for agricultural products. Simple growth accounting shows that the increase in global demand comes for about 70 percent on account of population growth, 22 percent on account of the increased availability of calories per person and 8 percent on account of other factors, mainly changes in the commodity composition driven by shifts in diets. The latter two factors are predominantly determined by the increase in per capita income, so that overall one could state that at the world level increases in demand and production are 70 percent determined by population growth and 30 percent by per capita income growth.

Table 4.2 Agricultural production growth rates (percent p.a.)

	1961- 2007	1987- 2007	1997- 2007	2005/2007- 2030	2030- 2050
World	2.2	2.2	2.2	1.3	0.8
Developing countries	3.3	3.5	3.1	1.6	0.9
idem, excl. China and India	2.9	3.0	3.3	1.8	1.2
Sub-Saharan Africa	2.6	3.2	3.1	2.5	2.1
Latin America and the Caribbean	2.9	3.3	3.8	1.7	0.8
Near East / North Africa	3.0	2.7	2.6	1.6	1.2
South Asia	2.9	2.7	2.4	1.9	1.3
East Asia	4.0	4.2	3.3	1.3	0.5
Developed countries	0.9	0.2	0.5	0.7	0.3
44 countries with over 2700 kcal/person/day in 2005/2007*	2.6	2.9	2.0	1.1	0.5

* Accounting for 57 percent of the world population in 2005/2007.

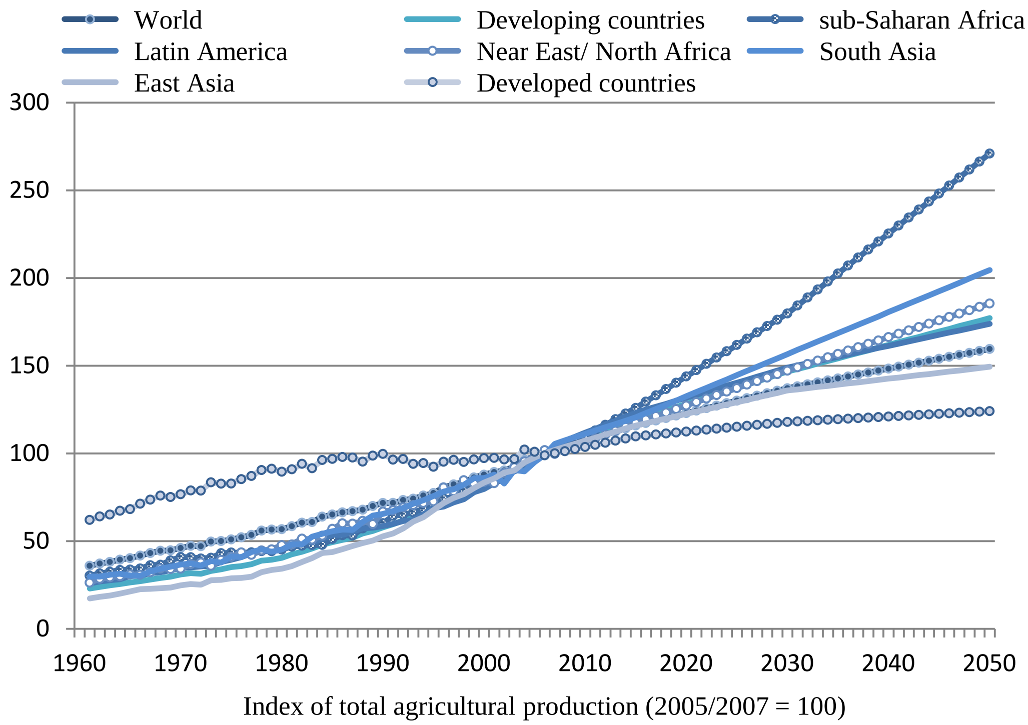
Table 4.2 shows historical and projected annual growth rates of total agricultural production. It clearly brings out the slowdown in expected production growth as compared with the past. The reasons for this were discussed in Chapter 3: mainly the projected deceleration in demand for agricultural products which in turn is a reflection of the decelerating growth of population and of the fact that an ever increasing share of population

[65] Since total agricultural production is measured by weighing individual products with average international prices, the price-based index of the volume of production grows faster than aggregates expressed in physical units or using a calorie-based index as diets change away from staples to higher value commodities (see Chapter 3, Box 3.1).

gradually attains middle to high levels of food consumption. This slowdown is particularly pronounced in developed countries[66] and for East Asia, while the group of better-off countries (defined as having a 2005/2007 daily calorie supply of over 2700 kcal per person) is expected to follow a similar pattern.

Figure 4.1 shows the increase of agricultural production (over its base year level) by region. It brings out that although growth in production would slowdown, it still means that by 2050 agricultural production could more than double in South Asia and nearly triple in sub-Saharan Africa.

Figure 4.1 Agricultural production by region



The annual growth of world agricultural production is projected to fall from 2.2 percent over the last decade to 1.3 percent over the period to 2030 and 0.8 percent from 2030 to 2050 (Table 4.2). However, one should not lose sight of the fact that the incremental quantities involved are considerable: by 2050 annual cereal production would increase by 940 million tonnes (+46 percent) and meat production by almost 200 million tonnes (+76 percent). The latter would require ample increases in the production of concentrate feeds. For example, almost 60 percent of the additional 443 million tonnes of maize produced annually by 2050 would be for animal feeds (23 percent for biofuels) and soybean production would need to increase by nearly 80 percent to 390 million tonnes in 2050. The share of livestock production (meat, milk and dairy products and eggs) in total world production would increase from 36 percent in 2005/2007 to 39 percent in 2050 (from 30 to 35 percent in the developing countries).

Nearly 90 percent of the increase in (annual) production would take place in developing countries, which would raise their share in world agricultural production from 67 percent in

[66] The slight increase in the annual growth rate for 2005/2007 to 2030 as compared with the growth rate of the preceding decade is due to additional production to meet the demand for biomass feedstock in biofuel production.

2005/2007 to 74 percent in 2050. This increase would be particularly strong for livestock production, going from 55 percent in 2005/2007 to 68 percent in 2050.

With a view to analyzing natural resource use in agricultural production, one should bear in mind that the bulk of the foods consumed are produced locally. On average at present only 19 percent[67] of world production enters international trade (corresponding to 17 percent for cereals and 14 percent for meats), with of course wide variation among individual countries and commodities.

4.2 Crop production

Growth in crop production (Table 4.3) mirrors growth in total agricultural production (Table 4.2) and the observed deceleration in growth is even more accentuated with the weight of livestock production in total agricultural production increasing in all regions (except in developed countries). Crop production growth is seen to decelerate in all regions, in particular in developed countries[68] and East Asia. Naturally, growth prospects differ among countries and crop sectors with, in general, slow growth foreseen for cereals like rice and more vigorous growth for coarse grains and some oilseeds used for feeding purposes in the livestock sector (see section 3.2 in Chapter 3).

Table 4.3 Annual crop production growth (percent p.a.)

	1961-2007	1987-2007	1997-2007	2005/2007-2030	2030-2050
World	2.2	2.3	2.3	1.3	0.7
Developing countries	3.0	3.1	3.0	1.4	0.8
idem, excl. China and India	2.8	2.8	3.2	1.7	1.0
Sub-Saharan Africa	2.6	3.3	3.0	2.4	1.9
Latin America and the Caribbean	2.7	2.9	3.7	1.7	0.7
Near East / North Africa	2.9	2.5	2.4	1.4	0.9
South Asia	2.6	2.4	2.1	1.5	0.9
East Asia	3.4	3.6	3.2	1.1	0.3
Developed countries	0.8	0.4	0.5	0.8	0.3
44 countries with over 2700 kcal/person/day in 2005/2007*	2.6	2.9	2.1	1.1	0.4

* Accounting for 57 percent of the world population in 2005/2007.

4.2.1 Sources of growth

Growth in crop production comes on account of growth in crop yields and expansion in the physical area (arable land) allocated to crops which, together with increases in cropping intensities (i.e. by increasing multiple cropping and/or shortening of fallow periods), leads to an expansion in the actually harvested area.

For the purposes of this study, a detailed investigation was made of present and future land/yield combinations for 34 crops under rainfed and irrigated cultivation conditions, for 105 countries and country groups. The informal method applied takes into account whatever information was available but is in the main based on expert-judgment (see Box 4.1 for a brief description of the approach followed).

[67] Measured as ((gross imports + gross exports) / 2) / production.
[68] The observation made in footnote 66 is particularly valid here since only crops are used as feedstock in biofuel production.

The summary results shown in Table 4.4 should be taken as rough indications only. For example, yields here are weighted yields (international price weights) for 34 crops[69], historical data for arable land are often unreliable for many countries, data on cropping intensities for most countries are non-existent and were derived by comparing data on harvested land, aggregated over all crops, with data on arable land, and so on.

Table 4.4 Sources of growth in crop production (percent)

	Arable land expansion		Increases in cropping intensity		Yield increases	
	1961-2007	2005/2007-2050	1961-2007	2005/2007-2050	1961-2007	2005/2007-2050
All developing countries	23	21	8	6	70	73
Sub-Saharan Africa	31	20	31	6	38	74
Near East/North Africa	17	0	22	20	62	80
Latin America and the Caribbean	40	40	7	7	53	53
South Asia	6	6	12	2	82	92
East Asia	28	0	-6	15	77	85
World	14	10	9	10	77	80
memo items						
Developing countries with less than 20 percent of their potentially arable land in use in 2005/2007*		35		6		59
Developing countries with over 60 percent of their potentially arable land in use in 2005/2007**		4		6		90

* 24 countries with a gross land balance exceeding 80 percent of total suitable land in 2005/2007.
** 19 countries with a gross land balance less than 40 percent of total suitable land in 2005/2007.
Source historical estimates: Bruinsma (2011).

Some 80 percent of the projected growth in crop production in developing countries would come from intensification in the form of yield increases (73 percent) and higher cropping intensities (6 percent; Table 4.4). The share due to intensification goes up to 94 percent in the land-scarce region South Asia and to 100 percent in Near East/North Africa and East Asia where increases in yield in some countries would also have to compensate for the foreseen decline in their arable land area. Arable land expansion will remain however an important factor in the growth of crop production in many countries of Latin America and sub-Saharan Africa although less so than in the past.

These summary results mask, of course, a wide variation among countries. The actual combination of the factors used in crop production (such as land, labour and capital) in the different countries will be determined by their relative prices. 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 it is. For the 24 developing countries, which at present use less than 20 percent of their land estimated to have rainfed crop production potential (the gross balance of prime and good land – see below), arable land expansion is

[69] Yields for the aggregate crop sector are gross values of production per harvested ha of all crops (comprising grains, vegetable oils, fruit, coffee, cotton, etc.). As such they are not very appropriate metrics for discussing yield growth issues, which is best done in terms of physical units (see Box 1.1 in Chapter 1).

projected to account for over one-third of their crop production growth. At the other end of the spectrum, in the group of 19 land-scarce countries (defined here as countries with more than 60 percent of their prime and good land already in use), the contribution of further land expansion to crop production growth is estimated to be very small (4 percent – see Table 4.4).

In the developed countries, the area of arable land in crop production peaked in the late 1960s, then remained stagnant for some time and has been declining since the mid-1980s. Hence growth in crop yields accounted for all of their growth in crop production and in addition compensated for declines in their arable land area. This trend is foreseen to continue also for the period to 2050 (see below). As a result, intensification (higher yields and more intensive use of land) is at the world level seen to contribute 90 percent to the growth in crop production over the projection period.

It is interesting to note that growth in wheat and rice production in more and more developing countries will have to come (at least on average) entirely from gains in yield (Table 4.5), with yield increases in many countries also compensating for a decline in the harvested land allocated to these crops. This reflects the fact that food consumption of these commodities reaches saturation levels in an increasing number of countries by 2050 (see also Chapter 3).

In the developing countries, 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. Expansion of harvested land therefore will continue to be a major contributor to production growth of maize.

Table 4.5 Sources of growth for major cereals in developing countries

		Annual growth (percent p.a.)			Contribution to growth (percent)	
		Production	Harvested land	Yield	Harvested land	Yield
Wheat	1961-2007	3.62	0.68	2.92	19	81
	2005/2007-2050	0.87	0.01	0.86	1	99
Rice, paddy	1961-2007	2.46	0.54	1.91	22	78
	2005/2007-2050	0.58	-0.05	0.63	-9	109
Maize	1961-2007	3.55	1.05	2.47	30	70
	2005/2007-2050	1.43	0.59	0.83	41	59

As discussed in Chapter 3, an increasing share of the increment in the production of cereals, mainly coarse grains, will be used for feeding purposes in livestock production. As a result, maize production in the developing countries is projected to grow at 1.4 percent p.a. against 0.9 percent for wheat and ‘only’ 0.6 percent for rice. Such contrasts are particularly marked in China where wheat and rice production are expected to grow only marginally up to 2030, then to actually decline over the remainder of the projection period, while maize production is still expected to grow by 37 percent. Hence there will be corresponding declines in the areas allocated to wheat and rice and an increase in the maize area.

An attempt was made to unfold crop production into rainfed and irrigated production, which offers an opportunity to estimate the contribution of irrigated crop production to total crop production. At present, irrigated agriculture, covering some 16 percent of the arable land in use, accounts for 44 percent of all crop production and some 42 percent of cereal production in the world. Similar estimates for developing countries are somewhat higher with 21 percent of arable land, accounting for 49 percent of all crop production and 60 percent of cereal production. The aggregate result of individual country projections is that these shares would change little over the projection period. It should be emphasized that except for some major crops in some countries, there is only limited data on irrigated land and production by crop and the results presented here are in good measure based on expert-judgment (see Box 4.1). Nevertheless, the results suggest a continuing importance of irrigated agriculture.

Box 4.1 **Projecting land use and yield growth**

This box gives a brief account of the approach followed in making projections for land use and future yield levels (see Appendix 2 in Bruinsma (2003) for a summary of the methodology applied).

These projections took as a starting point the crop production projections for 2030 and 2050 presented in Chapter 3. The crop production projections are based on demand and trade projections (including for livestock and feed commodities) which together make up consistent commodity balances and clear the world market. The base line scenario presents a view how the key food and agricultural variables may evolve over time, not how they should evolve from a normative perspective to solve problems of nutrition and poverty. An effort was made to draw to the maximum extent possible on FAO's in-house knowledge available in the various disciplines present in FAO. The quantitative analysis and projections were therefore carried out in considerable detail, also in order to provide a basis for making statements about the future concerning individual commodities and groups of commodities as well as agriculture as a whole, and for any desired group of countries. The analysis of land use and yields was carried out for as large a number of individual crops and countries as practicable (105 countries and country groups covering some 146 countries in total, 34 crops –see Appendix 1– and two land classes, rainfed and irrigated agriculture).

A major part of the data preparation work is the unfolding of the data for production (i.e. the FAOSTAT data for area harvested and average yield for each crop and country for the three-year average 2005/2007, converted into the crop classification used in this study) into its constituent components of area, yield and production for rainfed and irrigated land. Such detailed data come in part from AQUASTAT but are not generally available in any standard database. It became therefore necessary to piece them together from fragmentary information, from both published (e.g. from EUROSTAT for the EU countries) and unpublished documents giving, for example, areas and yields by irrigated and rainfed land at the national level or by administrative districts, supplemented by a good deal of expert-judgement. For a number of countries (e.g. for the United States of America, China, EU27, India and Indonesia) the data for irrigated agriculture were assembled at the sub-national level.

