POLESTAR 5

Global Land & Food in the 21st Century

Trends & Issues for Sustainability

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The POLESTAR Project

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This study is an output of SEI's PoleStar Project. Named after the star that guided voyagers through uncharted waters, the PoleStar Project aims to develop and apply appropriate methods, concepts and data for sustainability planning and for other environment/ development issues.

The PoleStar project has three main components: *scenarios generation*, *capacity building*, and *sustainability evaluation*. Each addresses a critical aspect of the transition to sustainability: understanding global trends and possibilities, strengthening professional capabilities for a new era of development, and fashioning strategies and policies. To support these efforts, the project has developed the PoleStar System© a *comprehensive*, *flexible* and *user-friendly* framework for mounting economic, resource and environmental information, and for examining alternative development scenarios. The PoleStar System is an adaptable *accounting system* designed to *assist* the analyst engaged in sustainability studies—not a rigid model reflecting a particular approach to environment and development interactions.

An application begins with *current accounts*, a snapshot of the current state of affairs. Then, *scenarios* are developed to explore alternative futures. A scenario is a set of future socio-economic, resource and environmental accounts, based on assumptions developed by the user. Analyses are conducted through a set of linked modules, where data and assumptions are developed on demographics, economics, and a number of sectors such as households, industry and minerals, transport, agriculture and land uses, services, energy, water, and waste. Scenario results are *evaluated* with reference to *sustainability thresholds* for such indicators as nutrition, greenhouse gas emissions, ground level pollutants, forest and wetland preservation, non-renewable resource depletion rates, water stress, chemical hazard loads and so on. Comparison of scenario results with such measures provides a bird's eye view of areas of stress between a scenario and sustainability targets, and provides insight into the requirements for building alternative scenarios for achieving a sustainable future.

Through this process, the PoleStar Project asks four fundamental questions for sustainable development at global, national and local levels: where are we? where are we going? where do we want to go? how do we get there? The responses shed light, respectively, on the current state of development and the environment, projections and trends, desirable long-range development pathways, and the strategies and policies required for a sustainable future.

The first six papers in the PoleStar publication series address global issues. They are:

1. The Sustainability Transition: Beyond Conventional Development (Raskin, Chadwick, Jackson and Leach)
2. PoleStar System Manual (Raskin, Heaps and Sieber)
3. Global Energy in the 21st Century: Patterns, Projections and Problems (Raskin and Margolis)
4. Water and Sustainability: A Global Outlook (Raskin, Hansen and Margolis)
5. Global Land and Food in the 21st Century: Trends and Issues for Sustainability (Leach)
6. Accounting for Toxic Emissions from the Global Economy: The Case of Cadmium (Jackson and MacGillivray)

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Trends & Issues for Sustainability

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The study also benefited greatly from the use of unpublished data on land capability and crop yield responses to irrigation and other technical inputs, developed for the UN Food and Agriculture Organisation's 'Agriculture: Towards 2010' project. Many thanks for providing this information are offered to Dr. Nikos Alexandratos and Dr. Jelle Bruinsma of FAO and Dr. Günther Fischer of the Institute of Applied Systems Analysis, Laxenburg, Austria.

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1.1 The Population-Food Debate

Two centuries ago a French nobleman and an English vicar, the Marquis de Condorcet and Thomas Malthus, considered the limits to the growth of human numbers on a finite planet and came to rather different conclusions. Malthus thought "the power in the earth to produce subsistence for man" was already falling behind population and that "the period when the number of men surpass their means of subsistence has long since arrived" (Malthus, 1798). Condorcet concluded that scientific knowledge and rational behaviour will overcome these problems (Condorcet, 1795; and Sen, 1994). Some fifty years later, when hunger gripped the poor of Europe, Karl Marx enlarged the argument by attacking Malthus for blaming famine on natural laws rather than social forces. Famine was not a failure of supply but of demand. Its cause was lack of purchasing power - poverty - and was rooted in political and economic injustice.

Two hundred years on we find that world population has increased six-fold, most people are better fed than ever before, world prices of cereals and other basic foods continue their century-long decline, and food production continues to grow well ahead of human numbers in most regions, especially the most densely populated areas such as South and Southeast Asia (S & SE Asia). Yet this undoubted success story has its darker side. Some 700 million of the world's poorest people now face chronic hunger and malnutrition. Food production has failed to increase, or actually declined, in many countries, notably in Africa. Millions attempt to survive on ecosystems so fragile that quite small perturbations - of weather, civil order, or market prices - can tip them into serious food shortages. Environmental problems of many kinds associated with the spread and modernisation of agriculture appear to be threatening the productivity and sustainability of farming systems. Indeed, even for confirmed optimists the prospect of feeding *another* doubling of world population by the middle of the next century, on a limited (some would say, declining) natural resource base, is a truly formidable challenge.

Not surprisingly, these contrasting perspectives combined with huge uncertainties about our future technical and social abilities, ensure that in modern form the arguments of Condorcet, Malthus and Marx continue unabated in a flow of more or less extreme projections of feast or famine, cornucopia or catastrophe.

A small sample of these speculations reveals the range of human faith in progress and our capacity to meet our most basic needs. In the mid-1950s Brown (1954) concluded that increased yields and irrigation could raise the 1950 global food supply six-fold, enough to feed 15 billion people. In the mid-1960s Zierhoffer (1966) argued that 41 billion people could be well-fed if every farmer grew food as productively as the Japanese. In the mid-1970s the MOIRA study (Linemann et al., 1979) estimated the absolute physical limit to world agricultural output to be about 30 times the 1965 production volume. This maximum production level assumes optimal plant growth conditions with respect to water management, soil cultivation, fertiliser use, pest control, and so forth. Although these conditions would never be met in practice, the study concluded that over the next decades a 3-5 fold increase of global production would not be ruled out by natural constraints. Its achievement would depend instead upon having the correct mix of economic, social and political conditions. Meanwhile in the 1960s Paul Ehrlich was warning that "the battle to feed all humanity is over" and that "hundreds of millions of people are going to starve to death" during the 1970s (for example, Ehrlich, 1968). Soon after this catastrophe failed to occur we find the economist John Simon (1981) maintaining that there is no long-run physical limit to food production.

In the present decade several further studies and projections have appeared across the spectrum of pessimism versus optimism. Comparing the huge differences in their assumptions and conclusions makes one wonder if some of the authors are in fact living on the same planet (McCalla, 1994).

Best known on the pessimistic side has been a series of books and reports from the Worldwatch Institute, usually by its director Lester Brown (for example, Brown & Kane, 1994). The basic premise of recent Worldwatch reports is that the 1990s mark a critical turning point between an era when "green revolution" technologies were able to keep food ahead of population and a future when mounting technical and environmental constraints will make it far more difficult to sustain year-on-year increases in food production:

> "Many knew that this time would eventually come, that at some point the limits of the earth's natural systems, the cumulative effects of environmental degradation of cropland productivity, and the shrinking backlog of yield-raising technologies would slow the record growth in food production in recent decades. But because no one knew when or how this would happen, the food prospect was widely debated. Now we can see that several constraints are emerging simultaneously to slow the growth in food production" (Brown & Kane, 1994, p. 22).

This statement is worth considering for a moment. The foundation of the Worldwatch argument that a grim new era is upon us refers mostly to a down-turn of per capita global cereal production. As shown in Figure 1.1, this quantity peaked around 1985 and has tended to decline since then (total production and yields have continued to increase). But as also shown in the Figure, this trend might have been caused by changes in cereal demand rather than emerging production constraints. Per capita cereal food consumption has grown very slowly and has stabilised since 1985 as people have turned increasingly to higher-valued foods such as fruit and vegetables, sugar and animal products (see Chapter 2 for further details). Per capita cereal animal feed consumption has fallen slowly since 1980, presumably because cheaper alternatives have become available. Per capita consumption of cereal food plus feed has consequently followed much the same trend as production. Meanwhile, world cereal prices have continued their long-term decline in real terms (World Bank, 1993a), suggesting that falling demand is not a response to increased supply scarcity or prices. The dire trend noted by the Worldwatch authors through focusing on only one factor in a more complex reality - and by others with similar arguments (Kendall & Pimentel, 1994; and CGIAR, 1994) - may actually be telling us more about agricultural successes in allowing these demand-side changes than anything about future production problems or limits.

On the optimistic side, a notable recent contribution is a detailed model by two World Bank authors (Mitchell & Ingco, 1993). Projecting to 2010, they assume that global population growth will continue to slow and world grain production will grow at 2% per year from now to 2010. Consequently, global food production will more than keep pace with increasing demand, and whilst food imports by developing countries will grow by more than 4% annually, they will easily be met by expanded exports from more developed countries. Their final paragraph concludes:

> "The world food situation has improved dramatically during the past thirty years and the prospects are very good that the twenty-year period from 1990 to 2010 will see further gains. However, these gains depend on continued increases in food production along the trends of the past. *This will not occur automatically*, rather it will require continued investments in research to increase crop yields and in other factors of production. If past crop yield trends continue and if population growth rates slow as projected, then the gains in the world food situation seen during the past thirty years should continue. If Malthus is ultimately to be correct in his warning that population will outstrip food production, then at least we can say: "*Malthus must wait*". [Emphasis added].

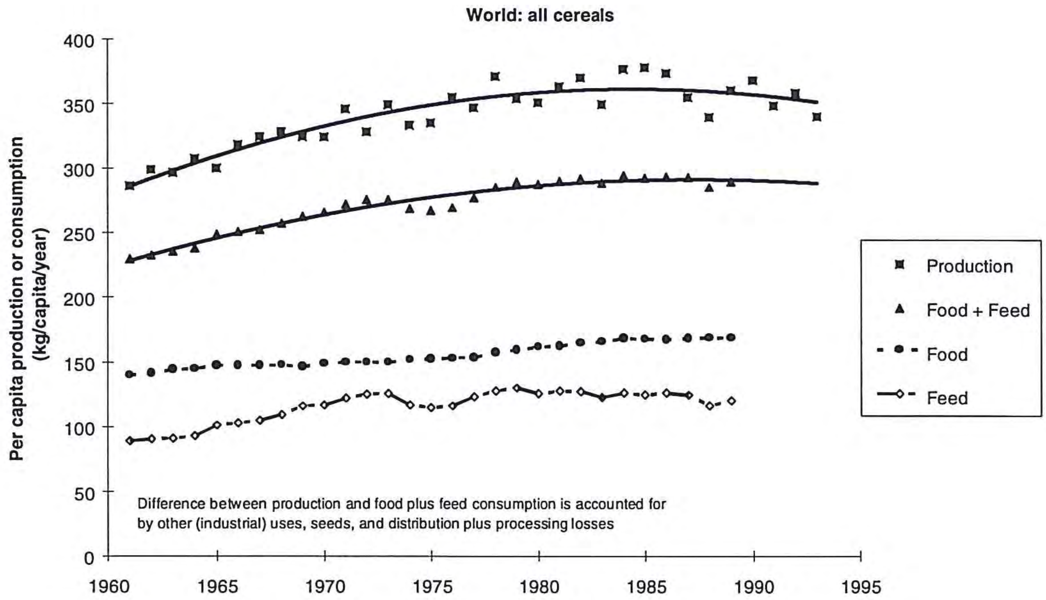

Figure 1.1. World per capita cereal production and consumption.
Sources: FAO Agrostat database (FAO, 1992) and FAO 'State of Food and Agriculture 1993'.

Other recent studies such as the UN FAO's 'Agriculture: towards 2010' (FAO, 1993) and a projection also to 2010 by the International Food Policy Research Institute (Rosegrant & Agcaolli, 1994) reach similar, if not identical, conclusions. The FAO study concludes that per capita food supplies will increase and the absolute numbers suffering chronic malnutrition will decline, in large part due to a projected 2.2% per year growth in cereal grain production, made up of a 1.8% per year increase in yield and a 0.8% per year increase in harvest area. The IFPRI simulation model also concludes that there will be no global food problem as production grows ahead of demand, even to the point that harvested areas decline. However, it stresses that there will be local problems, notably in Sub-Saharan Africa and South Asia, but clearly identifies their cause as poor economic access to food: a problem of poverty rather than food production.

1.2 Why Another Study?

Since we cannot know which of these (or other) projections to believe, what is the point of yet another speculative study; in particular, one which is as rich in detail as this one? That is a good question, but it also has some reasonable answers. At this point we highlight three.