No data exist on total harvested land, but a proxy can be obtained by summing up the harvested areas reported for the different crops. Data are available for total arable land in agricultural use (physical area, called in FAOSTAT "arable land and land under permanent crops"). It is not known whether these two sets of data are compatible with each other, but this can be evaluated indirectly by computing the cropping intensity, i.e. the ratio of harvested area to arable land. This is an important parameter that can signal defects in the land use data. Indeed, for several countries (in particular for sub-Saharan countries but not only) the implicit values of the cropping intensities did not seem to be realistic. In such cases the harvested area data resulting from the crop statistics were accepted as being the more robust (or the less questionable) ones and those for arable area were adjusted (see Alexandratos, 1995 for a discussion of these problems) .

Data reported in FAOSTAT on arable irrigated land refer to 'area equipped for irrigation'. What is needed is the 'irrigated land actually in use' which is often between 80 and 90 percent of the area equipped. Data for the 'area in use' were taken from FAO's AQUASTAT data base.

The bulk of the projection work concerned the unfolding of the projected crop production for 2030 and 2050 into (harvested) area and yield combinations for rainfed and irrigated land, and making projections for total arable land and arable irrigated area in use.

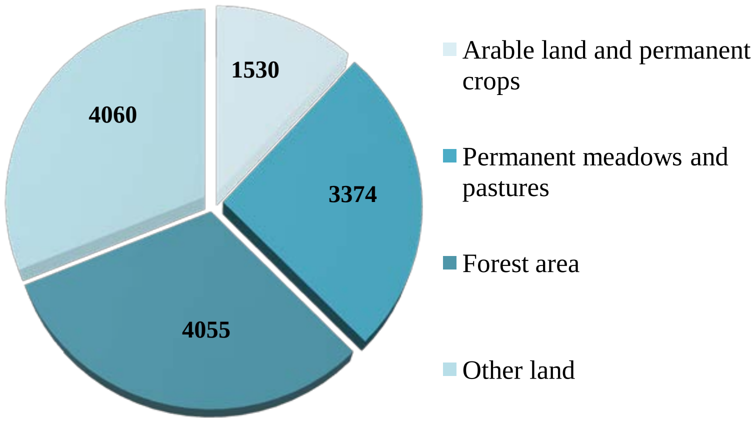
An initial mechanically derived projection for rainfed and irrigated harvested area and yield by crop (constrained to arrive at exactly the projected production) was evaluated against such information as recent growth in land and yield (total by crop) and the 'attainable yield' levels for most crops from the Global Agro-Ecological Zone (GAEZ) study (Fischer *et al*., 2011), and adjusted where needed. A similar projection was made for total arable rainfed and irrigated area which were then evaluated against estimates for the (maximum) potential areas for rainfed agriculture (from the GAEZ) and for irrigated agriculture (from AQUASTAT) and adjusted where needed. In addition, for irrigated area cropping patterns were checked against and made to obey certain cropping calendars (i.e. not all crops can be grown in all months of the year). A final step was to derive the implicit cropping intensities for rainfed and irrigated agriculture (by comparing harvested land over all crops with the arable area) and again adjusting areas (and yields) where needed. Normally it required several iterations before arriving at an 'acceptable' picture of the future.

Since the whole exercise is dependent on expert-judgment and requires an evaluation of each and every number, it is a time-consuming exercise. The projections presented in this study are not trend extrapolations as they take into account all knowledge available at present as to expected developments that might make evolutions in major variables deviate from their trend path (see also Appendix 2).

4.2.2 Land with crop production potential

According to FAOSTAT, in 2005/2007 about 12 percent (more than 1.5 billion ha; Figure 4.2) of the globe's land surface (13.0 billion ha, excluding 'inland water') is used for crop production (arable land and land under permanent crops). Arable land at present takes up some 28 percent of the prime (very suitable) and good (suitable and moderately suitable) land (see Table 4.7). This leaves a gross balance of unused prime and good land of some 3.2 billion ha and a net balance (i.e. excluding forests, strictly protected land and built-up areas) of some 1.4 billion ha. These balances of land with crop production potential suggest that there is still scope for further expansion of agricultural land. However, there is also a perception in some quarters that no more, or very little, additional land could be brought under cultivation. This section attempts to shed some light on these contrasting views, first by briefly discussing some estimates of land with crop production potential and some constraints to exploiting these suitable areas, and then by presenting the projected expansion of agricultural area over the period up to 2050.

Figure 4.2 World land area by category (million ha in 2005/2007)



Source: FAOSTAT (extraction April 2011).

How much land is there with crop production potential?

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 are favourable. A frequently asked question 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 a growing population?

A new version of the Global Agro-Ecological Zones (GAEZ v3.0) analysis was recently finished (Fischer G. *et al*., 2011). The GAEZ, combining soil, terrain and climate characteristics with crop production requirements, estimates the suitability (in terms of land extents and attainable yield levels; Box 4.2) for crop production of each land grid cell at the 5-arc-minute-level, at four technology and management levels (low, intermediate, high and mixed; see Box 4.3).

The suitability assessments provide extents for a range of suitability classes as follows: Very suitable, suitable, moderately suitable, marginally suitable, very marginally suitable and not suitable. Fischer *et al.* (2010) condense these six classes into three classes, (i) prime land, (ii) good land and (iii) marginal and not suitable land. *Prime land* is characterized as very suitable land with attainable yields of over 80 percent of maximum constraint-free yields. *Good land* represents suitable and moderately suitable land with attainable yield levels of 40 to 80 percent of maximum constraint-free yields and *marginal and not suitable land* includes all land with estimated attainable yields that are less than 40 percent of maximum constraint-free yields.

Box 4.2 **Agro-ecological zone (AEZ) methodology**

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

In summary, the AEZ framework contains the following basic elements:

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

Source: excerpt from Fischer *et al.* (2010).

Box 4. 3 **Assumed levels of inputs and management**

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

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

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

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

(1) Determine all land very suitable and suitable at high level of inputs.

(2) Of the balance of land after (1), determine all land very suitable, suitable or moderately suitable at intermediate level of inputs.

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

Source: Excerpt from Fischer *et al.* (2010).

Summing over all the crops covered in GAEZ and the technology levels considered ('mixed level of inputs'), about one-third (34 percent) of the world's land surface, or 4.5 billion ha[70], is estimated to be of prime (very suitable) or good (suitable and moderately suitable) quality for rainfed agriculture (Table 4.6). Of this area, some 1.6 billion ha is already under cultivation. It is interesting to note that of this 1.6 billion ha, some 300 million ha (or 19 percent) of agricultural land is on areas the GAEZ deems only marginally suitable or even not suitable, at least for rainfed agriculture. Such areas might have been made productive by applying irrigation (e.g. 32 million ha in desert areas). Excluding irrigated areas, still some 220 million ha (or 17 percent) of rainfed agriculture is apparently taking place on marginally and not suitable areas. An explanation could be that farmers might have no choice or maybe are prepared to accept (relatively) low yields or that not suitable land (43 million ha) has been made suitable through man-made interventions (e.g. through terracing of land with too steep slopes like in Yemen). The remainder of the discussion below is limited to areas of prime and good quality.

Table 4.6 Land with rain-fed crop production potential (world; million ha)

	Total	Potential	VS**	S	MS	mS	vmS	NS
Total land*	13 295	4 495	1 315	2 187	993	1 111	1 627	6 061
of which in agricultural use (1999/2001)	1 559	1 260	442	616	201	120	104	75
of which rain-fed land	1 283	1 063	381	516	166	93	84	43
of which irrigated land	276	197	61	100	35	27	20	32
Gross balance of land with rain-fed potential		3 236	873	1 571	792	991	1 523	
Under forest	3 736	1 601	453	854	293	342	530	1 263
Strictly protected land***	638	107	30	50	27	39	59	432
Built-up land	152	116	41	61	14	12	10	15
Net balance of land with rain-fed potential		1 412	349	606	458	598	923	

Source: GAEZ-v3.0 in Fischer *et al.* (2011).

* Crops considered: cereals, roots and tubers, sugar crops, pulses and oil-bearing crops.

** Suitability classes are defined according to attainable yields as a percentage of the maximum constraint-free yield as follows: VS=Very Suitable, 80-100%, S=Suitable, 60-80%, MS= Moderately Suitable, 40-60% mS=marginally Suitable, 20-40%, vmS=very marginally Suitable, 5-20%, NS=Not Suitable, <5%; Prime land = VS and Good land = S + MS.

*** Of land at present not cultivated, under forest or built-up.

[70] There are major differences with the results of the 2002 version of the GAEZ analysis (Fischer *et al.*, 2002) as reported in Bruinsma (2003). In general, the estimates for the extents of suitable land are higher in the 2011 analysis, certainly considering that in the present version certain crops (e.g. fruits and vegetables) and lands that are only marginally suitable were not taken into account. Given the multiple changes as compared with the GAEZ 2002 (completely new data, many more LUTs, etc.) it is extremely difficult to trace back the sources for the differences in the results of the 2002 and 2011 versions of the GAEZ.

Likewise developing countries as a whole have some 2.9 billion ha of prime and good quality land (see Table 4.7) of which a quarter (700 million ha or 24 percent) was in 1999/2001 in use in agriculture. The gross land balance at world level of 3.2 billion ha (2.2 billion ha in developing countries) would therefore seem to provide significant scope for further expansion of agriculture. However, this favourable impression needs to be qualified by a number of considerations and constraints.

First, the gross balance ignores land uses other than for growing crops, so forest cover, protected areas and land used for human settlements and economic infrastructure are not taken into account. Excluding prime and good land currently under forests or built-up areas or on strictly protected land (grasslands, scrub and woodland and non-vegetated land not yet in agricultural use), the remaining net balance amounts to 1.4 billion ha (960 million ha in developing countries), still a considerable amount compared with the current arable area.

Second, the net land balance is very unevenly distributed among regions and countries. For example, some 85 percent of the remaining 960 million ha in developing countries is to be found in sub-Saharan Africa (450 million ha) and Latin America (360 million ha) with very little or no land remaining in the other regions. In addition, about half of the remaining land is concentrated in just seven countries (Brazil, Argentina, Sudan, China, the Democratic Republic of the Congo, Angola and Mozambique). At the other extreme, there is virtually no prime and good land left in many countries in the Near East and North Africa, South Asia, and in Central America and the Caribbean. Even within the relatively land-abundant regions there is great diversity of land availability, in terms of both quantity and quality, among countries and sub-regions.

Third, and probably more important than allowing for non-agricultural uses of land with crop production potential is the method used to derive the estimates: it is enough for a piece of land to support a single crop at a minimum yield level (40 percent of the maximum constraint-free yield) for it to be classified as suitable (prime or good) land. For example, large tracts of land in North Africa that permit the cultivation of only olive trees (and a few other minor crops) are counted as suitable, even though there may be little use for them in practice. The notion of overall land suitability is therefore of limited meaning, and it is often more appropriate to discuss suitability for individual crops.

Fourth, much of the remaining land suffers from constraints such as ecological fragility, low fertility, toxicity, high incidence of disease or lack of infrastructure. These factors reduce its productivity, and require high input use and management skills to permit its sustainable use or prohibitively high investments to make it accessible or disease-free. Fischer *et al.* (2002) show that more than 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 and human intervention can also lead to deterioration of the land's productive potential, for example through soil nutrient mining, soil erosion or salinization of irrigated areas. Hence the evaluation of suitability may contain elements of overestimation, and much of the land balance cannot be considered as a resource that is readily useable for food production on demand.

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 the estimates of available cultivable land, together with their underlying methods, and shows their extremely wide range. Young (1999) offers a critique of the estimates of available cultivable land, including those given in Alexandratos (1995), stating that they often represent gross overestimates.

Table 4.7 Land with rain-fed crop production potential by region (million ha)

	Total land surface	Suitable land*	Of which		Of which in use as (1999/2001)		Gross balance	Not usable**	Net balance
			Prime land	Good land	Rainfed land	Irrigated land			
World	13 295	4 495	1 315	3 180	1 063	197	3 236	1 824	1 412
Developing countries	7 487	2 893	816	2 077	565	138	2 190	1 227	963
Sub-Saharan Africa	2 281	1 073	287	787	180	3	890	438	451
Latin America	2 022	1 095	307	788	137	15	943	580	363
Near East / North Africa	1 159	95	9	86	38	12	45	9	37
South Asia	411	195	78	117	85	55	55	43	11
East Asia	1 544	410	126	283	122	53	234	140	94
Other developing countries	70	25	9	15	2	0	23	16	7
Developed countries	5 486	1 592	496	1 095	497	58	1 037	590	447
Rest of the world***	322	11	3	8	2	0	8	7	1

Source: GAEZ-v3.0 in Fischer *et al.* (2011).

* Crops considered: cereals, roots and tubers, sugar crops, pulses and oil-bearing crops. Includes Very Suitable, Suitable and Moderately Suitable land.

** Land under forest, built-up or strictly protected.

*** Countries not included in the regions above and not covered in this study.

4.2.3 Expansion of land in crop production

Recently concerns have been voiced that agriculture might, in the not too distant future, no longer be able to produce the food needed to sustain a still growing world population at levels required to lead a healthy and active life. The continuing decline of arable land (in use) per person (Figure 4.3) is often cited as an indicator of impending problems. The underlying cause for such problems is perceived to be an ever increasing demand for agricultural products facing finite natural resources such as land, water and genetic potential. Scarcity of these resources would be compounded by competing demands for them originating in urbanization, industrial uses and use in bio-fuel production, by forces that would change their availability such as climate change and the need to preserve resources for future generations through environmentally responsible and sustainable use.

Naturally, one could interpret the declining arable land per person in parallel with the observed increasing average food consumption per person as a sign of ever increasing agricultural productivity (crop yields). In practice, changes in arable land (in use) per person will be the result of these countervailing forces (population / demand growth and increasing crop yields) with the exact outcome differing among countries. This section will address a few of the above-mentioned issues by unfolding the resource use implications of the crop production projections presented in the preceding chapter but, as shown in Figure 4.4, an advance conclusion could be that the average area of arable land in use per person is expected to stabilize towards the end of the projection period.

The perception that there is no more, or very little, new land to bring under cultivation might be well grounded in the specific situations of land-scarce countries and regions such as South Asia and the Near East/North Africa but may not apply, or may apply with much less force, to other parts of the world. As discussed above, there are still as yet unused 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, as noted, this land may lack infrastructure, be partly under forest cover or in wetlands which should 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 continues to take place. It does so mainly in countries which 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. It also has been expanding in countries with abundant land resources that could profit from the growth of demand for their exports, e.g. Brazil. On average at the global level, 4 million hectares of arable land were added annually over the period 1961 to 2007 (Figure 4.4). The data show that expansion of arable land continued to be an important source of agricultural growth in sub-Saharan Africa, Latin America and East Asia (Table 4.8). This includes countries with ample land resources with potential for crops facing fast demand growth, particularly for exports and for non-food uses, e.g. soybeans in South America and the oil palm in Southeast Asia. Indeed, oil crops have been responsible for a good part of the increases in total cultivated land in the developing countries and the world as a whole, albeit often at the expense of forest land.

The projected expansion of arable land in crop production shown below in Tables 4.8, 4.9 and 4.10, has been derived for rainfed and irrigated land separately. Starting with the production projections for each crop, the land and yield projections were derived drawing on expert judgement and taking into account: (a) base year (2005/2007) data on total harvested land and yield by crop; (b) data or often estimates for harvested land and yield by crop for rainfed and irrigated land; (c) data on total arable rainfed and irrigated land and their expected increases over time; (d) likely increases in yield by crop and land class; (e) plausible increases in cropping intensities, and (g) the (net) land balances for rainfed and irrigated agriculture[71]. Base year data for total arable land were for several developing countries adjusted[72] to – among other things – arrive at cropping intensities that seemed more meaningful. This is reflected in column '2005/2007 adjusted' in Table 4.8.

The overall result for developing countries is a projected net increase in the arable area of some 107 million ha (from 968 in the base year to 1075 in 2050), an increase of 11 percent (see Table 4.8). Not surprisingly, the bulk of this projected expansion is expected to take place in sub-Saharan Africa (51 million) and Latin America (49 million), with almost no land expansion in South Asia, and a constant area in Near East/North Africa and East Asia.

The arable area in the world as a whole expanded between 1961/63 and 2005/2007 by 176 million ha, the result of two opposite trends: an increase of 230 million ha in the developing countries and a decline of 54 million ha in the developed countries (Table 4.8). The arable land area in the latter group of countries peaked in the mid-1980s (at 684 million ha) and declined ever since. This decline in the arable area has been accelerating over time. 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. The projections of this study foresee a further slow decline in their arable area to 608 and 586 million ha in 2030 and 2050 respectively (it should be noted that this could change should a sustained growth in the demand for biofuels materialize).

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[71] See Box 1 in Bruinsma (2011) for an explanation of the approach followed.

[72] Also, data on total arable land and harvested land by crop for China are often unreliable and have been adjusted based on additional information.

Figure 4.3 Arable land per capita (ha in use per person)

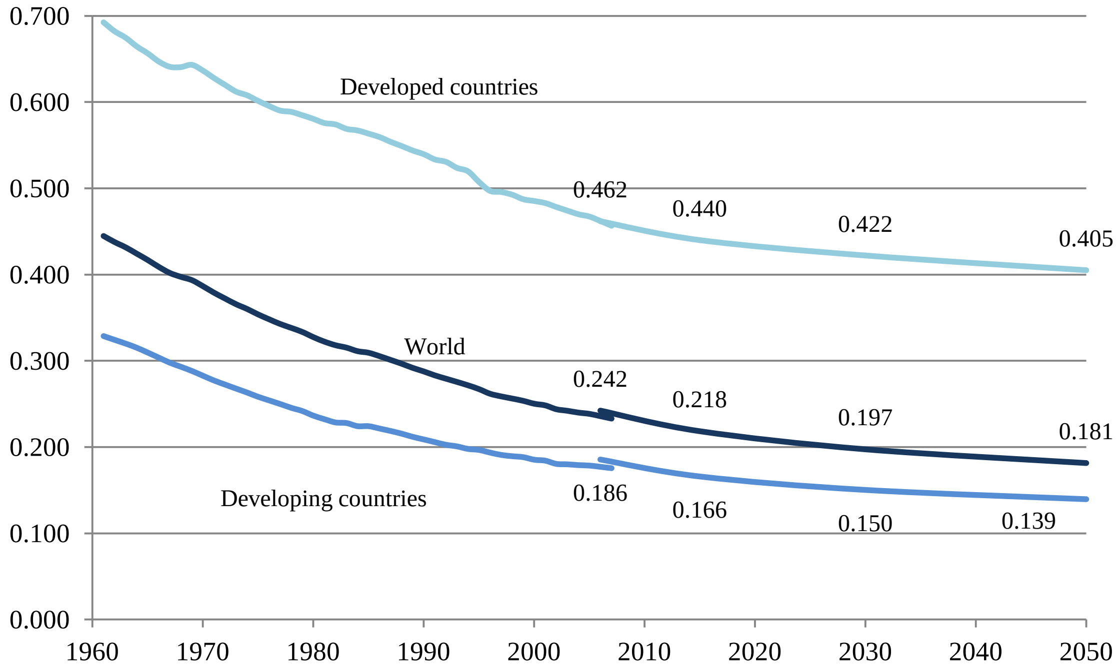
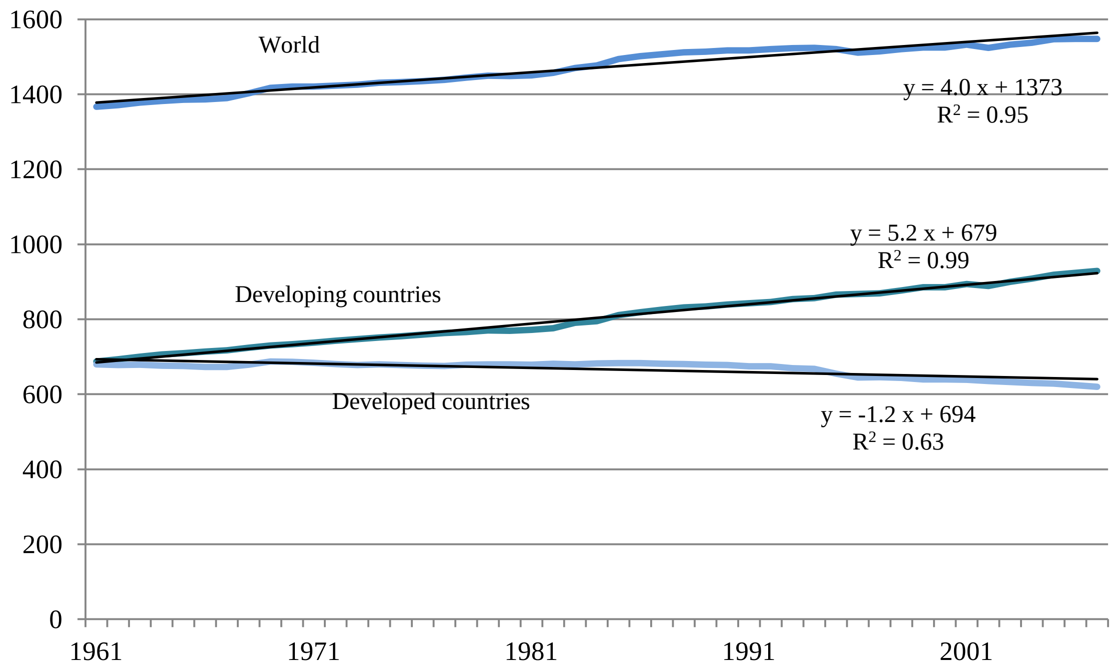


Figure 4.4 Arable land and land under permanent crops: past developments



The overall results are shown in Figure 4.5. The slowdown in the expansion of arable land (and its eventual decline) is of course a direct consequence of the projected slowdown in the growth of crop production and the assumed continuing (albeit slower than in the past) increase in crop yields (see below). Measured from the base year 2005/2007, the net result for the world as a whole would by 2050 be an increase in the arable land area of some 70 million ha, consisting of an increase by almost 110 million ha in the developing countries and a decline by nearly 40 million ha in the developed countries (Table 4.8).

Table 4.8 Total arable land in use: data and projections

	Arable land in use					Annual growth		
	1961/1963	2005/2007	2005/2007 adjusted	2030	2050	1961-2007	1991-2007	2005/2007-2050
	million ha					percent p.a.		
World	1 372	1 548	1 592	1 645	1 661	0.28	0.13	0.10
Developed countries	678	624	624	608	586	-0.17	-0.51	-0.14
Developing countries	693	923	968	1 036	1 075	0.65	0.60	0.24
idem excl. China and India	427	604	668	734	775	0.74	0.70	0.34
Sub-Saharan Africa	133	200	240	266	291	0.83	1.25	0.44
Latin America	105	167	202	235	251	0.98	0.61	0.49
Near East / North Africa	86	97	84	84	84	0.31	-0.17	0.00
South Asia	191	204	206	210	213	0.14	0.06	0.08
East Asia	178	255	236	241	236	0.93	0.87	0.00

It should be emphasized that all the estimates for expansion of arable land presented above are estimates of net expansion of arable area, i.e. they do not take into account the development of additional hectares of arable land needed to compensate for land taken out of production due for example to severe land degradation. Unfortunately there is only anecdotal evidence of the extent of this phenomenon and there are no reliable estimates of the extents of land that need to be replaced annually on a global scale. Bringezu *et al.* (2010) mention an estimate of 2 to 5 million ha of global arable land lost every year to soil erosion and another estimate of 3 million ha lost annually to severe land degradation, but these estimates should be taken as rough indications only.

The bulk of arable land in use is concentrated in a small number of developing countries (Figure 4.6). An increasing number of developing countries would witness a decline in the arable land area towards the end of the projection period and embark on a pattern already seen for most developed countries (with production only increasing very slowly and increases in yield permitting a reduction in harvested crop areas).

Although the developing countries' arable area is projected to expand by 107 million ha over the projection period, the harvested area would increase by 130 million ha or some 14 percent, due to increases in cropping intensities (Table 4.9). The overall cropping intensity for developing countries could rise by about 3 percentage points over the projection period (from 95 to 98 percent). Cropping intensities continue to rise through shorter fallow periods and more multiple cropping. An increasing share of irrigated land in total agricultural land also contributes to more multiple cropping. Over one-third of the arable land in South and East Asia is irrigated (land in use), a share which is projected to rise to over 36 percent in 2050. This high share of irrigation in total arable land is one of the reasons why the average cropping intensities in these regions are considerably higher than in other regions. Average cropping intensities in developing countries, excluding China and India (which together account for well over half of the irrigated area in the developing countries) are and will continue to be much lower.

Figure 4.5 Arable land and land under permanent crops: past and future

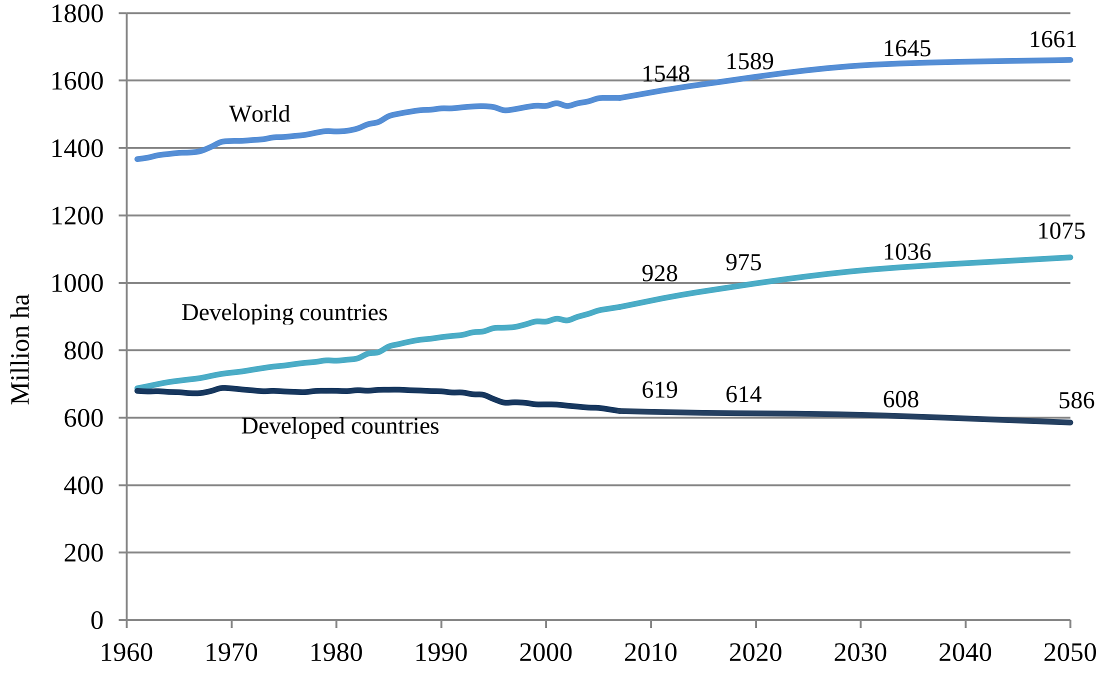
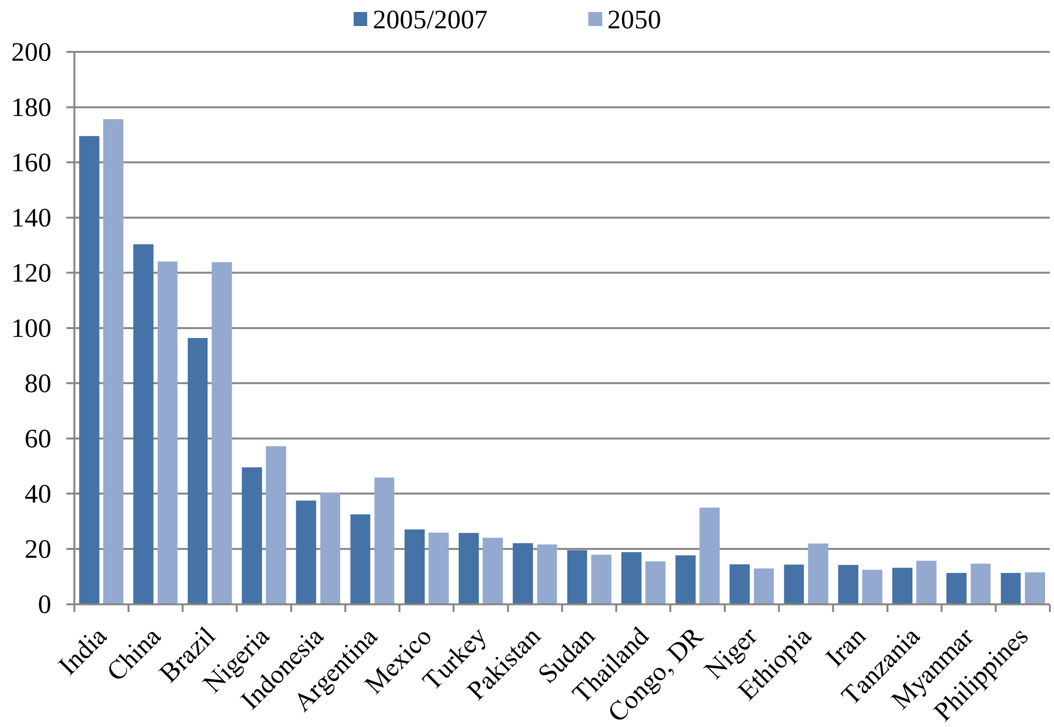


Figure 4.6 Developing countries with over 10 million ha of arable land in use



Note: These 18 countries account in 2005/2007 for 75 percent of the total arable land in use in developing countries.

Table 4.9 Arable land in use, cropping intensities and harvested land

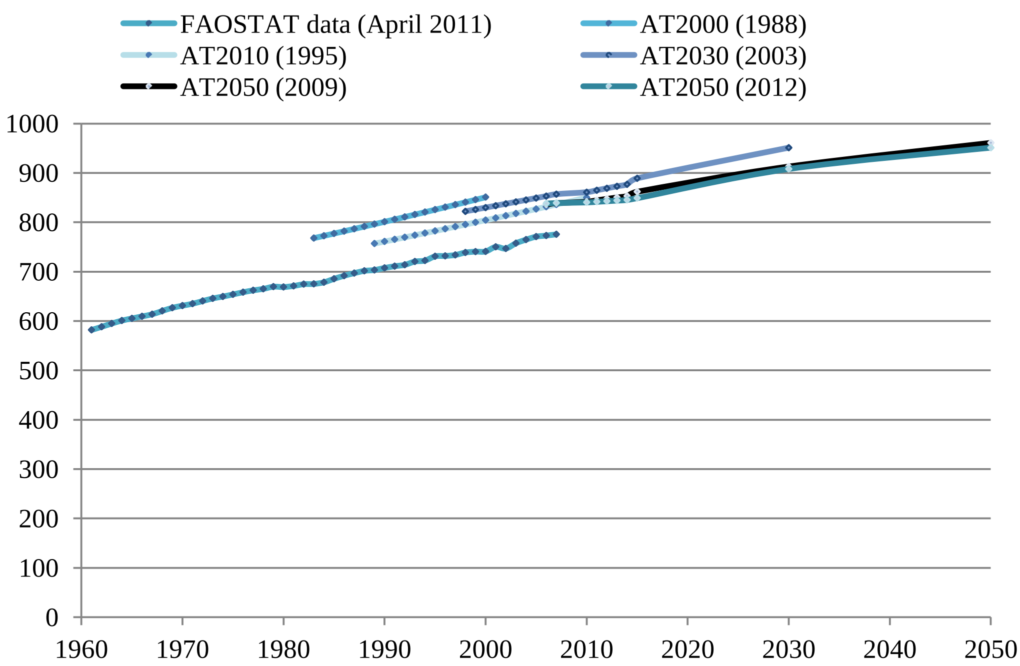
		Total land in use			Rainfed land			Irrigated land*		
		ARL#	CI	HL	ARL	CI	HL	ARL	CI	HL
World	2005/2007	1 592	88	1 393	1 335	80	1 067	257	127	326
	2050	1 661	92	1 527	1 385	84	1 162	277	132	365
Developed countries	2005/2007	624	75	470	569	74	419	56	91	50
	2050	586	81	474	530	79	420	56	97	55
Developing countries	2005/2007	968	95	923	767	84	648	201	137	276
	2050	1 075	98	1 053	855	87	742	220	141	310
excl. China and India	2005/2007	668	82	551	581	77	445	88	121	106
	2050	775	87	674	676	81	549	99	125	125

ARL = arable land (million ha); CI = (HL/ARL) = cropping intensity in percent; HL = harvested land (million ha).
* Irrigated area actually in use as distinguished from 'area equipped for irrigation' (Table 4.10).