First, this report looks ahead to 2050 rather than 2010, the time horizon for most of the projections noted above. This longer time scale may add to incredulity about the scenario assumptions and results but is necessary to capture some crucial, slow-acting trends or long-delayed situations which nevertheless bear heavily on the visions and actions which we need to adopt today. These include probable reductions in the growth of population and per capita food consumption as these critical factors reach saturation limits in the next few decades; widening disparities between regional food demand and supply capacities, and hence large increases in the need for food trade; impending bio-physical limits to the continued expansion of cultivable land in some major world regions; and possible production constraints in the longer term due to other natural resource problems such as water supply.

Second, this report is rich in detail for a purpose. In considering the present and future of a topic as large and complex as world agricultural production and demand, it is vital to preserve some of the complexity of the issues which, in the real world, have to be understood adequately before they can be tackled successfully. Again, this invites disbelief by multiplying up the number of variables that have to be considered and projected in the scenario model. But it is perhaps better to grasp this problem of complexity than over-simplify the issues by, for example, modelling the food-population future on the basis only of cereal grain supply and demand, or global cereal production. Several of the studies cited above fall into this trap, in some cases, as noted above, with possibly most misleading consequences.

Third, the present study is part of a wider and systematic exploration of sustainable futures by the Stockholm Environment Institute in its PoleStar project. Integration between major sectors such as "energy", "water", "land and agriculture" is a cardinal feature of this exercise. Preliminary work established the point that if this integration was to produce meaningful results, the land and food sector in particular would have to be modelled in a fairly comprehensive manner. In other words, all world regions, all major crops, all key relationships between crop production and land requirements and, ideally, all land uses, would have to be modelled. Although this last ideal in particular has not been met here - largely due to data problems - the scenario structure does provide a framework for considering it in future developments of PoleStar.

1.3 A Model Structure

As we have just suggested, the ways in which humans use land to grow food and other commodities are complex and diverse. Large ranges of soil, rainfall, temperature and other physical conditions influence what crops can be grown, where, and how successfully. The effects of these conditions can be modified greatly by the precise combinations of human skills and technologies which are used by the farmer or animal herder. These processes in turn occur within highly varied cultural and economic environments which greatly affect both the demand for agricultural products and the myriad production choices farmers make to meet these demands.

This complexity makes the design of a suitable framework for modelling agricultural production and consumption rather problematic. Obviously, a great deal of simplification and aggregation is necessary, but not so much that important trends and patterns are overlooked or misinterpreted, or issues ignored which are relevant to the desirability or feasibility of a particular set of projections. The choice of which key variables to model and their degree of aggregation depends of course on the availability of data, especially of historic data for reasonably long periods so that major trends can be identified and quantified as a guide to possible future trends.

These data limitations in turn have a profound effect on the type of model which can be used. Most importantly, they rule out economic models which rely on driving variables such as prices and incomes. The relevant economic data for food production and/or consumption exist only for a handful of countries and for some isolated, small-scale regions which have been intensively studied. Information is therefore lacking for most countries and large-scale regions. Instead, physical parameters such as tons of food produced or hectares of cropland required, and so forth, have to be used. This does not preclude the use of judgements to link these physical values to economic and developmental factors such as the growth of average income, increased urbanisation, or better transport infrastructures which improve the links between farmers and markets.

One important consequence of using such a physical model is that agricultural demand and supply must in a formal sense be treated independently. In the real world, patterns of food consumption and production are linked in a two-way process by prices and incomes and other economic factors. In the model used here, food demand is assumed to alter according to demographic changes and per capita dietary patterns independently of production and supply. The role played by economic factors is mimicked by setting the (physical) parameters determining food supply and production to values which meet this demand. The plausibility of the scenario projections can then be evaluated with respect to the socio-economic, resource and environmental dimensions.

This approach has many distinguished predecessors, such as the series of long-range global projections made by FAO during the 1980s and early 1990s (FAO, 1993). It also fits well with the viewpoint of many economists that present levels of agricultural productivity and production say little about potential levels because they are a response only to present levels of demand and price conditions. This elementary economic point has been expressed concisely by Amartya Sen (1994). After noting that in the decade to 1990-92 per capita food production rose by more than 20% in Asia, including over 22% in India and 36% in China, Sen writes:

> "Food is produced by peasants, farmers and others not to *demonstrate* how much can be grown, but to make *economic use* of them - to eat, to sell, to exchange. We cannot directly infer how much *could have been* produced merely by looking at what *was* actually produced. To be sure, we do know that what was actually produced certainly was possible, but we do not know how much more *could have* been produced if there were economic incentives for expanding output...... The pessimists.....may note that food production is growing only a little faster than population, and this

they may tend to interpret as evidence that we are reaching the limits of what we can produce. Such a presumption would not be right, since it ignores the effects of economic incentives that govern production: food will not be produced beyond the effective demand for it." [Original emphasis].

The remainder of this section outlines the chosen model structure and its component parts, starting with the background perspective or development paradigm to the scenario as a whole.

1.3.1 The Conventional Development Paradigm[1]

In looking to the future, people often assume that the values and dynamics of today's dominant techno-industrial system will be progressively played out indefinitely and on a global scale. Though often tacit, this perspective represents a vision of a long-range global future - a vision which in SEI's PoleStar project is referred to as the Conventional Development Paradigm - which is continuous with the patterns of resource use, socio-economic arrangements, values and lifestyles that evolved during the industrial era.

In other words, the constellation of values that have underpinned industrial development over at least the past half century provide, by extension, the principles that shape the conventional development vision. These include free markets, private investment and competition as the fundamental engine for economic growth and wealth allocation; rapid industrialisation and urbanisation; possessive individualism as the motive of human agents and the basis for the "good life"; and the nation-state and liberal democracy as the appropriate forms of governance in the modern era.

The conventional development (CD) scenario envisions the unfolding of these processes without major social, technological, or natural surprises and disruptions. In this picture, the cluster of factors shaping the world of the 21st century might be thought to include the globalisation and deepening of the information revolution; the progressive homogenisation of culture on a global scale; the expansion of consumerist and individualist personal values; the convergence of developing country economies, technologies and cultures towards those of industrial countries; and the increasing economic dominance of large multinational corporations on an international economic field.

In fact, a number of significant social, environmental and cultural uncertainties could undermine this picture. The aim here is to explore the dimensions of food production, agriculture and land resources of a conventional development framework in order to identify such uncertainties. The bulk of the scenario assumptions and results are contained in Chapter 2 (on food consumption) and Chapter 3 (on food production, trade and use of land). In each chapter and its sub-sections, presentations of future assumptions and projection results are preceded by a review of the current picture and past trends. Chapter 4 completes the study with a brief review of the stresses, uncertainties and risks associated with the scenario and its assumptions, and the policies required to achieve its successful outcome.

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[1] This sub-section is based on part of the SEI/PoleStar global energy scenario: P. Raskin & R. Margolis (1995): *Global Energy in the 21st Century: Patterns, Projections and Problems.* PoleStar Series Report no. 3. SEI-Stockholm. 113 p.

1.3.2 Regional Aggregation

One major simplification of the model structure is the aggregation of countries into 10 regions, five representing today's more economically developed countries (MDC) and five the less developed countries (LDC). This regional aggregation is common to other PoleStar scenarios and is outlined in Table 1.1. The complete regional structure is given at the end of this Chapter in Table 1.6. This degree of aggregation is not ideal for considering land use and agriculture, since it combines sub-regions and countries with marked contrasts in climate and land capabilities, but compromises had to be made owing to time and data constraints.

Tables 1.2 and 1.3 give regional population and per capita GDP for the baseline year and for the two scenario projection years, 2025 and 2050. For reasons of data availability, the baseline year for most of this report is 1989, though the baseline GDP values are for 1990. This difference matters little as GDP is not an explicit scenario driver. The assumptions for 2025 and 2050 are common to other SEI-PoleStar Conventional Development scenarios.

The population projections are the standard UN mid-range estimates, which give a near doubling of human numbers to just over 10 billion in 2050. Most of this growth occurs in the LDCs, where population increases from close to 3.9 billion today to nearly 8.7 billion in 2050. One-third of this 120% increase occurs in Africa. In contrast, the more developed (MDC) region grows by only 165 million in the next 30-odd years and has virtually no change in population from 2025 to 2050. As a result, the MDC share of world population falls from 24% in 1989 to 14% in 2050. There are strong declines in population growth rates in all regions between the present and the latter period of the scenario.

As one would expect, these demographic changes have a profound effect on projected regional food demand. However, the scenario structure avoids any reverse effects of food availability (or its lack) on mortality, fertility, migration and so forth, and hence on total regional population. The regional population numbers shown in Table 1.2 are thus basic and fixed parameters in the scenarios.

Per capita GDP, or gross domestic product, is often used as an indicator of economic development. The many problems of using GDP in this role, of measuring it, and of its comparison across countries, are well-recognised and frequently reviewed (Raskin & Margolis, 1995). In this study per capita GDP is used only as a qualitative guide to stages of development which might affect key aspects of the food system such as dietary patterns, farm 'modernisation', or the quality of transport infrastructure and its bearing on access to farm inputs and crop markets. In other words, GDP is not used as an explicit, quantitative variable but as an underlying qualitative guide to changes in patterns and potentialities.

Table 1.1. Regional structure.

PoleStar Regions	Equivalent FAO Regions and countries (1990 and earlier statistics)
Africa	Africa
Latin America	Latin America developing
Middle East	Near East developing + [Israel] - [Egypt, Libya, Sudan, Turkey]
China+	China, Korea DPR, Laos, Mongolia, Viet Nam
S & SE Asia	Far East developing + [Papua New Guinea] - [Cent. Plan. Asia]
N America	Canada + USA = N America developed
W Europe	Europe + [Turkey] - [E Europe]
E Europe	Albania, Bulgaria, Czechoslovakia, Hungary, Poland, Romania
OECD Pacific	Japan, Australia, New Zealand (+ S. Pacific Islands) = Oceania +[Japan] - [Papua New Guinea]
Former USSR	USSR

Table 1.2. Population projections.

Region	Population (millions)			Growth rate (% per year)	
	1989	2025	2050	1989-2025	2025-2050
Africa	623.1	1,519	2,204	2.51	1.50
Latin America	439.2	699	812	1.30	0.60
Middle East	142.5	384	557	2.79	1.50
Cent Plan Asia	1,215.0	1,733	1,867	0.99	0.30
S & SE Asia	1,523.4	2,634	3,214	1.53	0.60
N America	274.3	330	322	0.51	-0.10
W Europe	454.1	489	477	0.21	-0.10
E Europe	99.4	115	121	0.41	0.20
OECD Pacific	145.6	161	157	0.28	-0.10
Former USSR	287.3	332	349	0.40	0.20
Less developed	3,943.2	6,969	8,674	1.59	0.88
More developed	1,260.7	1,427	1,426	0.34	0.00
World	5,203.9	8,396	10,080	1.34	0.73

Sources: for 1989, FAO Agrostat; for 2025, 2050 - World Bank (Bulatao, 1989) and the United Nations (1992).

Table 1.3. Per capita GDP projections.

Region	Per capita GDP (US$ 1990)			Growth rate (% per year)	
	1990	2025	2050	1990-2025	2025-2050
Africa	626	1,091	1,926	1.56	2.3
Latin America	2,233	4,315	7,435	1.85	2.2
Middle East	3,585	5,832	9,110	1.36	1.8
Cent Plan Asia	369	1,557	3,423	4.08	3.2
S & SE Asia	667	1,877	3,930	2.92	3.0
N America	21,804	45,127	65,477	2.04	1.5
W Europe	15,726	32,548	49,607	2.04	1.7
E Europe	2,108	4,073	5,626	1.85	1.3
OECD Pacific	24,304	50,301	74,803	2.04	1.6
Former USSR	2,956	5,712	7,889	1.85	1.3
Less developed	849	2,089	3,973	2.53	2.61
More developed	14,055	28,922	42,023	2.02	1.51
World	4,048	6,649	9,355	1.39	1.38

Sources: for 1990, World Bank (1993b); for 2025 & 2050, the IPCC 1992a scenario.

Again, the GDP assumptions follow standard mid-range "business as usual" projections. Per capita GDP generally grows faster in less developed regions than in the MDCs, reflecting recent trends. Growth in the MDCs as a whole declines towards the end of the scenario period (2025-2050) while it accelerates slightly in the LDCs. As a result, the share of global GDP accounted for by the MDCs falls from 84% in 1990 to 74% in 2025 and 64% in 2050. The ratio of per capita GDP in the MDCs to that of the LDCs - a broad indicator of regional economic inequity - also declines from nearly 17:1 in 1990 to just over 10:1 in 2050. However, the *absolute* difference in per capita GDP between the MDCs and LDCs increases substantially over the next 60 years.

1.3.3 Product Aggregation

The second major simplification in the model involves the aggregation of food and other agricultural products. The FAO-Agrostat supply and utilisation accounts (FAO, 1992) cover approximately 100 food and other agricultural commodities, but data quality varies greatly and is generally better for commodity groups than for individual items.