Rising cropping intensities could be one of the factors responsible for increasing the risk of land degradation and thus threatening sustainability, in particular when not accompanied by land conservation measures, including adequate and balanced use of fertilizers to compensate for the removal of soil nutrient by crops. It is expected that this risk will continue to exist because in many cases the socio-economic conditions do not favour the implementation of the technological changes required to ensure the sustainable intensification of land use.

Addendum

Comparison with the previous AT20XX projections for arable land (million ha) in developing countries excluding China.



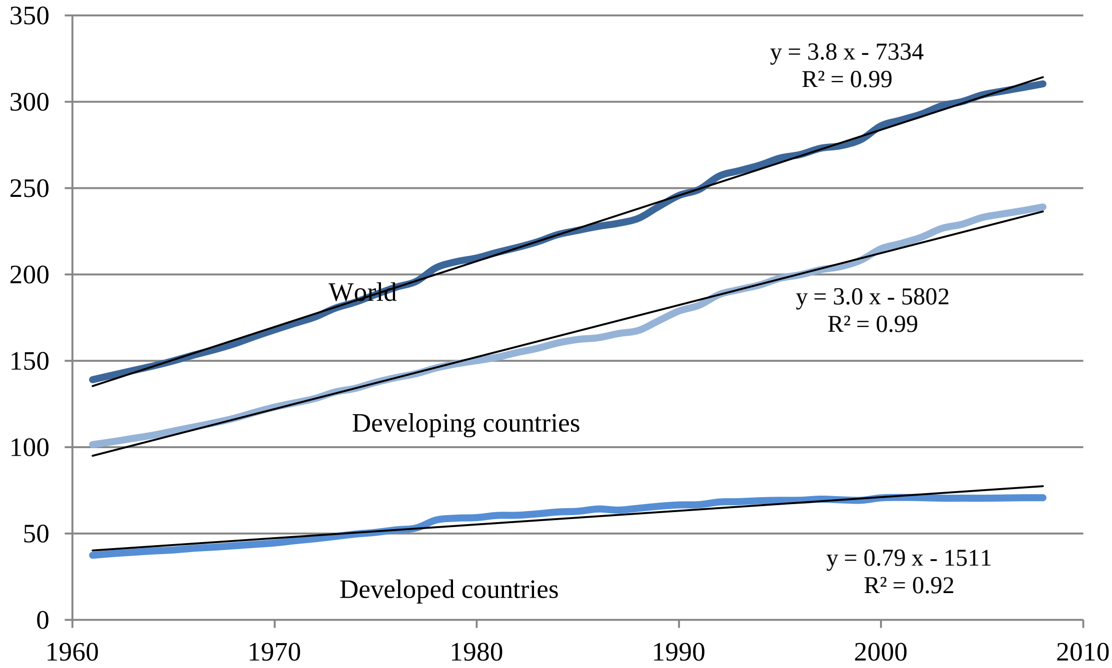
Notes: (i) The AT2000 and AT2010 studies did not include China; (ii) The difference between the FAOSTAT data and the base year data for the projections reflects the adjustments made in the base year data for this study as explained above (Table 4.8).

4.2.4 Expansion of irrigated land

The area equipped for irrigation has been continuously expanding (mainly in developing countries and only slowly in developed countries) although more recently this expansion has slowed down (Figure 4.7 and Table 4.10). The projections of irrigation presented below reflect necessarily scattered information on existing irrigation expansion plans in the different countries, potentials for expansion (including water availability) and need to increase crop production. The projections include expansion in both formal and informal irrigation, the latter being important in particular in sub-Saharan Africa.

The importance of irrigated agriculture cannot be overstated. At present it accounts with 16 percent of the arable area for 44 percent of total crop production (see section 4.2.1 above). Not surprisingly therefore irrigated arable area has been expanding faster than rainfed area and on a net basis the world expansion of arable area over time seems to come all on account of irrigated area (see SOLAW – FAO, 2011b and Figure 4.8[73]). On closer inspection however it is noted that this near-constancy of rainfed area at the global level consists of a fairly sharp decline in the developed countries and a compensating increase in the developing countries.

Figure 4.7 Area equipped for irrigation (million ha)



The aggregate projection result shows that the area equipped for irrigation could expand by 20 million ha (or 6.6 percent) over the period from 2005/2007 to 2050 (Table 4.10), nearly all of it in the developing countries. This means that some 10 percent of the land with current irrigation potential in this group of countries could be brought under irrigation, and that by 2050 some 60 percent of all land with irrigation potential[74] (417 million ha) would be in use.

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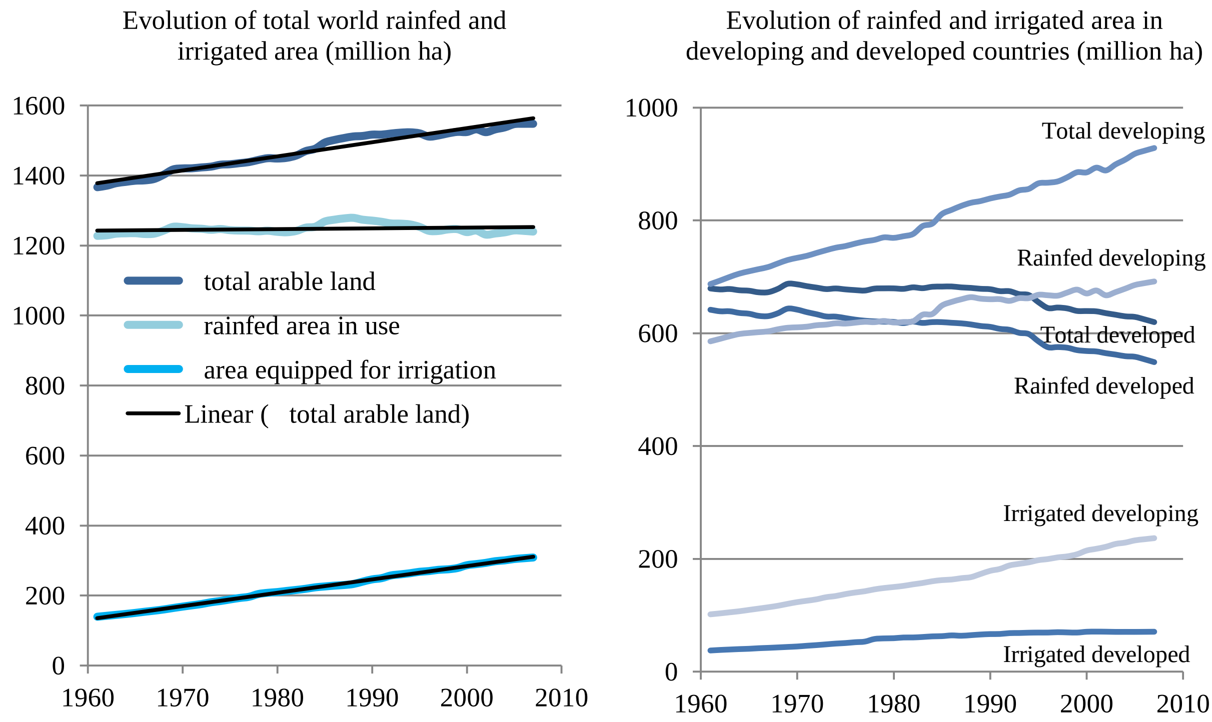
[73] The rainfed area in Figure 4.8 has been derived as the difference between total arable land in use and the area equipped for irrigation. This is not entirely correct as the irrigated area in use as a share of the equipped area is at present some 85 percent. If however one assumes that this share is constant over time, the developments in rainfed and irrigated areas can be compared.

[74] Estimates of "land with irrigation potential" are difficult to make and such estimates should only be taken as rough indications.

If one takes into account new irrigated areas required to replace those parts of existing irrigated areas lost to degradation, water shortages, etc., the remaining areas in developing countries suitable for irrigation but not yet in use, will be much less.

Figure 4.8 The historical evolution of rainfed and irrigated arable area



The expansion of irrigation would be strongest (in absolute terms) in the more land-scarce regions hard-pressed to raise crop production through more intensive cultivation practices, such as East Asia (+8 million ha), South Asia (+3 million ha), and the Near East/North Africa (+3 million ha), although in the latter region further expansion will become increasingly difficult as water scarcity increases and competition for water from households and industry will continue to reduce the share available to agriculture. China and India alone account for more than half (54 percent) of the irrigated area in developing countries. Although the overall arable area in China is expected to decrease further, the irrigated area would continue to expand through conversion of rainfed land.

The developed countries account for over a fifth of the world's irrigated area, 68 out of 302 million ha (Table 4.10). Annual growth of their irrigated area reached a peak of 3.0 percent in the 1970s, dropping to 1.1 percent in the 1980s and to only 0.1 percent over the last decade for which data are available (1997-2007). For the developed countries as a group only a very marginal expansion of the irrigated area (supplemented with improvements on existing areas) is foreseen over the projection period so that the world irrigation scene will remain dominated by events in the developing countries. In terms of annual growth, the projected net increase in land equipped for irrigation would represent a sharp slowdown as compared with the historical growth. The projected slowdown which applies to most countries and regions, 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.

Table 4.10 Area equipped for irrigation

	1961/ 1963	2005/ 2007	2030	2050	1961 -2007	1997 -2007	2005/ 2007 -2050
	Million ha				Annual growth (% p.a.)		
World	142	302	314	322	1.8	1.3	0.1
Developed countries	38	68	69	69	1.5	0.1	0.0
Developing countries	103	235	246	253	1.9	1.7	0.2
idem excl. China and India	47	108	114	119	2.0	1.4	0.2
Sub-Saharan Africa	3	6	7	7	1.9	0.7	0.5
Latin America	8	20	22	23	2.1	1.0	0.3
Near East / North Africa	15	31	32	34	1.9	1.2	0.2
South Asia	37	90	90	93	2.1	1.6	0.1
East Asia	40	88	95	96	1.6	2.2	0.2

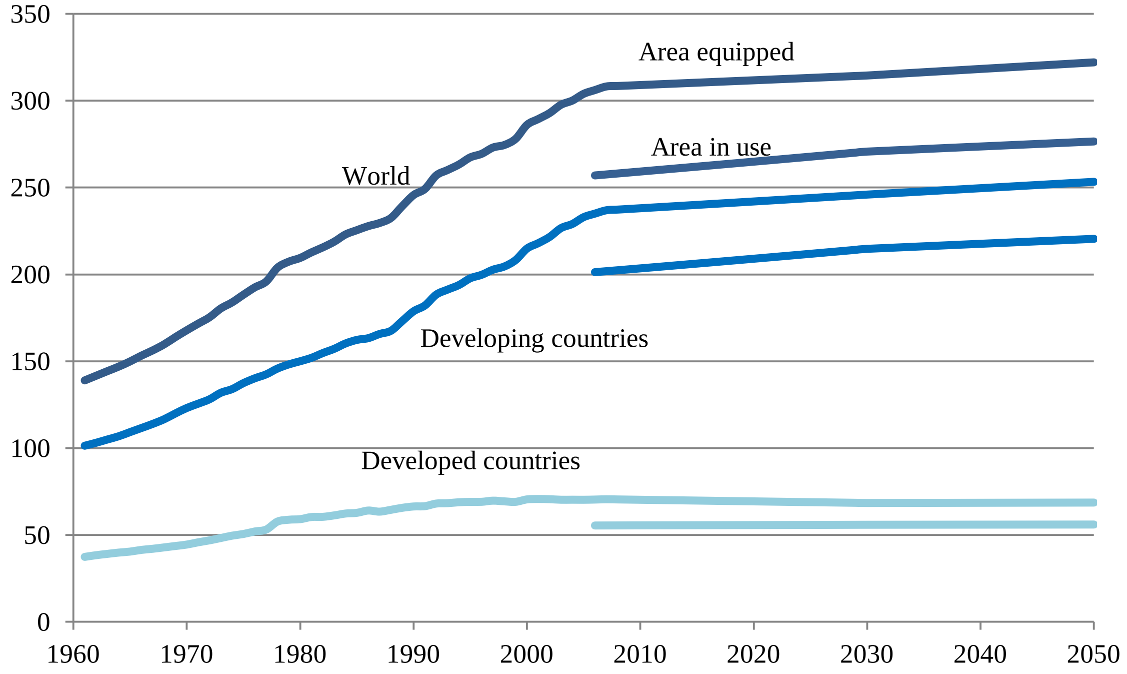
Most of the expansion of irrigated land is achieved by converting land in use in rainfed agriculture into irrigated land. Part of irrigation, however, takes place on arid and hyper-arid (desert) land which is not suitable for rainfed agriculture. It is estimated that of the 235 million ha irrigated at present in developing countries, some 39 million ha are on arid and hyper-arid land which could slightly increase over the period to 2050. In some regions and countries, irrigated arid and hyper-arid land forms an important part of the total irrigated land presently in use: 17 out of 31 million ha in the Near East/North Africa, and 16 out of 90 million ha in South Asia.

For the purpose of this study a distinction was made between the area equipped for irrigation and the irrigated area actually in use. Areas equipped might be temporarily or even permanently out of use for various reasons, including for maintenance, or because of degradation of irrigation infrastructure or since the area does not need to be irrigated in a particular year (the latter occurs often in developed countries with temperate climates where sprinkler irrigation is practiced only in dry summers). The percentage of the area equipped actually in use differs from country to country and could range from a low 40 to a high 100 percent, but on average over all countries is at present about 85 percent (expected to increase very slightly to 86 percent in 2050). So out of the 235 million ha equipped for irrigation in the developing countries in 2005/2007, some 201 million ha were assumed to be in use increasing to 220 million ha in 2050 (253 million ha equipped; see also Figure 4.9).

Although the irrigated area in use in developing countries would rise by 2050 by ‘only’ 10 percent (from 201 to 220 million ha from 2005/2007 to 2050), the harvested irrigated area could expand by 34 million ha (or 12 percent) due to a continuing increase in multiple cropping on both existing and newly irrigated areas (from 137 to 141 percent in 2050) and would account for well over a quarter of the total increase in harvested land (Table 4.9).