The chosen breakdown is shown in Table 1.4, together with the abbreviated 'code' used for each product group, in which the prefix "C" stands for vegetable crops and "A" for animal products. Also shown is an indicator of the importance of each group in terms of global harvest area. This value, together with regional area differences for the crop groups, was a major consideration in the product aggregation.

The reasons for this particular product structure deserve some comment. Cereals must obviously be considered separately because of their great importance to human diets, animal feed, and land use. Wheat plus coarse grains, and rice, are treated separately because of large regional differences in production patterns, yields and diets and the fact that paddy rice typically emits methane, an important greenhouse gas. Roots and tubers, pulses, oil crops and vegetables are distinguished for much the same reason. Even though in some regions some of these crop groups take up almost negligible areas of land, and might therefore have been ignored, dietary substitutions between groups can have substantial impacts on land use. For example, average yields of root crops (C2) and pulses (C3) in LDC regions are respectively 10-15 and 0.5-1 ton per hectare per year. In some of these regions consumption of roots has been giving way to pulses and other higher value crops with their lower yields and hence their higher land requirements for each ton of food consumed. Sugar crops are handled separately because of their typically large yields, rising sugar consumption in many regions, and their role in biomass energy. The grouping of all tree crops as one product group is an anomaly forced by data limitations but fortunately the land areas involved are relatively small.

Table 1.4. Aggregation of crop and animal products.

Product code	Percent world harvest area (1990) [a]	Crop groups (and individual crops)
C 11	53.6	**Wheat and coarse grains** (wheat, barley, maize, rye, oats, millet, sorghum)
C 12	13.9	**Rice**
C 2	4.8	**Roots & tubers** (cassava, potato, sweet potato, yam, taro)
C 3	6.6	**Pulses** (dry bean, dry broad bean, dry pea, chick pea, lentils)
C 4	15.0	**Oil crops, other than tree products** (soybean, groundnut, castor bean, seeds of sunflower, rape, sesame, safflower, cotton)
C 5	2.4	**Sugar crops** (sugar cane, sugar beet)
C 6	1.2	**Vegetables and fruit, other than tree products** (18 types)
C 7	--- [a]	**Tree crops and perennials** (7 types of nut, palm kernel, olive, olive oil, 17 types of tree fruit, coffee, cocoa beans, tea, hops)
A 1	---	**Meat & eggs** (slaughtered meat, offal, animal fat except milk & its products, eggs)
A 2	---	**Milk & milk products** (as milk equivalents)
A 3	---	**Fish & other aquatic products** (marine and freshwater fish, crustaceans, cephalopods, molluscs, other aquatic products)

Note: non-food crops are excluded from the analysis at the present stage. At a regional level their contribution to total harvest land area is very small (typically under 1%). These crops include tobacco leaves, natural rubber, linseed, hempseed, flax & hemp fibre, jute, sisal and other fibres.

[a] Harvest area excluding tree and other perennial crops ('permanent crops' in FAO land statistics).

1.3.4 Consumption and Supply Structures

As noted above, the model structure treats the consumption and supply/production sides of the land-agriculture-food system independently, each being represented by a separate chain of assumptions and calculations.

The consumption chain leads, for each region, year and food product, from the requirements for human food, animal feed and other (mostly industrial) uses to a value of required production which allows for processing and other losses as well as trade.

The supply chain leads from total cultivated land area through various supply side variables such as the intensity of land use, shares of harvested area under each crop group, and crop yields, to a value of achieved production for each crop product. Animal products are handled slightly differently.

In the scenario, achieved production is made equal to required production by adjustments to the supply side variables, which include net trade, crop yield, cropping intensity (equal to harvest area divided by cultivated area), share of harvest area devoted to each crop, and total cultivated area.

Table 1.5. Consumption and production calculation chains.

		Units	Product group or Land class
	Consumption chain		
⇓	population	M persons	
⇓ x	nutrition	total calories/person/day	
⇓ x	diet structure	fraction of total calories	C1-C7, A1-A3
⇓ ÷	food properties	calories/kg	C1-C7, A1-A3
⇓ x	scaling factor	(M calories/day to Mt/year)	
⇓ =	human food	Mt/year	C1-C7, A1-A3
⇓ +	other uses (including crop fuels}	Mt/year	C1-C7, A1-A3
⇓ +	animal feed [from livestock chain]	Mt/year	C1-C7, A1-A3
⇓ =	final demand	Mt/year	C1-C7, A1-A3
⇓ +	processed, losses, seeds, stock change	Mt/year	C1-C7, A1-A3
⇓ =	required supply	Mt/year	C1-C7, A1-A3
⇓ +	net exports	Mt/year	C1-C7, A1-A3
⇓ =	required production	Mt/year	C1-C7
	CONSUMPTION-PRODUCTION BALANCE Achieved production made equal to required production for each crop by altering production variables or net exports.		
	PRODUCTION CHAIN		
⇑ =	achieved production	Mt/year	C1-C7
⇑ x	yield	ton/hectare/year	C1-C7
⇑ =	harvest area x crop	Mha	C1-C7
⇑ x	cultivation pattern	fraction of total harvest area	C1-C7
⇑ =	total harvest area	Mha	rainfed, irrigated (all)*
⇑ x	cropping intensity	harvests per year (average for all crops)	rainfed, irrigated (all)*
⇑	total cultivated area	Mha	rainfed, irrigated (all)*

* Rainfed and irrigated area separately for regions AFR, LA, ME, SEA; combined for other regions.
M = million, t = metric tons, ha = hectare

Since the scenario methodology forces a balance between future food demand and supply for each region and food product group, it cannot and does not predict future regional food deficits. Average people in each region do not starve. The plausibility of a scenario depends instead on subjective judgements about the assumed future levels or rates of change of all the main variables - particularly on the supply side - which are needed to bring demand and supply into balance.

The consumption and supply calculation chains and the way in which these give rise to a balance between required production and achieved production, are outlined in Table 1.5. Further information about the main steps in the chains are given in the relevant sections of Chapters 2 and 3.

Table 1.6. Regional structure (detailed).

Africa (AFR)

Algeria
Angola
Benin
Botswana
Burkina Faso
Burundi
Cameroon
Central African Rep.
Chad
Congo
Côte d'Ivoire
Egypt
Ethiopia
Gabon
Gambia
Ghana
Guinea
Guinea-Bissau
Kenya
Lesotho
Liberia
Libya
Madagascar
Malawi
Mali
Mauritania
Mauritius
Morocco
Mozambique
Namibia
Niger
Nigeria
Reunion
Rwanda
Senegal
Seychelles
Sierra Leone
Somalia
South Africa
Sudan
Swaziland
Tanzania
Togo
Tunisia
Uganda
Zaire
Zambia
Zimbabwe
(+ 8 small states)

Latin America (LA)

Argentina
Bolivia
Brazil
Chile
Colombia
Costa Rica
Cuba
Dominican Rep
Ecuador
El Salvador
Guatemala
Guyana
Haiti
Honduras
Jamaica
Mexico
Nicaragua
Panama
Paraguay
Peru
Suriname
Trinidad & Tobago
Uruguay
Venezuela
(+ 24 small states)

Middle East (ME)

Afghanistan
Bahrain
Cyprus
Gaza Strip
Iran
Iraq
Israel
Jordan
Kuwait
Lebanon
Oman
Qatar
Saudi Arabia
Syria
U A Emirates
West Bank
Yemen

Centrally Planned Asia (CHINA+)

China (inc. Taiwan)
Korea DPR
Laos
Mongolia
Viet Nam

S & SE Asia

Bangladesh
Bhutan
Brunei
Cambodia/Kampuchea
Hong Kong
India
Indonesia
Korea, Republic
Malaysia
Myanmar/Burma
Nepal
Pakistan
Papua New Guinea
Philippines
Singapore
Sri Lanka
Thailand
(+ 3 small states)

North America (NA)

Canada
USA

Western Europe (WE)

Austria
Belgium
Denmark
Finland
France
Germany
Greece
Greenland
Iceland
Ireland
Italy
Luxembourg
Netherlands
Norway
Portugal
Spain
Sweden
Switzerland
Turkey
United Kingdom
Yugoslavia
(+ 8 small states)

Eastern Europe (EE)

Albania
Bulgaria
Czechoslovakia
Hungary
Poland
Romania

OECD Pacific (OECD-P)

Australia
Fiji
Japan
New Zealand
(+ 18 small states)

Former Soviet Union (FSU)

2 FOOD CONSUMPTION

2.1 Human Diets

During the last three decades human food consumption measured as dietary calories doubled. While population grew by 69% during 1961 to 1989 the average person's intake of food calories rose by 20%. These changes were even greater in the less developed world. In the five PoleStar LDC regions combined, population and per capita calories grew during the same period by 89% and 31%. As a result total food calories consumed in the LDCs increased nearly 2.5 fold. Yet despite this encouraging trend towards better average nutritional standards, poverty, war, drought and other stresses meant that many tens of millions went hungry and millions starved.

What are the prospects for the next six decades? This chapter looks at the total demand for food and other agricultural products, a quantity which could treble in the present LDCs by 2050 as populations, incomes and dietary standards increase and more food has to be grown both to feed people directly and to feed animals for the table.

We start with direct food consumption by humans and measure dietary standards by two broad indicators: average per capita daily food calories (*Totcal*) and the fraction of these provided by animal products (*Anfrac*). Historic values are taken from the FAO Agrostat Food Balance (intake) accounts (FAO, 1992). Most importantly, the measures are not for food actually consumed but food which is available for consumption at the retail level, as it enters households, restaurants and so forth. The dietary standards therefore include losses and wastage from food storage, kitchen preparation, cooking and plate waste, and are substantially greater than actual nutritional intake, especially in more affluent countries. The values used here could therefore overestimate future food needs if societies become more waste-conscious than today. On the other hand, storage and other food losses are likely to increase in LDCs as rising incomes and urbanisation promote lifestyles closer to current OECD country patterns.

How have these quantities been changing? Table 2.1 presents a summary for per capita calories (*Totcal*) and Table 2.2 for the share provided by animal products (*Anfrac*). Annual trend data for 1961-1989 are shown in Figures 2.1 and 2.2.

Starting with per capita calories, the substantial growth in all regions and the large absolute differences between the MDCs and LDCs are obvious features. Other notable points include the following.

- The slow-down in growth during the 1980s in nearly all regions, especially the LDCs (with the exception of S & SE Asia). In Latin America and Africa the slow-down started around 1980. It began more recently but at much higher levels in China+ and the Middle East, possibly due to saturation effects. In Eastern Europe and the former Soviet Union there were slight reductions in average calorie intakes during the 1980s.
- The very large increases in China+ and the Middle East, amounting to 62% and 45% respectively, which brought the latter region close to the level of North America and Europe in the early 1960s. These regions also experienced the most rapid per capita income growth amongst the LDCs.

Table 2.1. ***Totcal*: total per capita daily calories of available food.**

Region	kcal/capita/day 1961	1980	1989	Growth rate (% per year) 1961-80	1980-89	1961-89
Africa	2,083	2,344	2,363	0.62	0.09	0.45
Latin America	2,366	2,724	2,737	0.75	0.05	0.52
Middle East	2,048	2,793	2,979	1.65	0.72	1.35
China+	1,616	2,323	2,620	1.93	1.34	1.74
S & SE Asia	1,941	2,183	2,313	.0.62	0.64	0.63
N America	3,177	3,480	3,653	0.48	0.54	0.50
W Europe	3,041	3,370	2,432	0.54	0.20	0.43
E Europe	3,120	3,483	3,453	0.58	-0.10	0.36
OECD Pacific	2,558	2,856	2,993	0.58	0.52	0.56
Former USSR	3,086	3,375	3,371	0.47	-0.01	0.32
LDCs	1,898	2,333	2,486	1.09	0.71	0.97
MDCs	3,032	3,345	3,417	0.52	0.24	0.43
World	2,261	2,602	2,711	0.74	0.46	0.65

Table 2.2. ***Anfrac*: fraction (as %) of total calories provided by animal products.**

Region	Percentage 1961	1980	1989	Growth rate (% per year) 1961-80	1980-89	1961-89
Africa	7.8	7.9	7.4	0.07	-0.70	-0.18
Latin America	17.0	17.8	17.5	0.25	-0.20	0.10
Middle East	11.9	12.5	10.5	0.27	-1.88	-0.47
China+	3.7	7.2	10.7	3.64	4.42	3.89
S & SE Asia	5.9	6.1	7.1	0.16	1.70	0.65
N America	39.9	35.3	33.5	-0.65	-0.58	-0.63
W Europe	28.1	31.1	30.7	0.53	-0.13	0.32
E Europe	24.6	30.3	30.6	1.10	0.11	0.78
OECD Pacific	14.8	22.0	23.4	2.11	0.69	1.65
Former USSR	21.4	25.8	28.7	0.99	1.18	1.05
LDCs	6.8	8.2	9.5	1.05	1.62	1.23
MDCs	27.3	29.7	30.0	0.44	0.12	0.34
World	13.3	13.9	14.5	0.23	0.42	0.29

- The much lower growth in the MDCs, except OECD Pacific where the influence of Japan and its recent rapid changes in per capita income and life styles had a dominating effect.