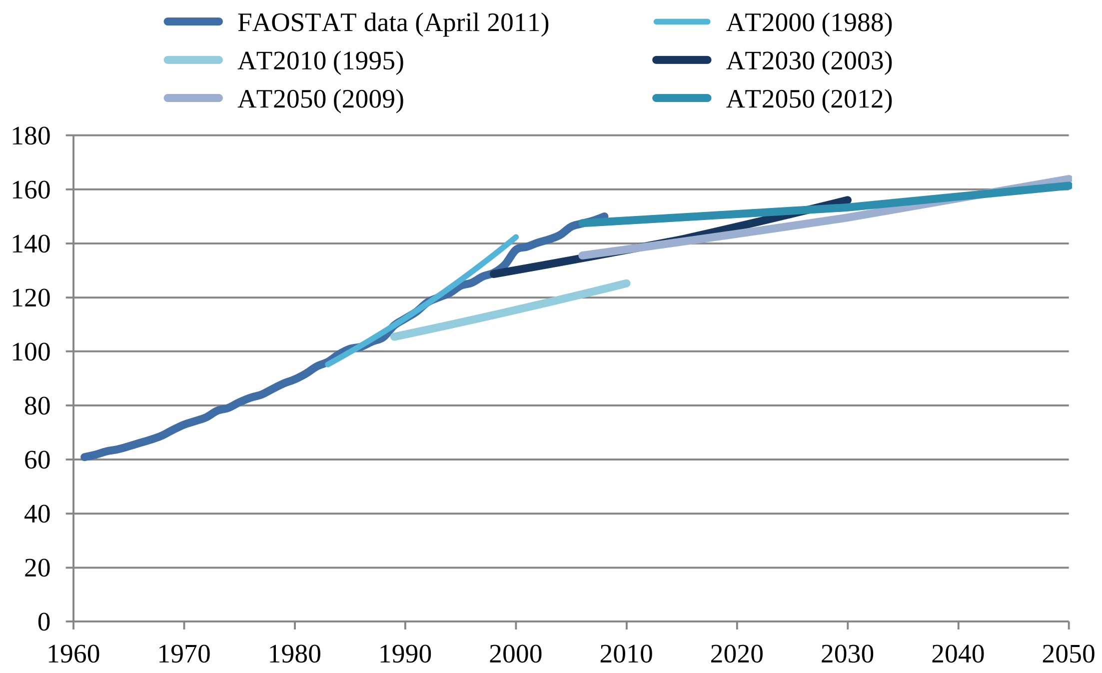
One should bear in mind that the projected expansion of irrigated land by 20 million ha is the increase in net terms. It assumes that losses of existing irrigated land due to, for example, water shortages or degradation because of salinization and water-logging, will be compensated for through rehabilitation 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. In investment terms, rehabilitation of existing irrigation schemes will represent the bulk of future expenditure on irrigation: 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 to 2050 would include some 172 million ha, of which nearly 90 percent would be for rehabilitation or substitution and the balance for net expansion.

Figure 4.9 Arable irrigated land: equipped and in use (million ha)



Addendum

Comparison with the previous AT20XX projections for irrigated arable land in use (million ha) in developing countries excluding China.



Notes: (i) The AT2000 and AT2010 studies did not include China; (ii) A problem is the continually revision of FAOSTAT data, sometimes fairly drastically (e.g. recently for India); (iii) FAOSTAT historical data were converted from 'equipped' into 'in use' applying a flat rate of 85.7 % to all years; (iv) The same procedure was applied to the projections of the AT2000, AT2010 and AT2030 studies which did not distinguish between irrigated arable land 'equipped' and 'in use'.

4.2.5 Irrigation water requirements and pressure on water resources[75]

A key question is whether there will be sufficient freshwater to satisfy the growing needs of agricultural and non-agricultural users. Agriculture already accounts for approximately 70 percent of the freshwater withdrawals in the world and is usually seen as one of the main factors behind the increasing global scarcity of freshwater.

The estimates of the expansion of land under irrigation presented in the preceding section provide a partial answer to this question since the assessment of irrigation potential already takes into account water limitations and since the projections to 2050 assume that agricultural water demand will not exceed available water resources[76].

The 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, and 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, runoff and groundwater recharge.

Table 4.11 shows the renewable water resources for the world and major regions. Average annual precipitation at the global level is about 800 mm per year, but varies from a low 160 mm in the most arid region (Near East/North Africa) to a high precipitation of about 1530 mm per year in Latin America. These figures give an impression of the extreme variability of climatic conditions facing the 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 intra-annual 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 due to 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 crop evapotranspiration and effective precipitation (i.e. precipitation minus runoff and groundwater recharge) over the growing period of the crop. It varies considerably with climatic conditions, seasons, crops and soil types. Consumptive water use in irrigation has here been computed for each country on the basis of the irrigated and harvested areas by crop as estimated for the base year (2005/2007) and as projected for 2050, taking into account crop growing phases and cropping calendars (see Hoogeveen, 2012 for an explanation of the methodology applied, a summary of which is also given in Bruinsma, 2011).

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[75] The methodology for estimating fresh water use in irrigation was developed by J. Hoogeveen of the Land and Water Division at FAO, who also performed the calculations for this report.

[76] 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 based on estimates of 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.

However, it is *water withdrawal for irrigation*, i.e. the volume of water extracted from rivers, lakes and aquifers for irrigation purposes, which is generally 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 and weed control.

Irrigation efficiency (here below termed *water use efficiency*) can be defined as the ratio between the crop water requirements, estimated as consumptive water use in irrigation plus water needed for land preparation and weed control in the case of paddy rice, and irrigation water withdrawal. Data on country water withdrawal for irrigation has been collected in the framework of the AQUASTAT programme. Comparison of these data with the consumptive use of irrigation was used to estimate water use efficiency[77] at the country level. For the world, it is estimated that the average water use efficiency was around 50 percent in 2005/2007, varying from 25 percent in areas of abundant water resources such as sub-Saharan Africa to 58 percent in South Asia where water scarcity calls for higher efficiencies (Table 4.11).

To estimate the irrigation water withdrawal in 2050, an assumption had to be made about possible developments in the water use efficiency (WUE) in 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 the water use efficiency: the estimated levels of water use efficiency in the base year and water scarcity[78]. A function was designed to capture the influence of these two parameters, bearing in mind that improving water use efficiency is a very slow and difficult process[79]. The overall result is that efficiency could increase marginally at the global level and in water rich regions, but more so in water scarce regions and countries (e.g. a 9 percentage point increase in the Near East/North Africa region; Table 4.11). 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 water use efficiency in water scarce regions. In contrast, in humid areas the issue of water use efficiency is much less relevant and is likely to receive little attention.

At the global level irrigation water withdrawal is expected to grow by about 6 percent, from the current 2760[80] km3/yr to 2926 km3/yr in 2050[81] (Table 4.11). The 6 percent increase in irrigation water withdrawal should be seen against the projected 12 percent increase in the harvested irrigated area (from 326 million ha in 2005/2007 to 365 million ha in 2050; Table 4.9). This difference is in part explained by the expected improvement in water use efficiency,

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[77] It should be noted that although the term 'water use efficiency' implies losses of water between source and destination, not all of this water is actually lost as much flows back into the river basin and aquifers and can be re-used for irrigation.

[78] Water scarcity or 'stress' measured as consumptive water use in irrigation as a percentage of renewable water resources.

[79] WUE was estimated across countries as: WUE = (country-specific intercept) – (1 / (1 + 1.85 * Stress))

[80] The estimated 2760 km3/yr is based on an estimated 1380 km3/yr consumptive water use and an average water use efficiency of 50 percent. The 1380 km3 consists of an 1190 km3 water consumption in irrigation (which is very close to the 1180 km3 estimated by Siebert and Döll (2009) for 1998-2002), and of an 190 km3 needed to flood rice paddy fields (94.3 million irrigated rice area in 2005/2007 flooded with on average 20 cm of water).

[81] A recent report from the OECD (OECD, 2012) estimates fresh water use in irrigation in 2000 at 2384 km3/yr (accounting for 67 percent of total fresh water use) and expects irrigation water use to fall by 2050 to 2049 m3/yr (37 percent of total fresh water use) mainly on account of fierce competition for fresh water from the industrial and domestic sectors.

leading to a reduction in irrigation water withdrawal per irrigated hectare, and in part due to 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. Due to its high water needs for flooding, the expected decline in the irrigated area allocated to rice, in particular in South and East Asia, is an important factor in limiting water demand. Globally it could fall from 94.3 million ha in 2005/2007 to 89.5 million ha in 2050, which alone would account for over 10 km3/yr decline in water withdrawals. Irrigated rice area declines are estimated as from 30.6 to 24.0 million ha in South Asia and from 53.5 to 52.7 million ha in East Asia (after peaking at 57.5 million ha in 2030).

Table 4.11 Annual renewable water resources and irrigation water withdrawal

	Renewable water resources*	Water use efficiency ratio		Irrigation water withdrawal		Pressure on water resources due to irrigation	
		2005/2007	2050	2005/2007	2050	2005/2007	2050
	cubic km	percent		cubic km		percent	
World	42 000	50	51	2 761	2 926	6.6	7.0
Developed countries	14 000	41	42	550	560	3.9	4.0
Developing countries	28 000	52	53	2 211	2 366	7.9	8.5
Sub-Saharan Africa	3 500	25	30	96	133	2.7	3.8
Latin America	13 500	42	42	183	214	1.4	1.6
Near East/North Africa	600	56	65	311	325	51.8	54.1
South Asia	2 300	58	58	913	896	39.7	38.9
East Asia	8 600	49	50	708	799	8.2	9.3

* Includes at the regional level ‘incoming flows’.

Irrigation water withdrawal in 2005/2007 was estimated to account for only 6.6 percent of total renewable water resources in the world (Table 4.11). However, there are wide variations between countries and regions, with the Near East/North Africa region using 52 percent of its renewable water resources in irrigation while Latin America barely uses 1.4 percent of its resources. At the country level, variations are even more pronounced. In the base year (2005/2007), 13 countries used already more than 40 percent of their water resources for irrigation, a situation which can be considered critical. An additional 9 countries consumed more than 20 percent of their renewable water resources, a threshold sometimes used to indicate impending water scarcity. The situation would worsen over the period to 2050, with two more countries crossing the 40 percent and another country the 20 percent threshold. If one would add the expected additional water withdrawals needed for non-agricultural use, the picture would not change much since agriculture represents the bulk of water withdrawal.

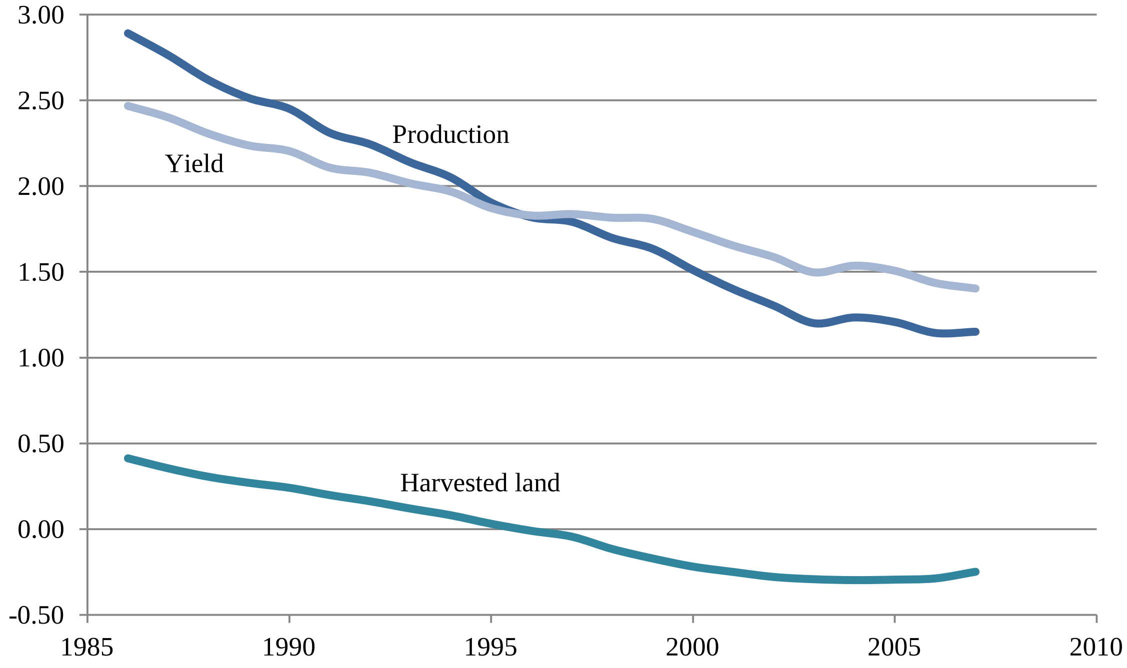
Nevertheless, for several countries, relatively low national figures may give an overly optimistic impression of the level of water stress: China, for instance, is facing severe water shortage in the north while the south still has abundant water resources. Already in 2005/2007, four countries (Libya, Saudi Arabia, Yemen and Egypt) used volumes of water for irrigation larger than their annual renewable water resources. Groundwater mining also occurs in certain parts of some other countries of the Near East and in South and East Asia, Central America and in the Caribbean; even if at the national level the water balance may still be positive. On average irrigation based on groundwater withdrawal accounts for some 38 percent of all irrigation at the world level (Siebert *et al.*, 2010), with high proportions for groundwater based irrigation in (apart from the countries mentioned above) India (64 percent), Bangladesh (74 percent) and the Syrian Arab Republic (68 percent). Such high reliance on groundwater extraction which often causes rapid declining groundwater levels should be a cause for concern.

In concluding this section on fresh water use in irrigation, for the developing countries as a whole, water use in irrigation currently represents a relatively small part of their renewable water resources. With the relatively small increase in irrigation water withdrawal expected between 2005/2007 and 2050, 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.

4.2.6 Crop yield growth

As discussed in section 4.2.1, it is expected that growth in crop yields will continue to be (and even more so than in the past) the mainstay of crop production growth, accounting for nearly 80 percent of the latter (well over 70 percent in developing countries and for all of it in the developed countries). Although the marked deceleration in crop production growth foreseen for the future (Table 4.3) could point to a similar deceleration in growth of crop 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. Some even believe 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 due to slower, evolutionary annual increments in yields, have, for all major crops, been far more important than quantum jumps in yields (for example see Byerlee, 1996).

Figure 4.10 Annual growth rates (percent) of world cereal production and yields (over preceding 25-year period; historical 1961 - 2007)



Such concerns are often based on the observed slowdown in yield growth for major crops, in particular cereals. Figure 4.10 shows the annual growth rates of cereal yields over sliding 25-year periods, which indeed confirm a gradual slowdown in such growth. The reasons for such slowdown however are more likely to be found in the observed slowdown in world cereal production than in certain resource constraints (including the genetic potential) becoming binding. As explained in Chapter 3, growth in cereal production, which at the global level equals demand for cereals, is decelerating in response to a slowing population growth and to an ever-increasing share of world population attaining medium to high levels of food intake. Figure 4.10 also shows that more recently growth in cereal yields even exceeded the growth in cereal production permitting a decline in the area allocated to cereals.

Harvested land and yields for major crops

As mentioned before, the production projections for the 34 crops covered in this report are unfolded into and tested against what FAO experts think are plausible land-yield combinations by agro-ecological rainfed and irrigated environment, taking into account whatever knowledge is available. A major input into this evaluation are the estimates regarding the availability of land suitable for growing crops and of yields attainable in each country and each agro-ecological environment which originate in the Agro-Ecological Zones work (Fischer *et al*., 2011). In practice such estimates are introduced as constraints to land and yield expansion but they also act as a guide to what can be grown where. The resulting land and yield projections, although partly based on past performance, are not mere extrapolations of historical trends since they take into account present-day knowledge about changes expected in the future. Chapter 1 (Figures 1.9 - 1.14) has examples of what future yields would be if they had been derived as mere extrapolations of historical trends.

The overall result for yields of all the crops covered in this study (aggregated with standard price weights) is, at the global level, a more than halving of the average annual rate of growth over the projection period as compared to the historical period: 0.8 percent p.a. during 2005/2007 to 2050 against 1.7 percent p.a. during 1961-2007 (for the developing countries the annual growth rates for these periods are 2.1 and 0.9 percent respectively). This slowdown in the yield growth is a gradual process which has been under way for some time (for example for the last ten-year period 1997-07, the annual yield growth was 1.6 and 1.9 percent for the world and the group of developing countries respectively) 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. The growth in soybean area and production (Table 4.12) has been remarkable mainly due to an explosive growth in Brazil and Argentina. Soybeans are 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 2050 the developing countries' share in world soybean production to over 70 percent, with four countries (Brazil, Argentina, China and India) accounting for 90 percent of total production in developing countries.

Table 4.12 Area and yields for major crops in the world

	Production million tonnes			Harvested area million ha			Yield tonnes/ha		
	1961/ 1963	2005/ 2007	2050	1961/ 1963	2005/ 2007	2050	1961/ 1963	2005/ 2007	2050
Wheat	235	614	858	206	222	225	1.1	2.8	3.8
Rice (paddy)	230	644	827	118	158	155	1.9	4.1	5.3
Maize	210	736	1 178	106	155	194	2.0	4.7	6.1
Soybeans	27	217	390	24	94	124	1.1	2.3	3.2
Pulses	44	60	100	69	73	62	0.6	0.8	1.6
Barley	84	137	186	59	56	64	1.4	2.4	2.9
Sorghum	44	60	102	47	45	53	0.9	1.3	1.9
Millet	25	32	60	43	37	42	0.6	0.9	1.4
Seed cotton	30	71	100	32	36	39	0.9	2.0	2.6
Rape seed	4	50	99	6	31	36	0.6	1.6	2.8
Groundnuts	15	36	68	17	24	35	0.9	1.5	2.0
Sunflower	7	29	49	7	23	28	1.0	1.3	1.7
Sugarcane	428	1 452	2 822	9	21	27	49	68	104
All cereals (rice milled)	843	2 069	3 009	654	704	763	1.3	2.9	3.9
All crops				978	1 256	1 380	439	924	1 296

Notes: crops selected and ordered according to (harvested) land use in 2005/2007 (excluding fruits and vegetables); Yields for 'all crops' are in ICP$ per ha.

For cereals, which occupy more than half of the harvested area in the world (56 percent) and in developing countries (52 percent), the slowdown in yield growth would be particularly pronounced: at the world level down from 1.9 percent p.a. in the historical period to 0.7 percent p.a. over the period to 2050 and from 2.3 to 0.8 percent p.a. in the developing countries (Table 4.13). Again this slowdown has been underway for some time.

The differences in the sources of growth for the various regions have been discussed before. Suffice it here to note that irrigated land is expected to play a more important role in increasing maize production, almost entirely due to China which accounts for over 40 percent of the developing countries' maize production and where irrigated land allocated to maize could almost double. Part of the continued, albeit slowing, growth in yields is due to 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 would not grow at all.

Increasing yields are often credited (see for example Borlaug, 1999) with saving land and thus diminishing pressure on the environment (e.g. 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 1242 kg/ha, 1604 million ha would have been needed to grow the 2069 million tonnes of cereals (rice milled) the world produced in 2005/2007. This amount was actually obtained on an area of only 704 million ha at an average yield of 2941 kg/ha Therefore, 900 million ha (1604 – 704) have been saved because of yield increases for cereals alone. This conclusion should be qualified however, since if there had been no yield growth, the most probable outcome would have been much lower production because of lower demand due to higher prices of cereals, and somewhat more land under cereals. Furthermore, in many countries the alternative of land expansion instead of yield increases does not exist in practice.

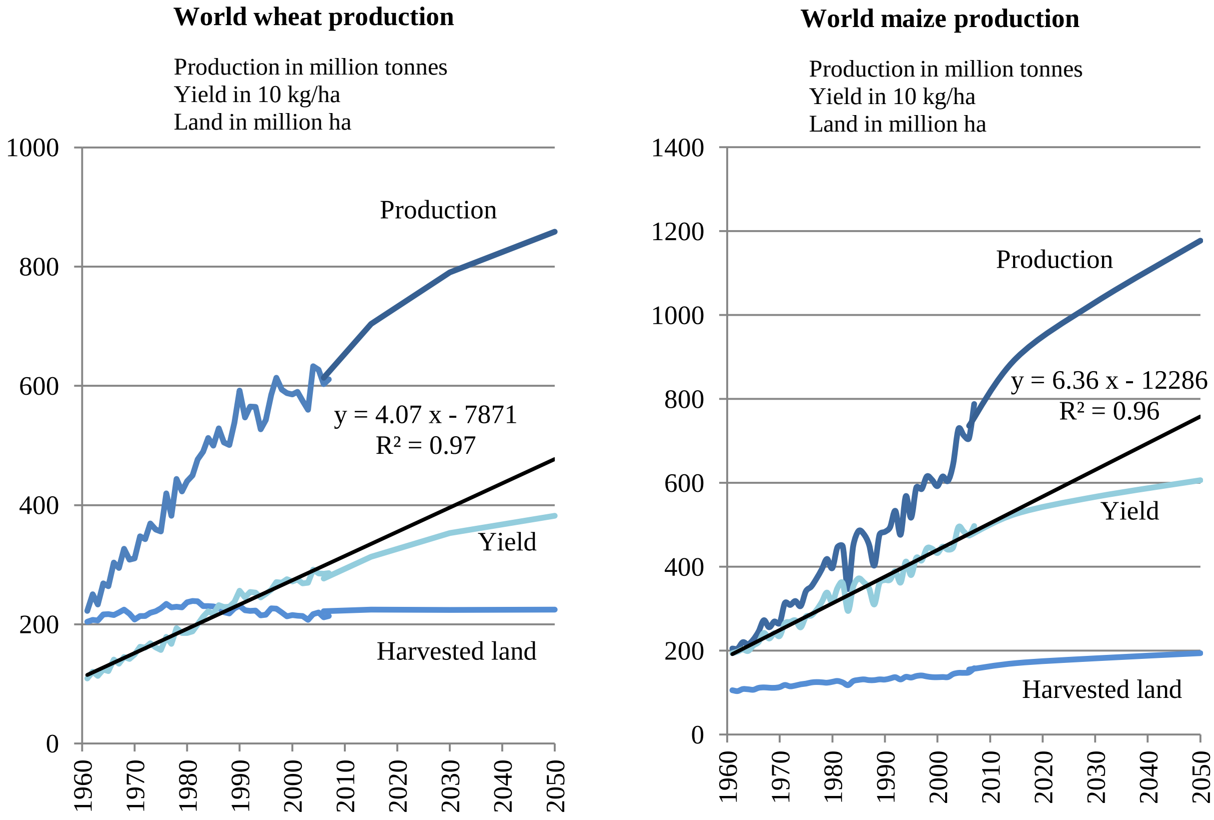
Table 4.13 Cereal yields, rainfed and irrigated

		Yield (tonnes/ha)			Annual growth (percent p.a.)		
		1961/ 1963	2005/ 2007	2050	1961-2007	1987-2007	2005/ 2007-2050
World							
Wheat	total	1.14	2.77	3.82	2.11	1.08	0.74
	rainfed		2.41	3.24			0.68
	irrigated		3.52	5.02			0.81
Rice (paddy)	total	1.94	4.07	5.32	1.80	1.10	0.61
	rainfed		2.57	3.60			0.77
	irrigated		5.08	6.59			0.59
Maize	total	1.99	4.74	6.06	1.98	1.95	0.56
	rainfed		4.25	5.65			0.65
	irrigated		6.81	7.43			0.20
All cereals (rice milled)	total	1.29	2.94	3.94	1.90	1.43	0.67
	rainfed		2.55	3.44			0.68
	irrigated		3.88	5.16			0.65
Developing countries							
Wheat	total	0.87	2.76	4.01	2.92	1.56	0.85
	rainfed		1.73	2.51			0.85
	irrigated		3.41	5.01			0.88
Rice (paddy)	total	1.83	4.01	5.28	1.91	1.13	0.63
	rainfed		2.57	3.60			0.77
	irrigated		5.02	6.56			0.61
Maize	total	1.16	3.25	4.68	2.47	2.12	0.83
	rainfed		2.70	4.02			0.91
	irrigated		5.41	6.43			0.39
All cereals (rice milled)	total	0.98	2.49	3.60	2.27	1.53	0.84
	rainfed		1.78	2.72			0.97
	irrigated		3.56	5.01			0.78

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

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 nearing ceilings obtained on research stations, the scope for raising yields is much more limited than in the past (Sinclair, 1998). Despite this, average yields have continued to increase, albeit at a decelerating rate. For example global wheat yields increased by some 40 kg p.a. over 1961 to 2007, and is projected to grow by 24 kg per year over the period 2005/2007 to 2050 (Figure 4.11). Likewise maize yields grew by some 64 kg p.a. over the historical period and are expected to grow by 30 kg p.a. over 2005/2007 to 2050.

Figure 4.11 World wheat and maize land, yield and production



The variation in yields among countries however remains very wide. Table 4.14 illustrates this for wheat, rice and maize in developing countries. Cereal yields in the ten percent of countries with the lowest yields (bottom decile, excluding countries with less than 50 000 ha under the crop), were in the early 1960s less than one-fifth of the yields of the best performers (top decile) and this ‘gap’ has been worsening over time so that at present they are less than 15 percent. If sub-national data were available, probably a similar pattern would be seen for intra-national differences as well. For wheat and maize this gap between worst and best performers is projected to narrow somewhat by 2050, while for rice this ‘closing of the gap’ would be more pronounced, with yields in the bottom decile reaching 25 percent of yields in the top decile by 2050. 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 these cereals, and it is therefore more important to examine what will happen to the yield levels obtained by the countries which account for the bulk of wheat, rice and maize production. Current (un-weighted) average yields of the largest producers[82] are about half the yields (and 38 percent in the case of maize) achieved by the top performers (Table 4.14). In spite of continuing yield growth in these largest producing countries, this situation is expected to improve somewhat but not to change dramatically by 2050.

[82] Top ten percent of countries ranked according to area allocated to the crop examined. For 2005/2007 these are China, India, and Turkey for wheat; India, China, Indonesia, Bangladesh and Thailand for rice; and China, Brazil, India, Mexico, Nigeria, Indonesia and Tanzania for maize.

Table 4.14 Top and bottom cereal yields in developing countries

	1961/1963		2005/2007		2050	
	tonnes/ha	% top decile	tonnes/ha	% top decile	t/ha	% top decile
Wheat						
Number of countries included	32		34		36	
Top decile	2.15		5.68		7.56	
Bottom decile	0.40	18	0.87	15	1.43	19
Decile of largest producers	0.87	40	2.80	49	4.38	58
All countries included	0.97	45	2.42	43	3.78	50
World	1.14		2.77		3.82	
Rice (paddy)						
Number of countries included	45		54		60	
Top decile	4.34		7.54		9.19	
Bottom decile	0.75	17	1.07	14	2.30	25
Decile of largest producers	1.80	42	4.10	54	5.50	60
All countries included	1.93	44	3.54	47	5.03	55
world	1.94		4.07		5.34	
Maize						
Number of countries included	59		67		71	
Top decile	2.15		7.30		10.94	
Bottom decile	0.44	20	0.64	9	1.48	14
Decile of largest producers	1.21	56	2.79	38	4.99	46
All countries included	1.06	49	2.52	35	4.39	40
World	1.99		4.74		6.06	

Notes: (i) only countries with over 50 000 harvested ha are included; (ii) countries included in the deciles are not necessarily the same for all years; (iii) average yields are simple averages, not weighted by area; (4) largest producers are the largest ones according to area.

The preceding brief analysis suggests that there has been and still is, considerable slack in the crop yields of the different countries, which could be exploited if the economic incentives so dictate. 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 inter-country yield gaps. Part of these differences of course simply reflects differing agro-ecological conditions. However, not all, or perhaps not even the major part, of yield differences can be ascribed to such conditions as 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 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 sub-optimal use of inputs and other cultural practices. This second component can be narrowed provided that it makes economic sense to do so and therefore is termed the ‘exploitable yield gap’ or ‘bridgeable gap’.

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, 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 as for example provided by the GAEZ analysis. 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 type of analysis has been undertaken frequently over the last two decades or so and by now there exists a fairly extensive literature clearly showing and confirming that a good part of the yield gap is of the second, exploitable type[83]. This implies that crop production could increase through the adoption of improved technologies and practices to bridge some of the gap that separates actual yields from obtainable yields. The broad lesson of experience seems to be that if scarcities develop and prices rise, farmers quickly respond by adopting such technologies and increasing production, at least those living in an environment of not-too-difficult access to improved technology, transport infrastructure and supportive policies. However, in countries with land expansion possibilities, the quickest response comes from increasing land under cultivation, including shifting land among crops towards the most profitable ones.

The preceding discussion may create the impression that all is well from the standpoint of potential for further production growth based on the use of existing varieties and technologies to increase yields. This statement should however be heavily qualified since the exploitation of bridgeable yield gaps means further spread of high external input technologies, which might aggravate related environmental problems, and perhaps more important from the standpoint of meeting future demand, ready potential for yield growth does not necessarily exist in the countries where the additional demand will be. When the potential demand is in countries with limited import capacity, as is the case in many developing countries, such potential can be expressed as effective demand only if it can be predominantly matched by local production. In such circumstances, the existence of large exploitable yield gaps elsewhere (e.g. in Argentina or Ukraine) is less important than it appears for the evaluation of potential contributions of yield growth to meeting future demand.

It follows that continued and intensified efforts are needed on the part of the agricultural research community to raise yields (including through maintenance and adaptive research) in the often unfavourable agro-ecological and often also unfavourable socioeconomic environments of the countries where the additional demand will be.

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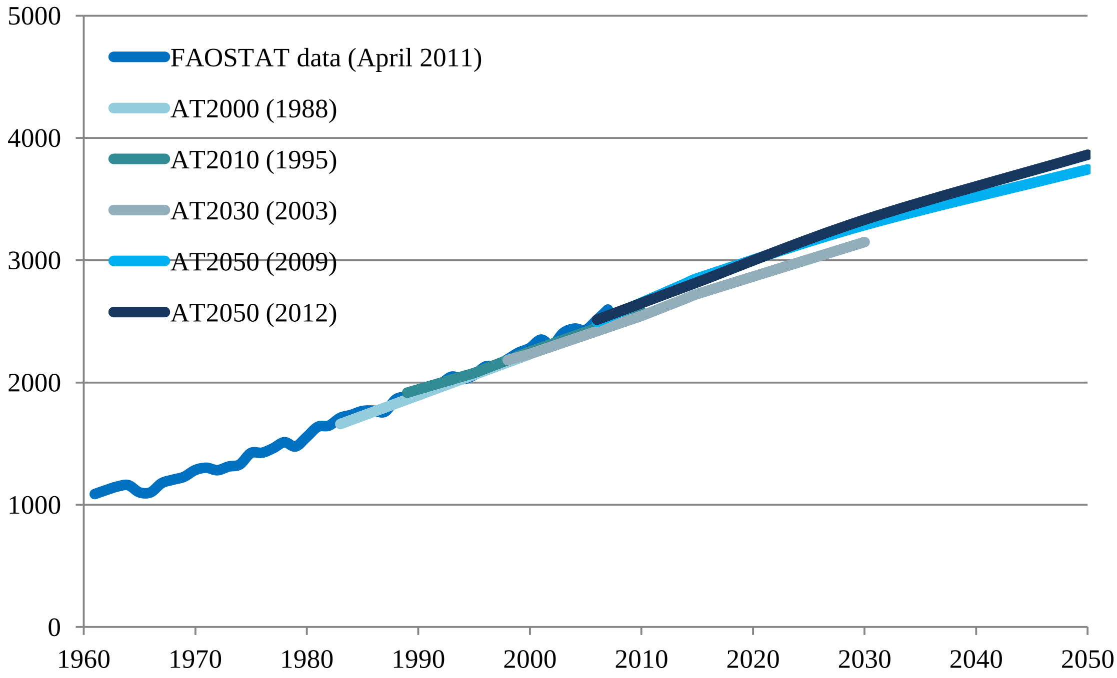
[83] There is no need to repeat this discussion here and the reader is referred to the literature. See for example World Bank (2008) pp. 66-69; Fischer, Byerlee and Edmeades (2011), Fischer *et al.* (2011), Bruinsma (2003) pp. 146-148 and 297-303, and Bruinsma (2011).