Turning to the dietary contribution from animal products, we find generally much smaller changes. In Africa and Latin America the change was no more than half a percentage point, with a small decline and a small increase respectively. The Middle East had a rather large decline, and S & SE Asia a larger rise. China+, on the other hand, saw a 3-fold increase from under 4% in 1961 to nearly 11% in 1989. In the MDCs the most striking features were the declines in North America and the convergence of all regions except OECD Pacific to a value of around 30%.

Substantial changes have also taken place in the mix of products which make up human diets within the broad patterns outlined above. Further large changes can be expected over the next decades as lifestyles and fashions alter. These changes of *Diet Structure* are represented in the model as shares of each food product C1-C7 and A1-A3 in the total calorie intake (*Totcal*). Table 2.3 summarises the regional diet structures in 1961 and 1989.

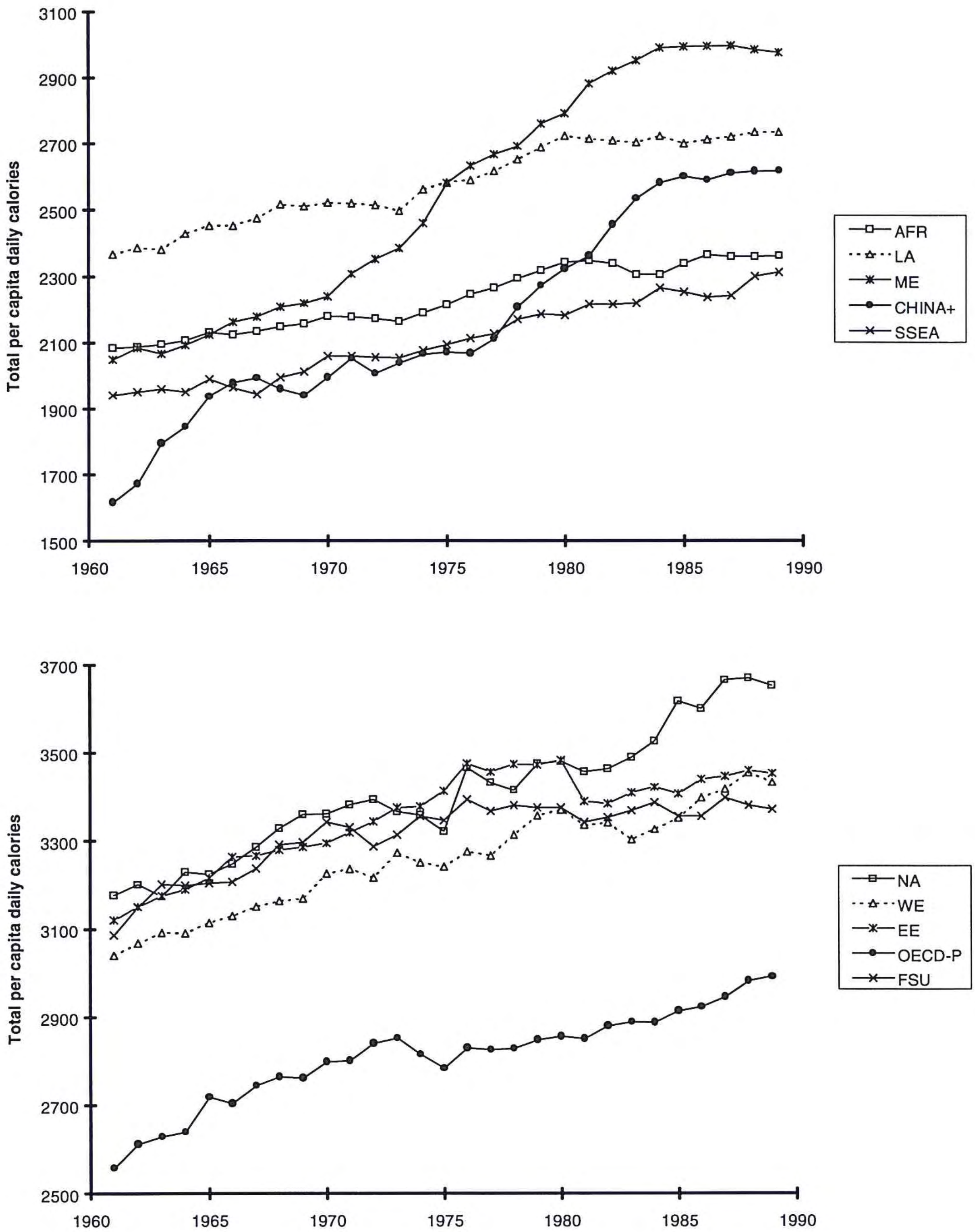
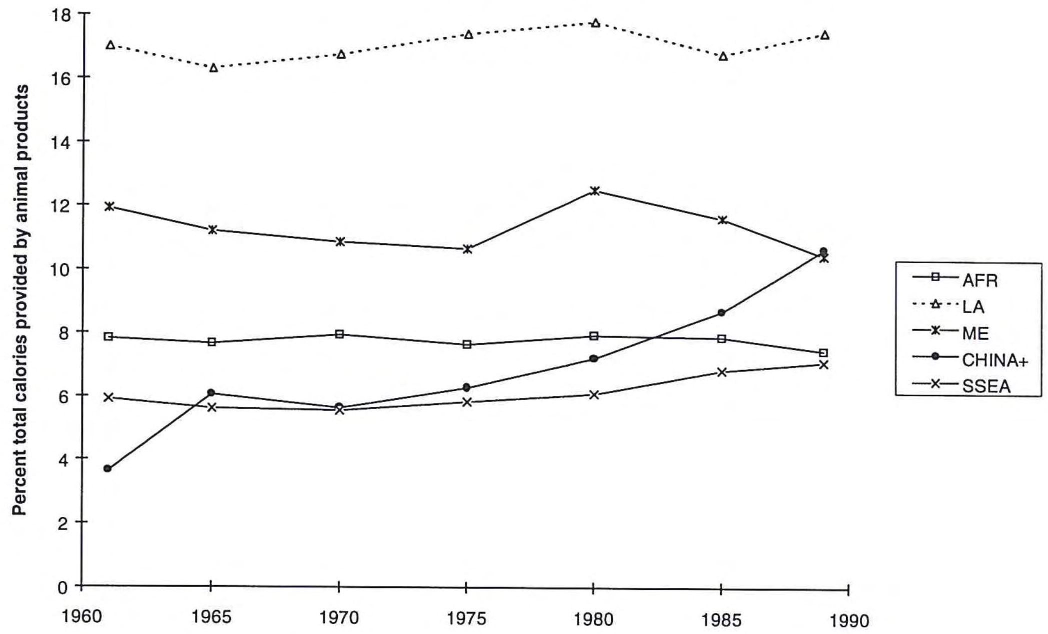


Figure 2.1. ***Totcals* (average per capita daily calories): 1961-89.**
Note different vertical scales and non-zero origins.



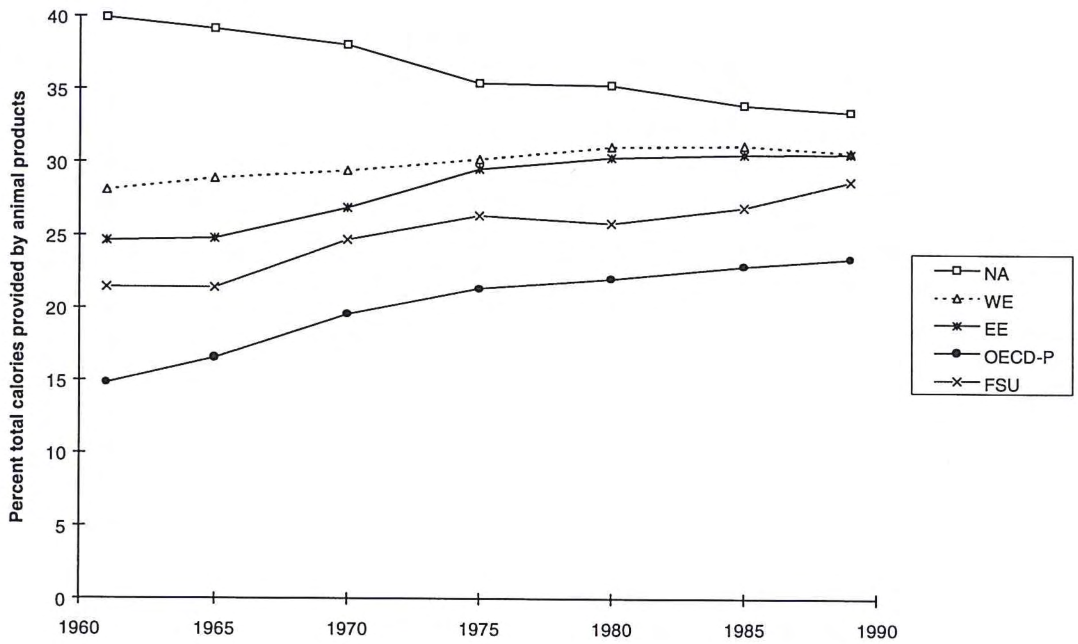


Figure 2.2. ***Anfrac*** **(percent of total calories provided by animal products): 1961-89.**
Note different vertical scales.

Table 2.3. Diet structure (percentage of total daily calories from each food group).

Regions →	AFR		LA		ME		CHINA+		S & SE Asia	
Food groups ↓	1961	1989	1961	1989	1961	1989	1961	1989	1961	1989
C1 all cereals	49.3	49.8	40.0	39.7	49.9	59.5	65.1	70.6	25.8	26.2
C11 cereals exc. rice	44.4	43.5	31.4	30.0	44.0	50.6	29.1	31.5	25.8	26.2
C12 rice	4.9	6.3	8.6	9.7	5.9	8.9	36.0	39.1	39.1	38.9
C2 roots & tubers	16.9	16.0	7.2	4.8	0.7	1.3	16.0	5.7	3.4	2.4
C3 pulses	4.0	3.4	5.5	3.5	1.5	1.9	6.2	1.0	7.2	3.9
C4 vegetable oils [a]	5.5	6.9	5.1	10.0	4.3	7.1	1.6	5.4	4.4	5.9
C5 sugar crops	4.9	6.5	16.0	16.1	8.1	9.0	1.2	2.3	8.6	8.2
C6-7 vegetables, fruit [b]	11.6	10.0	9.2	8.6	23.1	10.9	6.2	4.5	5.6	7.3
A1-A3 animal products	7.8	7.4	17.0	17.3	11.9	10.3	3.7	10.5	5.9	7.2
(A3, fish and other aquatic products)	0.5	0.6	0.4	0.5	0.2	0.3	0.5	0.7	0.6	0.8
Regions →	**NA**		**WE**		**EE**		**OECD-P**		**FSU**	
Food groups ↓	**1961**	**1989**	**1961**	**1989**	**1961**	**1989**	**1961**	**1989**	**1961**	**1989**
C1 all cereals	20.4	23.1	33.6	30.5	48.0	37.8	54.5	39.3	49.3	37.2
C11 cereals exc. rice	19.5	21.3	32.6	29.2	47.2	36.9	15.9	18.7	49.1	35.1
C12 rice	0.9	1.8	1.0	1.3	0.8	0.9	38.6	20.6	0.2	2.1
C2 roots & tubers	3.0	2.7	5.9	4.2	6.4	3.9	5.6	2.8	7.9	5.3
C3 pulses	1.1	0.6	1.3	1.2	0.9	0.9	1.3	0.7	1.0	0.5
C4 vegetable oils [a]	8.5	15.3	8.4	9.1	3.9	7.5	3.0	12.3	3.6	8.0
C5 sugar crops	16.6	15.8	10.3	10.6	8.8	11.9	8.1	11.5	10.0	13.6
C6-7 vegetables, fruit [b]	10.5	9.0	12.4	13.9	7.4	7.4	12.7	10.0	6.8	6.9
A1-A3 animal products	39.9	33.5	28.1	30.5	24.6	30.6	14.8	23.4	21.4	28.5
(A3, fish and other aquatic products)	0.7	0.9	0.9	1.5	0.4	0.6	3.9	6.6	1.0	2.2

[a] For 1961, vegetable oils include oils from trees; in 1989 these are placed in C7 with other tree crops. The resulting errors are small.