Comparison with previous AT20XX cereal yield projections for developing countries excluding China.

Cereal yields (kg/ha) for developing countries excluding China: data and projections



4.2.7 Fertilizer consumption

As discussed in section 4.2.1, the bulk of the projected increases in crop production will probably 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. Smil (2002) estimates that N fertilizer has contributed an estimated 40 percent to the increases in per-capita food production in the past 50 years, although there are local and regional differences and varying efficiencies. 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.

Daberkow *et al*. (2000) state that 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[84] 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 *et al.* (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 applying non-linear (piecemeal linear) relationships between yields and fertilizer application rates (separately for N, P and K fertilizer) for 34 crops grown under rainfed and irrigated conditions. Country-specific data from FAOSTAT for the base year 2005/2007 on N, P and K consumption and for harvested land and yield by crop were used to calibrate (scale) the functions (for 105 countries and country groups[85]) to reproduce the 2005/2007 fertilizer consumption in each country (see Bruinsma *et al*., 1983, for a description of the methodology).

The overall result, aggregated over all crops and countries, is that fertilizer consumption could increase from 166 million tonnes in 2005/2007 to 263 million tonnes in 2050 (see Figure 4.12 and Table 4.15). This would imply a continuing slowdown in the overall growth of fertilizer consumption (Table 4.15) with particularly slow growth in the developed countries and East Asia. The reasons for this will be explained below[86].

The developing countries account at present for almost 70 percent of world fertilizer consumption and this share could increase further to over three-quarters of world consumption in 2050. China and India alone account for almost two-thirds of the developing countries' fertilizer consumption but this could decline to about half the consumption in 2050 as other regions will catch up. The decline in world fertilizer consumption in the 1990s (Figure 4.12) was mainly caused by the decline in the transition countries following systemic reforms. 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. 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.

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[84] 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).

[85] See Appendix 1 for a list of the countries and crops included.

[86] Earlier fertilizer projections made in 2001-02 (Bruinsma, 2003, pp. 148-151) considerably underestimated developments in world fertilizer consumption, projecting a consumption of 165 million tonnes by 2015, a level which in practice had already been reached by 2005/2007.

Table 4.15 Fertilizer consumption: historical and projected

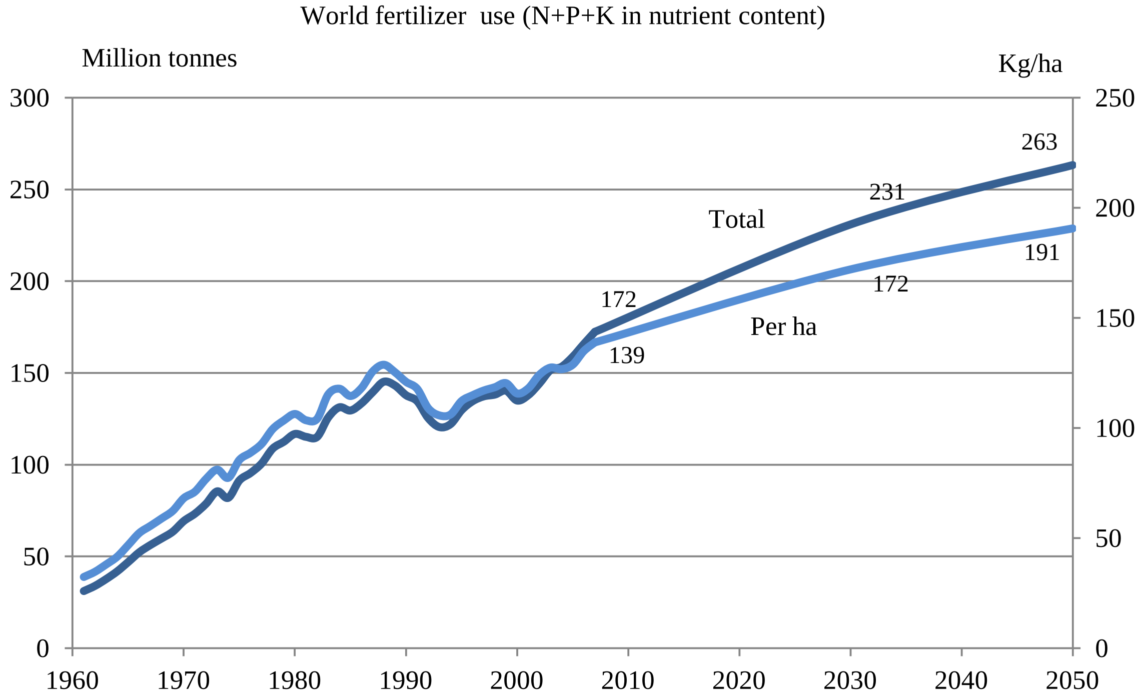
Total consumption	million tons of nutrient (N, P and K)			percent p.a.			
	1961/ 1963	2005/ 2007	2050	1961- 2007	1997- 2007	2005/ 2007 -2030	2030- 2050
Sub-Saharan Africa	0.2	1	6	4.3	0.4	3.7	3.1
Latin America	1.1	17	45	5.6	5.4	3.2	1.1
Near East / North Africa	0.5	8	12	6.0	2.6	1.1	1.1
South Asia	0.6	27	59	8.2	3.0	2.5	1.0
East Asia	1.9	62	79	7.7	4.0	0.8	0.3
Developing countries	4.3	114	201	7.2	3.8	1.7	0.8
excl. China and India	2.9	42	94	6.0	3.6	2.4	1.1
Developed countries	30.0	51	62	0.5	-0.3	0.6	0.3
World	34.3	166	263	3.0	2.4	1.4	0.7
Per harvested hectare	**kg/ha**			**percent p.a.**			
	1961/ 1963	2005/ 2007	2050	1961- 2007	1997- 2007	2005/ 2007 -2030	2030- 2050
Sub-Saharan Africa	1.9	8	27	2.6	-1.6	3.1	2.6
Latin America	15.1	122	250	4.4	3.0	2.4	0.7
Near East / North Africa	10.3	113	170	5.3	1.9	0.9	0.9
South Asia	3.4	121	268	7.7	2.7	2.5	1.0
East Asia	9.6	210	256	6.9	3.3	0.6	0.3
Developing countries	7.3	127	200	6.3	2.7	1.4	0.6
excl. China and India	9.6	79	144	4.7	1.9	1.9	0.8
Developed countries	75.9	144	166	0.8	0.0	0.3	0.3
World	35.0	132	191	2.5	1.7	1.1	0.5

Cereals, in particular wheat, rice and maize, account at present for some 60 percent of global fertilizer use, and are expected to still account for just over half of fertilizer consumption by 2050 (Table 4.16). Fertilizer applications to oilseeds (in particular to soybeans and rapeseed) are expected to grow fastest so that oilseeds by 2050 could account for over a fifth of all fertilizer consumption. The shares of N (57 percent), P (25 percent) and K (18 percent) in total fertilizer consumption are expected to change only marginally over the projection period.

Table 4.16 Fertilizer consumption by major crops

	Share (%) in total		Million tonnes of nutrient (NPK)			Annual growth (% p.a.)	
	2005/ 2007	2050	2005/ 2007	2030	2050	2005/ 2007-2030	2030- 2050
Cereals	60.5	51.7	100	128	136	1.0	0.3
Oilseeds	15.3	22.0	25	43	58	2.2	1.5
Vegetables, citrus and fruits	10.3	10.6	17	24	28	1.5	0.7
Roots and tubers	1.5	1.6	3	4	4	1.5	0.8
Other crops	12.4	14.1	20	32	37	1.9	0.7
Total	100	100	166	231	263	1.4	0.7

Figure 4.12 World fertilizer consumption: past and projected



Since the early 1960s, the use of mineral fertilizers has been growing rapidly in developing countries admittedly starting from a very low base (Table 4.15). This has been particularly so in East and South Asia following the introduction of high-yielding varieties. By now high application rates have been reached in East Asia and growth of fertilizer consumption in East Asia is expected to slowdown drastically and eventually fertilizer consumption is expected to decline. 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. 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, but more so for N-fertilizer than for P- and K-fertilizers (Syers *et al.*, 2008). The degree to which such productivity gains will be pursued depends to a great extent on economic incentives.

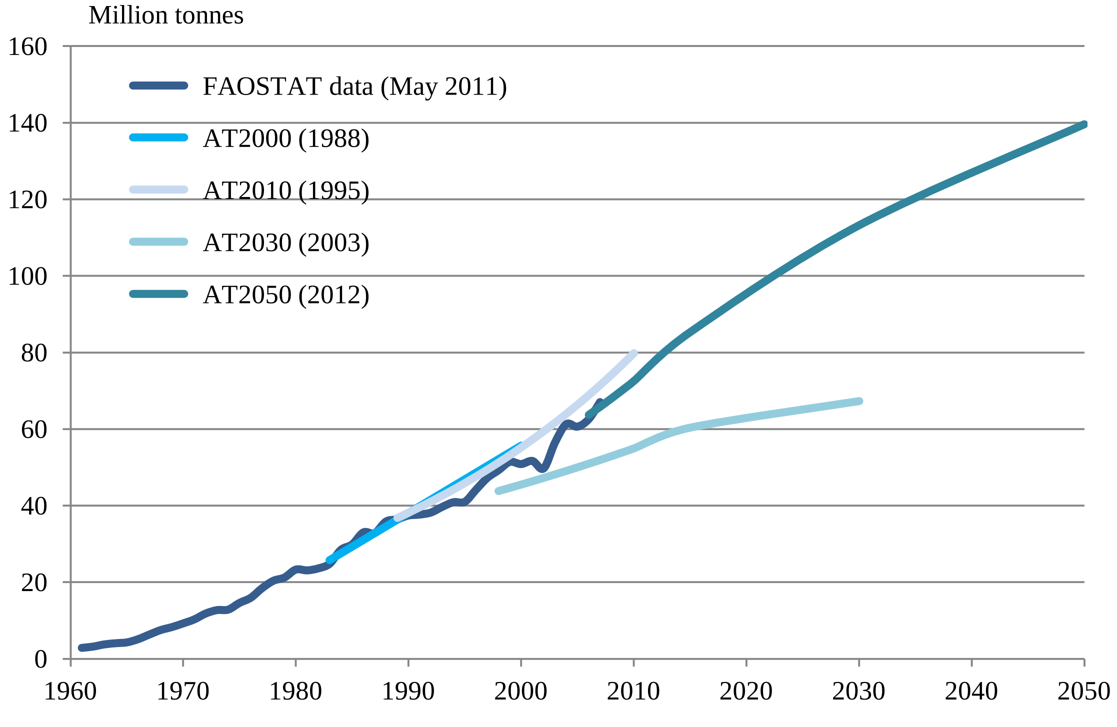
The projected slowdown in the growth of fertilizer consumption is in the first place due to the expected slowdown in crop production growth (Table 4.3). The reasons for this have been explained in Chapter 3. Again, this is not a sudden change but a gradual process already under way for some time, as illustrated by the annual growth rates for the last ten years (1997 - 2007) shown in Table 4.15. In some cases it would even represent a "recovery" as compared with recent developments (e.g. the decline of fertilizer consumption in transition countries during the 1990s). 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 4.2.4) will also slow the growth of fertilizer consumption.

Another factor is the continuing improvement in fertilizer use efficiency, partly driven by new techniques such as biotechnology and precision agriculture, which will continue to reduce mineral fertilizer needs per unit of crop output (at a steady but uncertain pace). For example, in this analysis the average application of N-fertilizer per tonne of cereal production declines slightly from 31.6 kg in 2005/2007 to 30.4 kg in 2050. This is an average at world level with little further improvement foreseen in most developed countries.

Then 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.

Addendum

Comparison with previous AT20XX projections for fertilizer consumption in developing countries excluding China.



4.3 Livestock production

Like crop production, growth in livestock production (Table 4.17) mirrors growth in total agricultural production (Table 4.2) although the observed deceleration in growth is slightly less than for crop production as the consumption of livestock products continues to increase its share in total food consumption. Sub-Saharan Africa is the only region where livestock production growth will continue to be fairly strong, while only slow growth is foreseen for the other regions (certainly in comparison with historical performance).

Table 4.17 Annual livestock production growth (percent p.a.)

	1961-2007	1987-2007	1997-2007	2005/2007-2030	2030-2050
World	2.2	2.0	2.0	1.4	0.9
Developing countries	4.3	4.5	3.4	2.0	1.3
idem, excl. China and India	3.4	3.6	3.5	2.1	1.5
Sub-Saharan Africa	2.5	2.8	3.3	2.7	2.6
Latin America and the Caribbean	3.2	3.8	3.8	1.6	0.9
Near East / North Africa	3.3	3.3	3.0	2.2	1.7
South Asia	3.7	3.6	3.2	2.7	2.2
East Asia	6.5	5.9	3.4	1.8	0.8
Developed countries	1.0	-0.1	0.6	0.6	0.2
44 countries with over 2700 kcal/person/day in 2005/2007*	2.7	2.9	1.8	1.1	0.5

* Accounting for 57 percent of the world population in 2005/2007.
Note: Aggregate livestock production was derived by weighting the four meats, milk products and eggs at 2004/06 international commodity prices.

Naturally, growth prospects differ among countries and livestock sectors with, in general, slow growth foreseen for pig meat and somewhat more vigorous growth for poultry and mutton (Table 4.18; see Chapter 3 for an extensive discussion of these issues).

Table 4.18 World livestock production by livestock sector

	1961/1963	2005/2007	2050	1961-2007	1987-2007	1997-2007	2005/2007-2050
World	**million tonnes**			**annual growth (% p.a.)**			
Total meat	72	258	455	2.9	2.5	2.2	1.3
Beef	30	64	106	1.6	0.9	1.2	1.2
Mutton	6	13	25	1.7	1.8	2.1	1.5
Pigmeat	26	100	143	3.1	2.3	1.7	0.8
Poultry	9	82	181	5.2	4.7	3.9	1.8
Milk	344	664	1 077	1.4	1.3	2.2	1.1
Eggs	14	62	102	3.5	3.3	2.3	1.1

Livestock production is the world’s largest user of land, either directly through grazing or indirectly through consumption of fodder and feed grains. Globally, livestock production currently accounts for some 36 percent of the gross value of agricultural production. In the developed countries this share amounts to half of total production and in developing countries for almost one-third. As mentioned above (section 4.1), developing countries are expected to continue to increase their share in world production so that by 2050 they could account for 70 percent of world meat production (up from 58 percent in 2005/2007) and for 61 percent of world milk production (46 percent in 2005/2007).

Increased production can be achieved by a combination of expansion in animal numbers and increased productivity. Higher productivity is a compound of higher off-take rates (shorter production cycles by, for example, faster fattening), and higher carcass weight and milk or egg yields. The projections (Table 4.19) show that the increase in livestock numbers will remain significant, but less so than in the past. Higher carcass weights will play a more important role in beef and mutton production, while higher off-take rates (shorter production cycles) will be more important in pig and poultry meat production.