[b] Vegetables (C6) plus orchard fruit, nuts & other perennial crops (C7).

Several major trends and regional differences in diet structures are worth noting, as follows.

- Cereals have lost ground in all the developed regions except North America. For the five MDC regions the dietary contribution from cereals fell from 35% to 28% during 1961-89. The largest fall, in OECD-Pacific, was due mostly to the substitution of rice in Japanese diets by animal products and higher value vegetable foods. As discussed in Chapter 1, these trends do much to explain the recent decline of per capita global cereal production, a trend which has prompted dire warnings that global food production is losing the race against population growth.
- In less developed regions cereals have roughly maintained their dietary share or increased it (notably in the Middle East and China+). In the LDC regions combined the contribution from cereals rose slightly from 59% to 61% during 1961-89. For the world, there was a small change from 53% to 55%.
- The great importance of rice in China+, S & SE Asia and OECD Pacific (through its inclusion of Japan) is striking. However, aggregation has masked some major counter-trends. In the most economically successful Asian countries the contribution of rice to the diet has fallen heavily and steadily. As suggested by the data for OECD Pacific in Table 2.3, in Japan the share of rice in total calories almost halved from 45% in the early 1960s to 24% in 1989. Equivalent changes were 52% to 37% in South Korea and 48% to 32% in Malaysia. In all

three countries total per capita calorie intakes rose considerably as rice intakes declined.

- Roots and tubers were major dietary items in 1961 in Africa and China+, but in the latter region the share had by 1989 fallen 3-fold to under 6%. The high share has been maintained in Africa, partly because high yields make these crops a good defence against hunger. The FAO expects this share to decline in the future as Africa becomes more urbanised and roots are replaced by higher value crops which are easier to transport and store. Roots have been fairly important in the European regions and Latin America, but the shares have declined substantially.
- Vegetable oils have increased their shares in all the regions, but especially in the MDCs (where shares have roughly doubled in four of the five regions) and Latin America. Vegetable oils are likely to increase their shares in other LDC regions as incomes rise.
- Sugar is a major part of diets in all MDC regions and Latin America, and its share has been rising in most other regions. Sugar is also a dietary indicator of affluence, but its high shares in the MDC regions may decline in future for health reasons. In North America, for example, the contribution of sugar to total dietary calories peaked at 17.6% in 1973 and has fallen about two percentage points since.

2.1.1 Primary Crop Equivalents

Two further steps complete the calculation chain for human food consumption. The first is to convert calories of secondary or processed food products into primary crop equivalents, a necessary step in order to use the complete Agrostat database in a consistent manner. The Agrostat Food Balance/utilisation accounts provide sufficient data to convert the main products that matter; namely, sugar into the equivalent tonnage of sugar crops (including separation of the latter into use for human food, biofuels and other industrial uses), vegetable oils into oil crops, and secondary cereal foods into primary cereal crops. The second step is simply to convert per capita food consumption from calories to weight units. This is easily done as Agrostat gives per capita consumption of each dietary item both as daily calories and annual kilograms, allowing calculation of a calorie per kg conversion factor or *food property* for each product group and region. This factor is held constant in all projections, thereby implicitly assuming no change in the mix of food items making up each product group.

The annual consumption of *human food* for each region and product group, as millions of tons (Mt) of primary crops, can now be calculated as follows:

> human food (Mt) = population (M) x *Totcal* (kcal/person/day, primary crop equivalent) x diet structure (fractional share) ÷ [food property (kcal per kg) x 0.365 (conversion of M kg per day to Mt per year)].

2.1.2 Human Diets: Scenario Projections

How will these dietary patterns change in the future? The scenario projections presented below are based on three main considerations. First, as average incomes grow more people will be able to buy their way out of hunger or other forms of nutritional deprivation into satisfying their food needs. However, even for the most affluent there are limits to individual food consumption. Consequently, *Totcal* and *Anfrac* are likely to increase where they are now low but might not increase, or might decline, where they are now high. Second, long-standing cultural values based in part on agricultural and climatic conditions will prevent very rapid changes in dietary structures, and to some extent in total per capita calorie intakes. Third, it is assumed that as incomes grow and urbanisation spreads in a Conventional Development future, there will be some convergence of dietary patterns roughly towards those of present-day Europe. This convergence is unlikely to be complete within the forecast period because of the continued income gap between the LDCs and MDCs and continuing cultural differences. More formal projection methods, such as the use of income elasticities based on historic data, were rejected because they produced many gross anomalies, such as *Totcal* values for some LDC countries of over 10,000 kcal/capita/day in 2050. These anomalies would have needed adjustment using the same kinds of judgement as have been used here to make the projections.

The assumptions for *Totcals* and *Anfrac* are outlined in Table 2.4. A better appreciation of how the projected values relate to past trends, and how present regional differences are reduced as values converge, can be gained from Figures 2.3 and 2.4, which show *Totcals* and *Anfrac* plotted against year, from 1961 to 2050, and Figures 2.5 and 2.6 which show 1989 and projected values plotted against per capita GDP.

Table 2.4. Human dietary variables (*Totcal, Anfrac*): 1989, 2025, 2050.

Region	*Totcals* (kcal/capita/day)			annual % change	*Anfrac* (% calories from animal products)		
	1989	2025	2050	1989-2050	1989	2025	2050
Africa	2,351	2,650	2,800	0.29	7.4	10	13
Latin America	2,729	2,920	3,000	0.16	17.3	20	22
Middle East	2,869	3,050	3,100	0.12	10.3	15	18
China+	2,618	2,900	3,000	0.22	10.5	18	21
S & SE Asia	2,307	2,700	2,850	0.35	7.2	13	16
N America	3,641	3,600	3,500	-0.06	33.5	31	30
W Europe	3,426	3,450	3,400	0	30.5	31	30
E Europe	3,450	3,450	3,400	0	30.6	31	30
OECD Pacific	2,971	3,250	3,300	0.17	23.4	27	28
Former USSR	3,372	3,400	3,400	0	28.5	30	30
LDCs	2,477	2,780	2,900	0.26	9.7	14.5	17.1
MDCs	3,410	3,450	3,412	0	30.0	30.4	29.8
World	2,703	2,894	2,972	0.16	15.9	17.7	19.2

With total calories, the slow historical increases in the MDC regions (other than OECD Pacific) are assumed to signal near-saturation conditions. Projected intakes remain close to the present level, but decline in North America, so that all four regions fall within the 3,400 to 3,500 kcal/capita/day band in 2050. The more rapid increase in OECD-Pacific slows until intakes reach 3,300 kcal/capita/day in the same year. With the LDC regions, two key assumptions are that Africa returns to its 1961-89 growth rate after the slow-down of the 1980s, as suggested by the scenario's macro-economic assumptions, and that following the very rapid increases of the 1960s and 1970s the recent sharp slowing of growth in China+ and the Middle East sets the trend for the coming decades. In 2050, per capita daily calorie intake in the LDCs ranges from 2,800 (Africa) to 3,100 (Middle East).

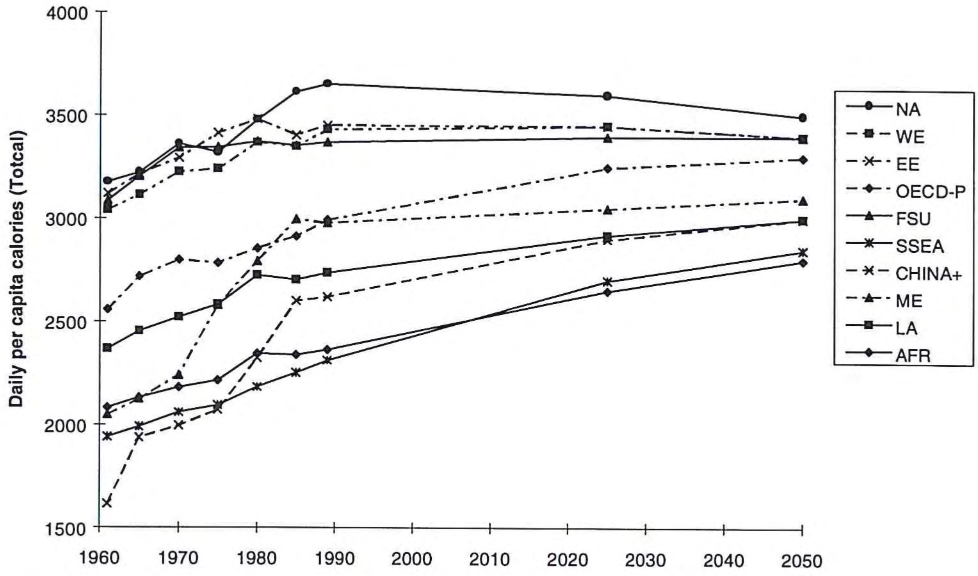


Figure 2.3. ***Totcal*** **against year: past trends and projections to 2050.**
Note non-zero origin of vertical scale.

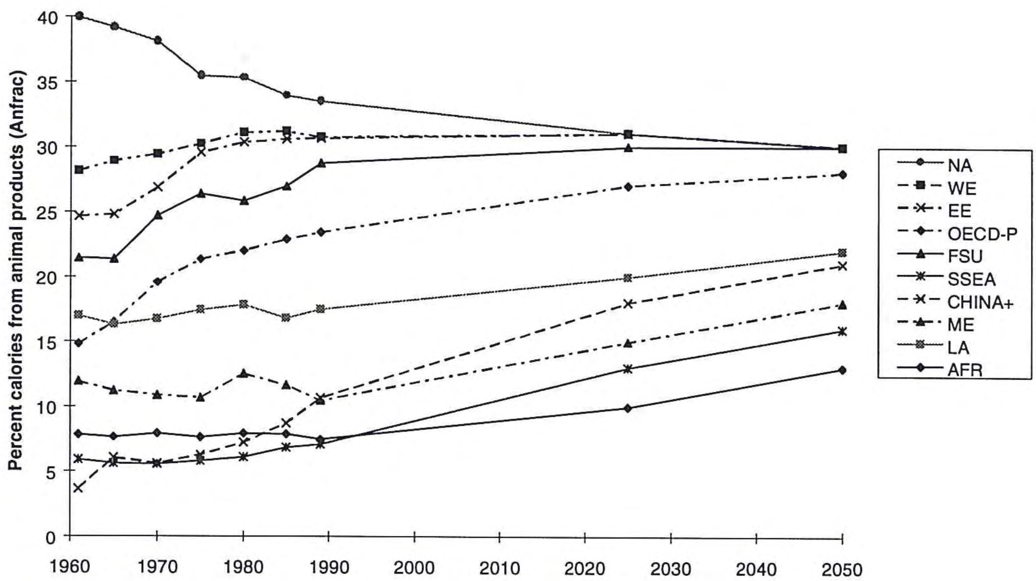


Figure 2.4. ***Anfrac*** **against year: past trends and projections to 2050.**

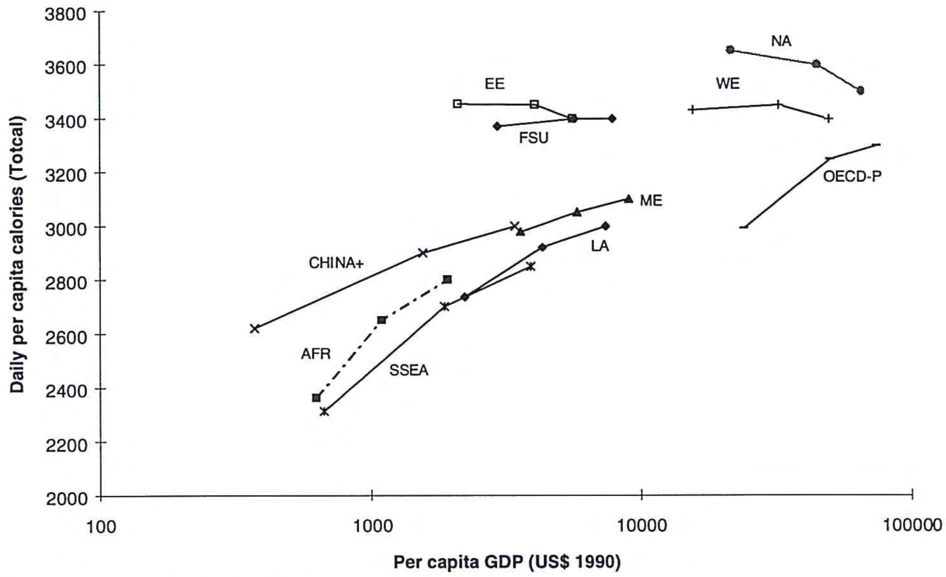


Figure 2.5. ***Totcal* against per capita GDP: 1989 and projections to 2050.**
Note non-zero origin of vertical scale.

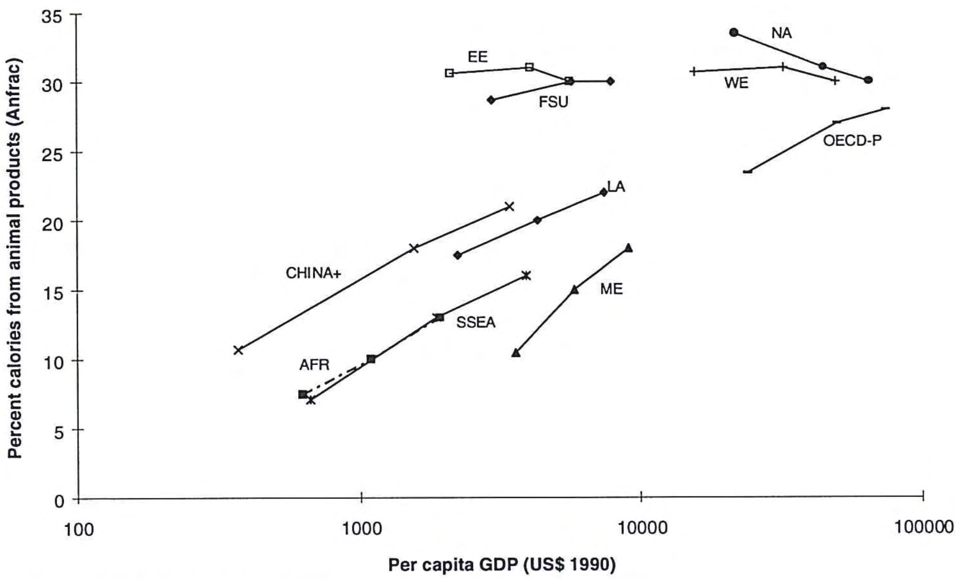


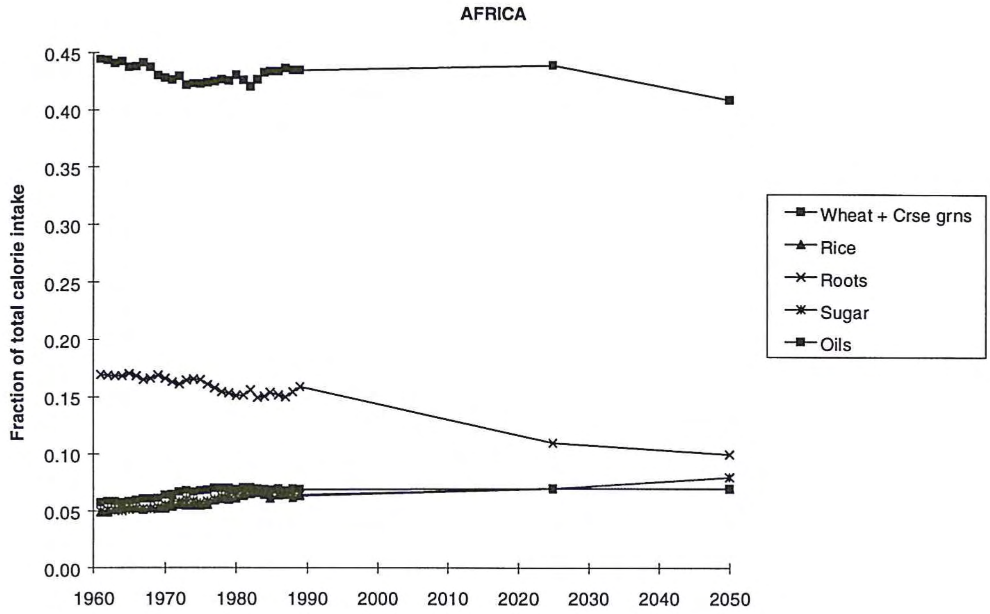
Figure 2.6. ***Anfrac* against per capita GDP: 1989 and projections to 2050.**

Due to these changes, the LDCs as a whole catch up considerably in absolute terms with the nutritional levels of the MDCs. Whereas the ratio of LDC to MDC per capita calories was 0.73 in 1989, it closes to 0.81 in 2025 and 0.85 in 2050. In other words, the LDC share of the global calorie intake rises from nearly 70% in 1989 to 84% in 2050.

Of crucial importance to the entire scenario and its results, are future growth rates of nutritional standards, which even in the increasingly well-fed LDCs, are much lower than in the past. This slow-down does much to temper the future increase in food requirements due to population growth. For example, the highest projected growth rate for per capita calories - 0.35% per year in S & SE Asia during 1989-2050 - is only slightly more than half the rate of 0.63% per year during 1961-89. For the LDCs as a whole, the projected 1989-2050 annual growth rate of 0.26% is just over one-quarter the historic rate of 0.97% per year. At the same time, the growth of per capita calorie intake in the MDCs more or less ceases.

With the animal calorie fraction (*Anfrac*) the broad assumption for the MDCs is that health concerns prevent a continued increase in consumption of meat and dairy products, but not to the extent of a major decline and shift to vegetarian diets. Consequently, the assumptions are broadly in line with those for total calories. The major exception is the much greater decline from the present level in North America, where the falling trend of the 1960s to 1980s continues, though at a slower pace. *Anfrac* converges to 30% in all the regions except for OECD-Pacific, which catches up from presently much lower levels to 28% in 2050. Amongst the LDCs, the assumptions are also quite similar to those for total calories. The gradual decline in Africa and the recent sharper fall-off in the Middle East are assumed to reverse, while the very rapid increase in China+ abates somewhat. As a result, *Anfrac* increases in all LDC regions, rising towards but remaining well below the level of the MDC regions, while maintaining the fairly wide spread found today. The ratio for all LDCs compared to MDC increases from 0.32 in 1989 to 0.48 in 2025 and 0.57 in 2050.

Some major changes are also projected for diet structures. In the LDCs the share of vegetable products combined has to decline since animal products are assumed to increase. This shift is accounted for mostly by reductions in cereals (plus roots in Africa), broadly reflecting what can be seen today in the more affluent countries in the regions. There are also increases in higher value foods such as vegetable oils, vegetables, sugar and fruit. In the MDCs the substitution of cereals by animal products is reversed. In North America and Western Europe cereal consumption expands as meat and milk consumption decline, but in the other three regions cereals continue to decline from the high levels of the past few decades, while vegetables and fruit increase. The historic trends and projections for the dietary shares of wheat and coarse grains, rice, roots, oil crops and sugar are shown for each region in Figures 2.7 (a) - (d).



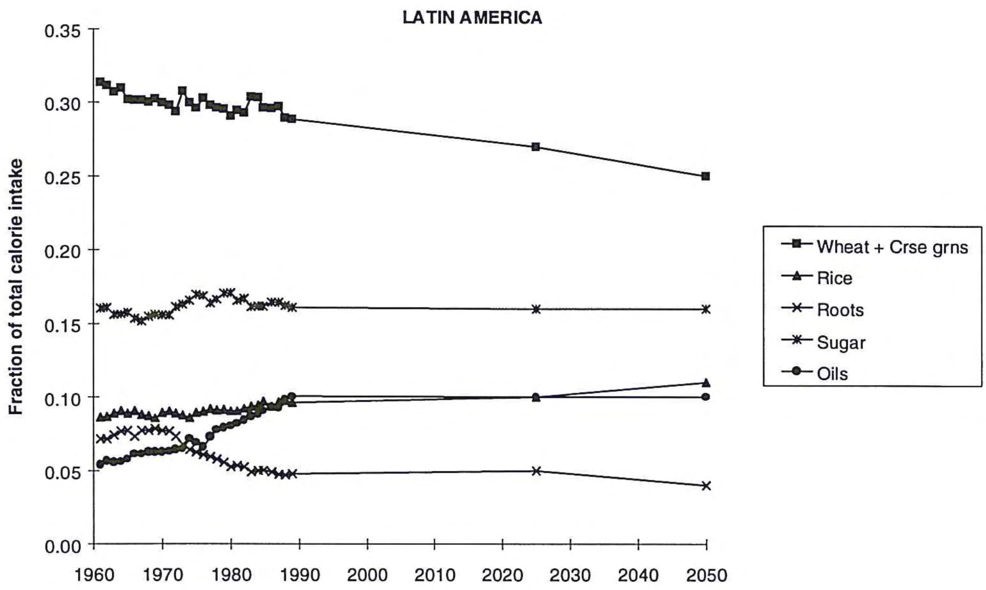
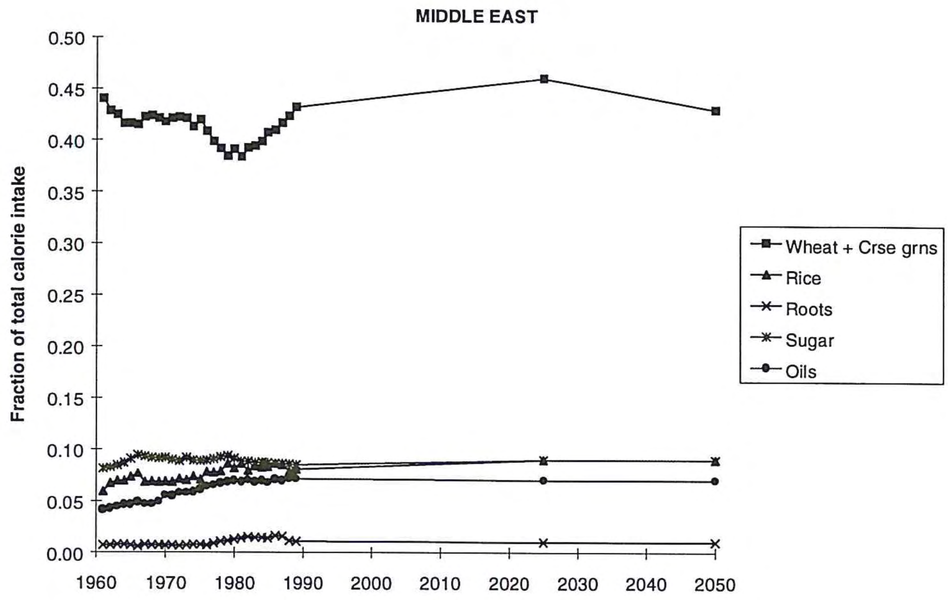


Figure 2.7 (a). Diet shares: cereals, roots, sugar, oil crops: 1961 - 2050.