There are considerable problems in getting reliable data for off-take rates and carcass weights. To circumvent these, meat production can be compared directly with herd sizes. For example, over the last decade (1997-2007), world beef production increased by 1.2 percent p.a., while cattle numbers increased by only 0.5 percent, implying an annual productivity improvement of 0.7 percent. Small ruminant production increased by 2.1 percent p.a. while flock size increased by only 1.1 percent, suggesting a 1.0 percent annual increase in meat production per animal in stock.

There are substantial differences between regions and countries, however. In sub-Saharan Africa the increase in pig numbers was greater than the growth in production, indicating a decline in meat productivity. In Asia, where land is scarce, growth in herd size for cattle and buffaloes was much lower than the growth in output, indicating that intensification and increased productivity were relatively more important. Considerable increases in productivity were seen for poultry production with an annual increase (over 1997-2007) of 2.5 percent in Latin America and a very high 5.5 percent in South Asia.

Meat or milk output per animal remains higher in developed countries than in developing ones. For example, in 2005/2007 the yield of beef per animal (carcass weight) in developing countries was 166 kg compared with 271 kg in developed countries (Table 4.19), while annual average milk yields were 1.3 and 5.0 tonnes per milking cow respectively. Pork and poultry productivity levels are more similar across regions, reflecting the greater ease of transfer and adoption of production techniques. With only slow growth foreseen in the yields levels in developed countries, these ‘yield gaps’ could slowly decline over the projection period.

Table 4.19 Meat production: number of animals and carcass weight

	Number of animals (million)			Number of animals annual growth (% p.a.)		Carcass weight (kg / animal)		
	1961/ 1963	2005/ 2007	2050	1961- 2007	2005/ 2007-2050	1961/ 1963	2005/ 2007	2050
World								
Cattle and buffaloes	1 045	1 532	2 032	0.8	0.6	158	202	227
Sheep and goat	1 356	1 915	2 939	0.8	1.0	14	14	17
Pigs	424	917	1 141	1.6	0.5	65	79	84
Poultry	4 435	19 160	37 030	3.6	1.5	1.3	1.6	1.7
Developed countries								
Cattle and buffaloes	352	318	320	-0.4	0.0	163	271	283
Sheep and goat	577	389	460	-0.9	0.4	15	17	18
Pigs	248	288	294	0.4	0.1	71	87	92
Poultry	2 568	5 239	7 212	1.6	0.7	1.3	1.9	1.9
Developing countries								
Cattle and buffaloes	692	1 215	1 712	1.3	0.8	150	166	209
Sheep and goat	779	1 526	2 478	1.5	1.1	12	13	17
Pigs	176	629	846	2.5	0.7	49	74	81
Poultry	1 867	13 921	29 817	5.0	1.7	1.1	1.4	1.6
Sub-Saharan Africa								
Cattle and buffaloes	106	232	332	1.6	0.8	135	129	204
Sheep and goat	151	456	855	2.5	1.4	11	12	18
Pigs	4	22	62	4.1	2.4	45	45	64
Poultry	218	790	2 625	2.8	2.8	0.9	1.0	1.4
Latin America								
Cattle and buffaloes	178	395	517	1.7	0.6	191	213	241
Sheep and goat	154	117	146	-0.7	0.5	14	14	16
Pigs	51	78	110	0.7	0.8	64	81	93
Poultry	376	2 716	4 812	4.6	1.3	1.2	1.8	1.9
Near East / North Africa								
Cattle and buffaloes	34	42	69	0.3	1.2	110	169	215
Sheep and goat	183	255	419	0.8	1.1	14	16	19
Pigs	0	0	0	-1.2	0.2	53	34	49
Poultry	133	1 534	3 248	6.0	1.7	1.1	1.3	1.5
South Asia								
Cattle and buffaloes	277	372	473	0.8	0.5	96	123	181
Sheep and goat	136	329	595	2.2	1.4	10	11	18
Pigs	5	15	21	2.7	0.8	35	35	49
Poultry	165	1 026	4 007	4.2	3.1	0.9	1.0	1.6
East Asia								
Cattle and buffaloes	97	173	319	1.5	1.4	150	141	191
Sheep and goat	154	363	457	2.0	0.5	12	14	15
Pigs	115	512	647	2.8	0.5	45	75	81
Poultry	969	7 770	14 801	5.5	1.5	1.1	1.4	1.5

Appendix 1
Countries and commodities included in the analysis

Developing countries and territories*			
Latin America and the Caribbean			
Argentina	Dominican Rep.	Honduras	Peru
Bolivia (Plurinational State of)	Ecuador	Jamaica	Suriname
Brazil	El Salvador	Mexico	Trinidad and Tobago
Chile	Guatemala	Nicaragua	Uruguay
Colombia	Guyana	Panama	Venezuela (Bolivarian Republic of)
Costa Rica	Haiti	Paraguay	
Cuba			
Sub-Saharan Africa			
Angola	Dem. Rep. of the Congo	Madagascar	Senegal
Benin	Eritrea	Malawi	Sierra Leone
Botswana	Ethiopia	Mali	Somalia
Burkina Faso	Gabon	Mauritania	Sudan
Burundi	Gambia	Mauritius	Swaziland
Cameroon	Ghana	Mozambique	Togo
Central African Rep.	Guinea	Namibia	Uganda
Chad	Kenya	Niger	United Rep. of Tanzania
Congo	Lesotho	Nigeria	Zambia
Côte d'Ivoire	Liberia	Rwanda	Zimbabwe
Near East/North Africa			
Afghanistan	Iraq	Morocco	Turkey
Algeria	Jordan	Saudi Arabia	Yemen
Egypt	Lebanon	Syrian Arab Rep.	
Iran, Islamic Rep.	Libya	Tunisia	
South Asia			
Bangladesh	Nepal	Sri Lanka	
India	Pakistan		
East Asia			
Cambodia	Indonesia	Myanmar	Thailand
China	Lao People's Dem. Rep.	Philippines	Viet Nam
China, Hong Kong SAR	Malaysia	Rep. of Korea	
Dem. Rep. of Korea	Mongolia		

* All other countries and territories are aggregated into one: “Other developing” region.

Developed countries		
	European Union *	
Australia	Austria	Latvia
Canada	Belgium	Lithuania
Israel	Bulgaria	Luxembourg
Japan	Cyprus	Malta
New Zealand	Czech Republic	Netherlands
Russian Federation	Denmark	Poland
South Africa	Estonia	Portugal
United States of America	Finland	Romania
	France	Slovakia
	Germany	Slovenia
	Greece	Spain
	Hungary	Sweden
	Ireland	United Kingdom of Great Britain and Northern Ireland
	Italy	
Other Western Europe*	**Other Eastern Europe***	**Central Asia***
Iceland	Albania	Armenia
Norway	Belarus	Azerbaijan
Switzerland	Bosnia and Herzegovina	Georgia
	Croatia	Kazakhstan
	Montenegro	Kyrgyzstan
	Republic of Moldova	Tajikistan
	Serbia	Turkmenistan
	The former Yugoslav Rep. of Macedonia	Ukraine
		Uzbekistan

* Country groups marked with an asterisk (*) were treated in the analysis as one aggregate.

Crops and commodities included		
	Crops	
Wheat	Cassava	Vegetable oil and oilseeds (in vegetable oil equivalent) [2]
Rice	Other roots	Cocoa
Maize	Plantains	Coffee
Barley	Sugar, raw [1]	Tea
Millet	Pulses	Tobacco
Sorghum	Vegetables	Cotton lint
Other cereals	Bananas	Jute and hard fibres
Potatoes	Citrus fruit	Rubber
Sweet potatoes and yams	Other fruit	
	Livestock	
Beef, veal and buffalo meat	Pig meat	Eggs
Mutton, lamb and goat meat	Poultry meat	Milk and dairy products (in whole milk equivalent)

[1] Sugar production is analyzed separately for sugar cane and sugar beet.
[2] Vegetable oil production is analyzed separately for soybeans, groundnuts, sesame seed, coconuts, sunflower seed, palm oil/palm-kernel oil, rapeseed and all other oilseeds.

Note on commodities

Commodity data and projections in this report are expressed in terms of primary product equivalent unless stated otherwise. Historical commodity balances (Supply Utilization Accounts –SUAs) are available for about 160 primary and 170 processed crop and livestock commodities. To reduce this amount of information to manageable proportions, all the SUA data were converted to the commodity specification given above in the list of commodities, applying appropriate conversion factors (and ignoring joint products to avoid double counting: e.g. wheat flour is converted back into wheat while wheat bran is ignored). In this way, one Supply Utilization Account in homogeneous units is derived for each of the commodities of the study. Meat production refers to indigenous meat production, i.e. production from slaughtered animals plus the meat equivalent of live animal exports minus the meat equivalent of all live animal imports. Cereals demand and trade data include the grain equivalent of beer consumption and trade. The commodities for which SUAs were constructed are the 26 crops and 6 the livestock products given in the list above. The production analysis was, however, carried out for 34 crops because sugar and vegetable oils are analyzed separately (for production analysis only) for the 10 crops shown in the footnote to the list.

Appendix 2

Summary note on methodology

In projecting the likely evolution of the key food and agricultural variables, a 'positive' approach has been followed, aiming at describing the future as it is likely to be to the best of our knowledge at the time of carrying out the study, and not as it ought to be from a normative point of view. A second aspect of the approach followed in the study was to draw to the maximum extent possible on FAO's in-house knowledge available in the various disciplines present in FAO. The quantitative analysis and projections were carried out in considerable detail in order to provide a basis for making statements about the future concerning individual commodities and groups of commodities as well as agriculture as a whole. Another reason for the high degree of detail has to do with the interdisciplinary nature of the study and its heavy dependence on contributions provided by FAO specialists in the different disciplines. Such contributions can find expression only if the relevant questions are formulated at a meaningful level of detail.

Variables projected in the study are the different final and intermediate uses, production and net trade balances for each commodity and country and the key agro-economic variables, i.e. for crops: area, yield and production by country and by agro-ecological zone such as rain-fed, irrigated areas, and for the livestock products: animal numbers total stock, off-take rates and yields per animal. A significant part of the total effort is devoted to the work needed to create a consistent set of historical and base year data. For the demand-supply analysis, the overall quantitative framework for the projections is based on the Supply Utilization Accounts (SUAs). The SUA is an accounting identity showing for any year the sources and uses of agricultural commodities in homogeneous physical units, as follows:

Food (Direct consumption) + Industrial Non-food Uses + Feed + Seed + Waste =
Total Domestic Use =
Production + (Imports - Exports) + (Opening Stocks - Closing Stocks)

The database has reports such SUA for each commodity, country and year from 1961 to 2007. The data preparation work for the demand-supply analysis consists of the conversion of the about 350 commodities for which the primary production, utilization and trade data are available into the 32 commodities covered in this study, while respecting the SUA identities (Appendix II). The different commodities are aggregated into commodity groups and into "total agriculture" using as weights world average producer prices of 2004/06 expressed in "international dollars". The growth rates for heterogeneous commodity groups or total agriculture shown in this study are computed from the thus obtained value aggregates.

A major part of the data preparation work is the unfolding of the SUA element 'production'; for the base year only, in this case the 3-year average 2005/2007, into its constituent components of area, yield and production which are required for projecting production. For most crops, the standard data in the SUAs contains also the harvested area and average yield for each crop and country. These national averages are not considered by the agronomists to provide a good enough basis for the projections because of the widely differing agro-ecological conditions in which any single crop is grown, even within the same country. An attempt was therefore made to break down the base year production data from total area under a crop and an average yield into areas and yields for rainfed and irrigated categories. The problem is that such detailed data are not generally available in any standard data base. It became necessary to piece them together from fragmentary information, from both published and unpublished documents giving e.g. areas and yields by irrigated and rainfed land at the national level or by administrative districts, supplemented by a good deal of guesstimates.

The bulk of the projection work concerns drawing up SUAs by commodity and country for the years 2030 and 2050, and the unfolding of the projected SUA item ‘production’ into area and yield combinations for rainfed and irrigated land, and likewise, for livestock commodities into the underlying parameters such as number of animals, off-take rates and yields.

The overall approach is to start with projections of demand, using Engel demand functions and exogenous assumptions on population and GDP growth. Subsequently, the entry point for the projections of production is to start with provisional projections for production for each commodity and country derived from simple assumptions about future self-sufficiency and trade levels. There follow several rounds of iterations and adjustments in consultation with specialists on the different countries and disciplines, with particular reference to what are considered to be ‘acceptable’ or ‘feasible’ levels of calories intakes, diet composition, land use, (crop and livestock) yields and trade. Accounting consistency controls at the commodity, land resources (developing countries only), country and world levels have to be respected throughout. The end-product may be described as a set of projections which meet conditions of accounting consistency and to a large extent respect constraints and views expressed by the specialists in the different disciplines and countries.

The projections of crop yields and land were carried out for as large a number of individual commodities and countries as practicable, that is 105 countries and country groups and 34 crops (Annex I) and rainfed and irrigated land classes).

A major part of the data preparation work is the unfolding of the data for production (i.e. the FAOSTAT data for area harvested and average yield for each crop and country for the three-year average 2005/2007, converted into the crop classification used in this study) into its constituent components of area, yield and production for rainfed and irrigated land. Such detailed data come in part from AQUASTAT but are not generally available in any standard database. It became therefore necessary to piece them together from fragmentary information, from both published (e.g. from EUROSTAT for the EU countries) and unpublished documents giving, for example, areas and yields by irrigated and rainfed land at the national level or by administrative districts, supplemented by a good deal of guesstimates. For a number of countries (e.g. for the United States of America, China, EU27, India and Indonesia) the data for irrigated agriculture were assembled at the sub-national level.

No data exist on total harvested land, but a proxy can be obtained by summing up the harvested areas reported for the different crops. Data are available for total arable land in agricultural use (physical area, called in FAOSTAT “arable land and land under permanent crops”). It is not known whether these two sets of data are compatible with each other, but this can be evaluated indirectly by computing the cropping intensity, i.e. the ratio of harvested area to arable land. This is an important parameter that can signal defects in the land use data. Indeed, for several countries (in particular for sub-Saharan countries but not only) the implicit values of the cropping intensities did not seem to be realistic. In such cases the harvested area data resulting from the crop statistics were accepted as being the more robust (or the less questionable) ones and those for arable area were adjusted.

Data reported in FAOSTAT on arable irrigated land refer to ‘area equipped for irrigation’. What is needed is the ‘irrigated land actually in use’ which is often between 80 and 90 percent of the area equipped. Data for the ‘area in use’ were taken from FAO’s AQUASTAT data base.

The bulk of the projection work concerned the unfolding of the projected crop production for 2030 and 2050 into (harvested) area and yield combinations for rainfed and irrigated land, and making projections for total arable land and arable irrigated area in use.

An initial mechanically derived projection for rainfed and irrigated harvested area and yield by crop constrained to arrive at exactly the projected production was evaluated against such information as recent growth in land and yield (total by crop) and the ‘attainable yield’ levels for most crops from the Global Agro-Ecological Zone (GAEZ) study (Fischer *et al.*, 2011), and adjusted were needed. A similar projection was made for total arable rainfed and irrigated area which were then evaluated against estimates for the (maximum) potential areas for rainfed agriculture (from the GAEZ) and for irrigated agriculture (from AQUASTAT) and adjusted where needed. In addition, for irrigated area cropping patterns were checked against and made to obey certain cropping calendars (i.e. not all crops can be grown in all months of the year). A final step was to derive the implicit cropping intensities for rainfed and irrigated agriculture (by comparing harvested land over all crops with the arable area) and again adjusting areas (and yields) where needed. Normally it required several iterations before arriving at an ‘acceptable’ picture of the future.

Since the whole exercise is heavily dependent on expert-judgement and requires an evaluation of each and every number, it is a time-consuming exercise. The projections presented in this study are certainly not linear trend extrapolations, as they take into account all knowledge available at present as to expected developments that might make evolutions in major variables deviate from their trend path.

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