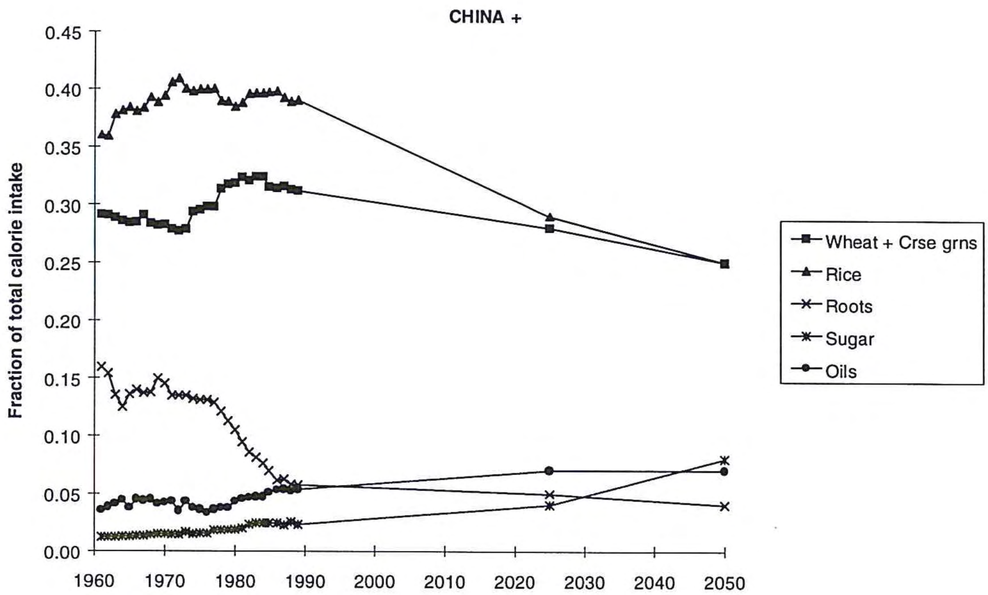
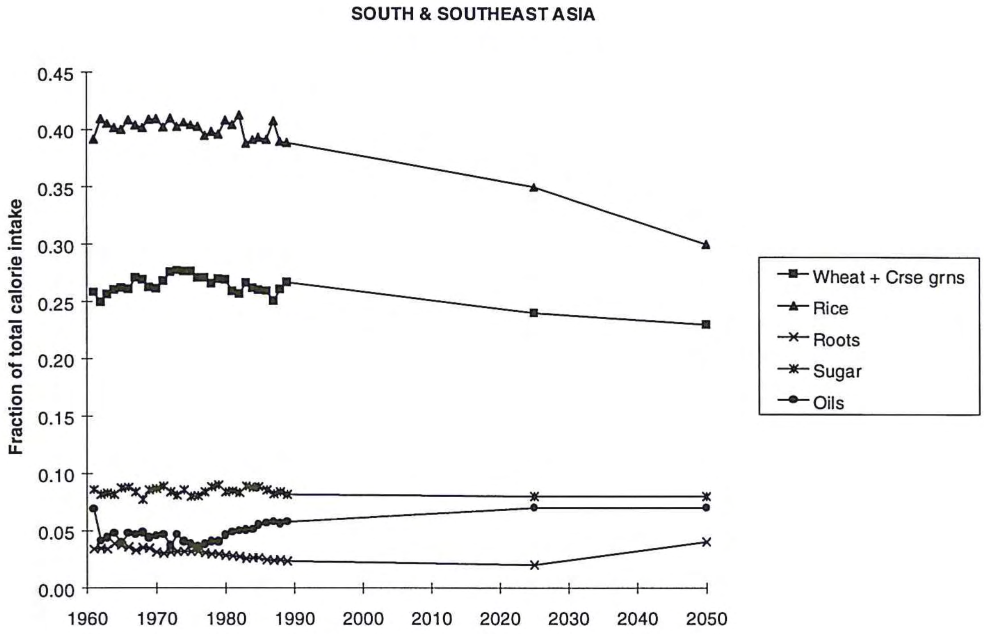


Figure 2.7 (b). **Diet shares: cereals, roots, sugar, oil crops: 1961 - 2050.**



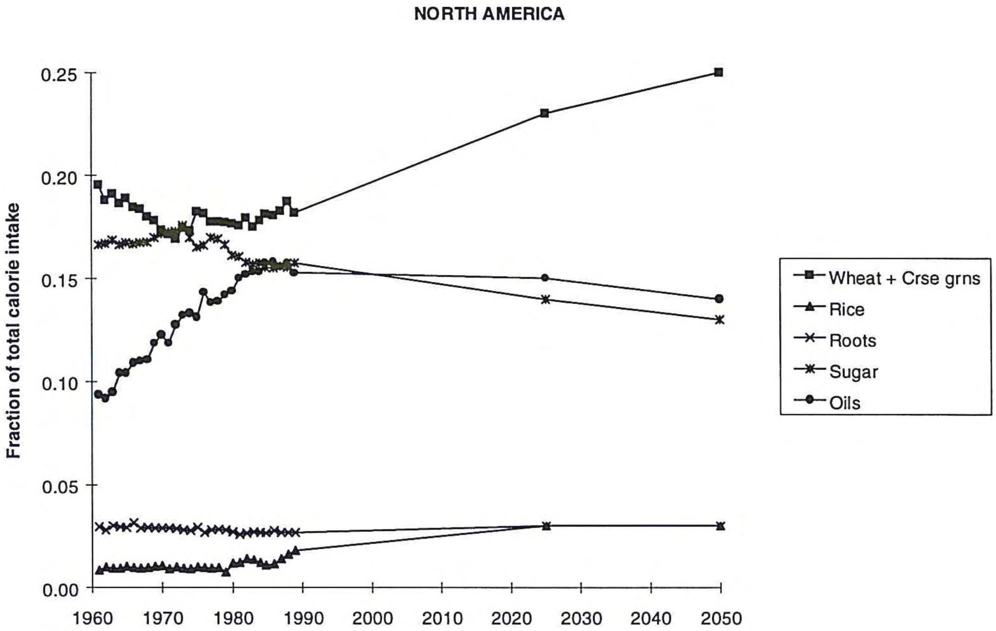
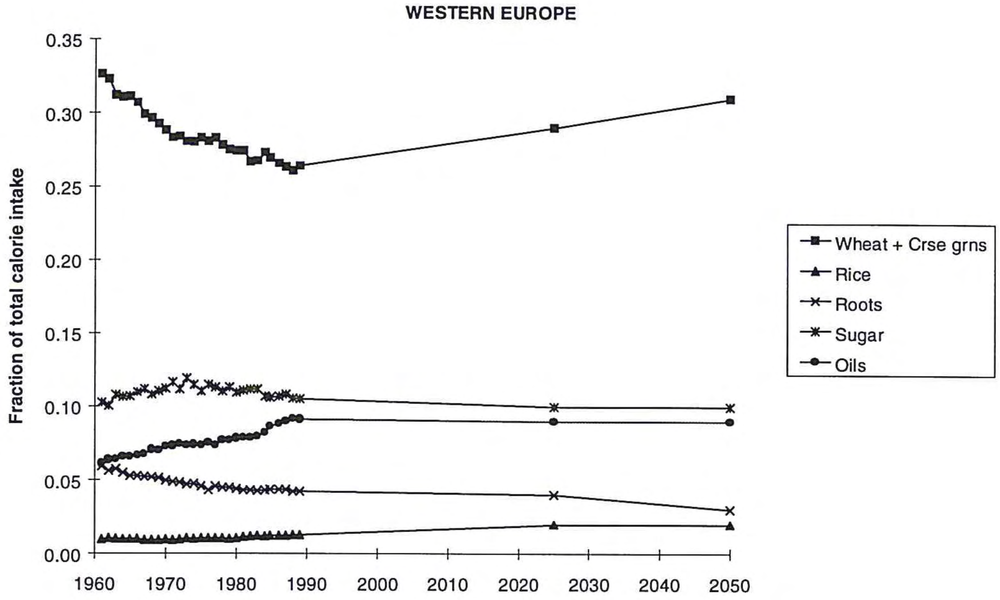


Figure 2.7 (c). **Diet shares: cereals, roots, sugar, oil crops: 1961 - 2050.**



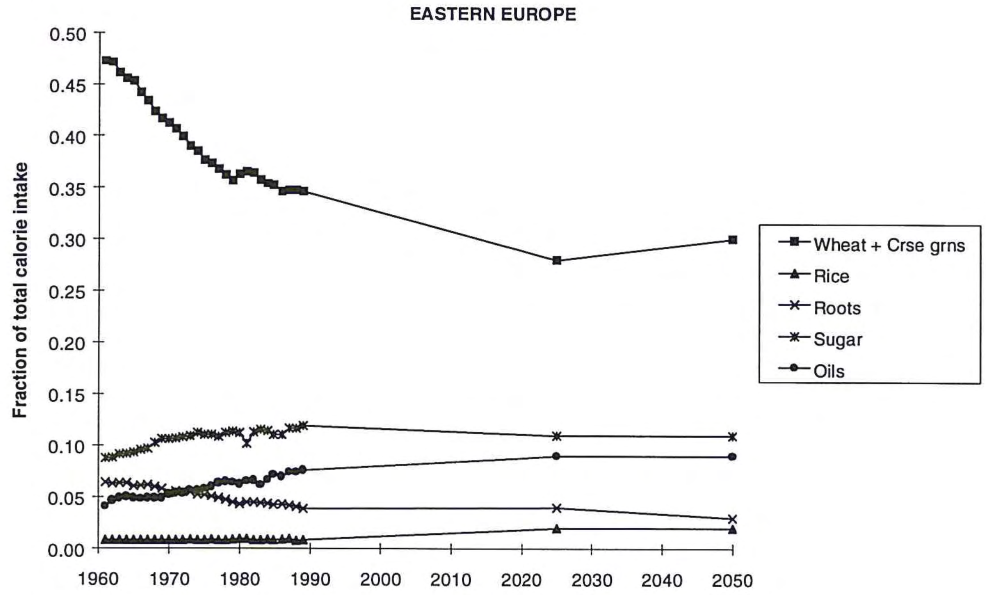
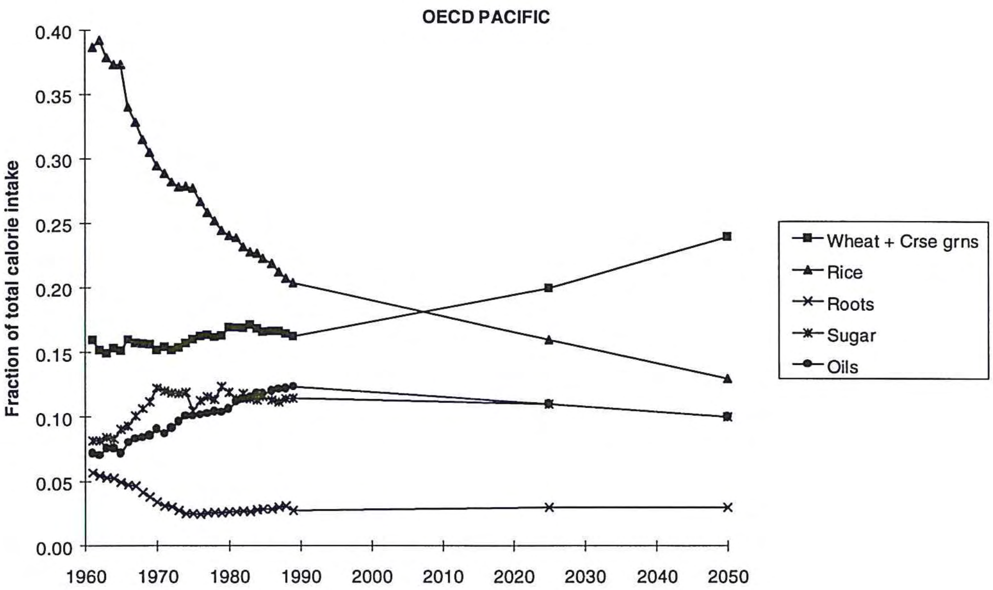


Figure 2.7 (d). **Diet shares: cereals, roots, sugar, oil crops: 1961 - 2050.**



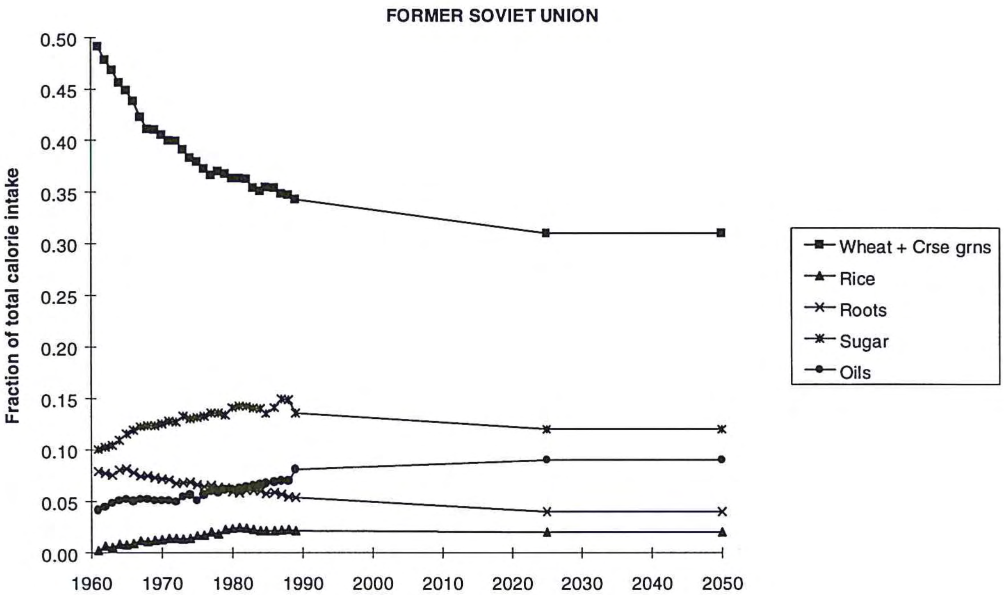


Figure 2.7 (e). **Diet shares: cereals, roots, sugar, oil crops: 1961 - 2050.**

2.2 Animal Feed

The numbers and mass of the Earth's farm and domestic animals are of the same order of magnitude as for humans: around 1.4 billion cattle and buffalo, 2.6 billion sheep, goats and pigs, 137 million equines and camels and 11.2 billion birds, according to FAO statistics for 1989. This vast population consumes prodigious amounts of food which could feed people directly, and even more biomass resources which do not compete with human nutritional needs, notably grass and cellulosic crop residues. In 1989 the world's farm animals consumed some 627 million tons of cereal grains, 145 million tons of root crops, 112 million tons of milk and 30 million tons of fish products. These quantities amounted to 70%, 45%, 28% and 42% respectively of those consumed directly by humans. In the MDCs the equivalent proportions were as high as 276%, 77%, 38% and 52%, respectively. Some 3.3 billion hectares - a quarter of the world's land surface - are designated as grazing land (FAO 'permanent pasture'), an area more than twice that of the world's croplands (1.48 billion hectares in 1989). These resource demands are bound to grow as more of the world's people turn to diets richer in meat and milk, even if there are countervailing vegetarian trends in more affluent regions and sections of society.

Any land-food model must obviously attempt to account for this sector and its resource needs. Unfortunately, this is difficult to do because of the large variety of possible animal feedstuffs and data weaknesses about them in most countries. If one considers the beef or milk cattle herd in a typical developing country, there is a large range of production techniques from full-time rough grazing through various mixes of rough grazing and stall-feeding (often a response to rising income, which makes labour-intensive herding increasingly uneconomic) to full-time stall-feeding. Consequently, the feed inputs to the national herd can include any of the following: (1) grass from "unmanaged" rough grazing lands; (2) grass or forage crops such as hay and silage from managed "farm" pastures; (3) grazed or cut-and-carried leaf forage from woodlands or farm trees; (4) grazed or cut-and-carried crop residues of many kinds; (5) vegetable crops which are grown especially for animal feed; (6) food products such as grain, roots and fish which are diverted or processed from, or recovered from wastes in, human food production streams; and (7) some of the products from the herd itself (e.g. milk for calf feeding).

Understandably, there are few if any reliable statistics on the first and major item, such as areas actually used for grazing, grass productivity on these areas, or the amount of grass actually eaten by the grazing herds. The same severe data problems apply to other major feed sources, notably crop residues. As a consequence, the only statistics related to these questions which are included in FAO's Agrostat data base are gross land areas of rough grazing (item 1) and detailed estimates of crop and animal products used as animal feedstuffs (items 6 and 7).

The approach adopted here follows that used by FAO in its AT2000 and AT2010 studies (FAO, 1993). Only the last two items in the list above (items 6 and 7) are considered as animal feed inputs. By implication, other inputs such as rough grazing and crop residues, with relatively poor feed characteristics, are regarded as "free goods". So long as they are available they will be used to feed animal herds. Higher value and more nutritious feeds derived from crops (or animal products) will be used increasingly to supplement this basic diet as part of well-established strategies to increase animal productivity and reduce net production costs.

We therefore define a gross *feed production ratio* (FPR) which measures for each region the quantity of all food products (commodity groups C1-C7 plus A1-A3) which are fed to animals divided by the quantity of food produced by animals (groups A1 and A2).[2] Also needed are estimates of the structure of animal feed in terms of shares of total feed provided by each commodity group.

Quantities of *animal feed* for each region and product group, as millions of tons of primary crops, can now be calculated as follows:

animal feed = production of food groups A1+A2 (Mt)
x feed production ratio (ton/ton) x feed structure (fractional share).

The product of the first two terms gives total animal feed requirement (Mt).

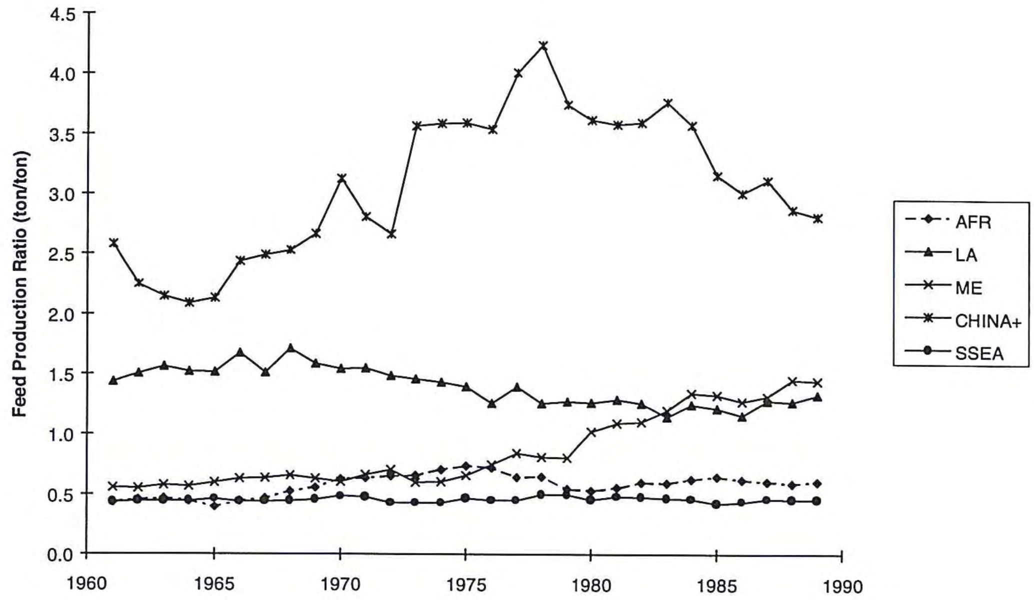
Before we look at actual and projected ratios it is worth considering briefly the major influences on the FPR value. First, the FPR obviously depends critically on the degree to which animals are fed with "prepared" cereal and other crop feeds, as opposed to feeding themselves on grass and crop residues, etc. If a herd survives entirely by grazing its FPR will of course be zero. Second, even with zero grazing the FPR can vary widely owing to the large variability in the efficiency with which farm animals convert their feed into products such as meat, fat, milk and eggs. Quantity and quality of feed, age of slaughter, animal breed, ambient temperature, exercise and, not least, the size of the total breeding herd which must be maintained compared to the number of productive animals, are amongst the many factors which determine overall efficiency (McDonald et al., 1973; Crampton & Harris, 1969). Estimates for the "whole herd" energy efficiency (edible food output/feed energy input for whole farm systems) in industrialised countries with temperate climates and relatively good quality stock centre on 20-35% for milk (with higher values for higher production per animal), 18% for pork, 12-16% for poultry meat and eggs and 6% for beef (Balch & Reid, 1976).

If we make the extreme assumption that animals are fed only on cereal grains (i.e. with no grazing or feeding with crop residues, etc.) on a weight/weight basis the FPR would be about 12 for beef, 4-5 for pork, poultry and eggs, and 0.7 to 1.2 for milk. This exercise shows that the mix of items in total animal production, especially the share of milk and its products, has a major influence on the FPR alongside the large differences in feeding practices. In 1989 this mix varied widely. The "milk fraction", or ratio A2/(A1+A2), ranged from over 80% in S & SE Asia and the Former USSR, to 77-79% in Europe, and 65-68% in all other regions except China+ where the ratio was only 16%.

All these influences lie behind the large regional differences in the current values and historic trends of the *feed production ratio*, shown in Figure 2.8. Considering the LDCs, Africa and S & SE Asia have maintained a remarkably steady ratio of below 0.5, probably due both to the high proportion of grazing and/or dependence on crop residue feedstuffs and also, for S & SE Asia, the dominance of milk in total animal production. In the Middle East the FPR was also as low as 0.5 in 1961 but has risen steadily since then to about 1.5, or roughly the value which Latin

[2] Initially this ratio was defined in caloric terms with later conversion to mass using the food property values in calories per kg. However, comparisons of historic regional trends showed that nothing would be lost if the FPR was defined instead as a mass ratio (tons of animal feed per ton of A1+A2 produced).

America maintained throughout the period. The erratic behaviour of the FPR in China+ may be due in part to data problems. In the MDCs the FPR values now range from close to 1.0 in Western Europe and OECD Pacific to 1.8 in Eastern Europe but have in all cases been fairly steady since around 1980. The fairly stable historic trends in all regions except China+ gives some confidence in the use of the FPR as a proxy for all animal feed inputs, and in projections based on these historic trends.



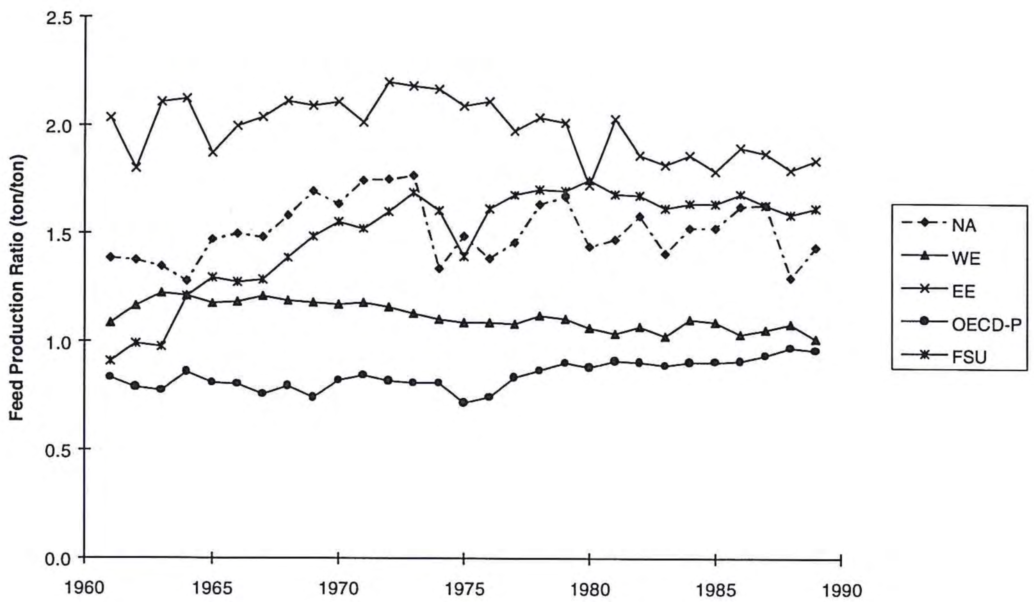


Figure 2.8. Feed production ratio: 1961 - 1989.

2.2.1 Animal Feed: Scenario Projections

Historic values and projections of the *feed production ratio* are shown in Table 2.5 and Figure 2.9. In most regions the changes from 1989 values are quite small because of the stability of the historic trends. In the other cases - notably the Middle East, China+, Eastern Europe and OECD Pacific, the projections take note of historic trends but also assume convergence towards a narrower range of values in 2050 than today. The mix of feedstuffs within the total feed input (feed structure) is maintained at the 1989 values throughout the scenario period, with one minor exception. The share of fish products (A3) is steadily reduced on the grounds that fish will increasingly be reserved for direct human consumption as global demand presses against relatively limited fishery resources (see Chapter 3). To compensate, the share of non-rice cereals (C11) is increased slightly. A more thorough analysis of FPR values by country and in relation to key variables such as the mix of animal production (e.g. meat versus milk), crop production, and grazing area compared to herd size might reduce the uncertainties surrounding these projected values.

Table 2.5. Animal feed production ratio (FPR): 1961 - 2050.

Region	1961	1989	2025	2050
Africa	0.44	0.61	0.8	0.9
Latin America	1.44	1.33	1.4	1.4
Middle East	0.56	1.44	1.9	1.9
Cent Plan Asia	2.49	2.82	2.0	1.8
S & SE Asia	0.39	0.46	0.55	0.6
N America	1.39	1.44	1.5	1.5
W Europe	1.09	1.02	1.0	1.0
E Europe	2.03	1.84	1.5	1.3
OECD Pacific	0.82	0.96	1.2	1.3
Former USSR	0.92	1.62	1.5	1.4

2.3 Other Food Consumption

2.3.1 Industrial Uses and Losses

Some crop and animal products are recorded in FAO Agrostat as being used by industry as feedstocks of various kinds. Generally the quantity of these *other uses* is small compared to human food and animal feed, although there are some notable exceptions. The most significant of these in 1989 was the conversion in Latin America (i.e. mostly Brazil) of 171 million tons of sugar cane (44% of total production) to alcohol transport fuels. Other notable examples were North America, where 7.5% of the wheat plus coarse grain crop was used by industry, and Western Europe, where 11% of the sugar crop and 13% of all tree crops (C7) were so used. The PoleStar accounting framework allows these uses to be projected without reference to human food and animal feed, especially bio-fuels. In the latter case, tonnage requirements are fed to the agricultural and land accounts from assumptions made in the energy accounts. However, in the scenarios presented here, these industrial uses are treated as by-products in which consumption maintains the same relationship to human food plus animal feed production as in the 1989 baseline year; with the exception that biofuels in Latin

America are held constant. These assumptions can be changed in later scenario development.

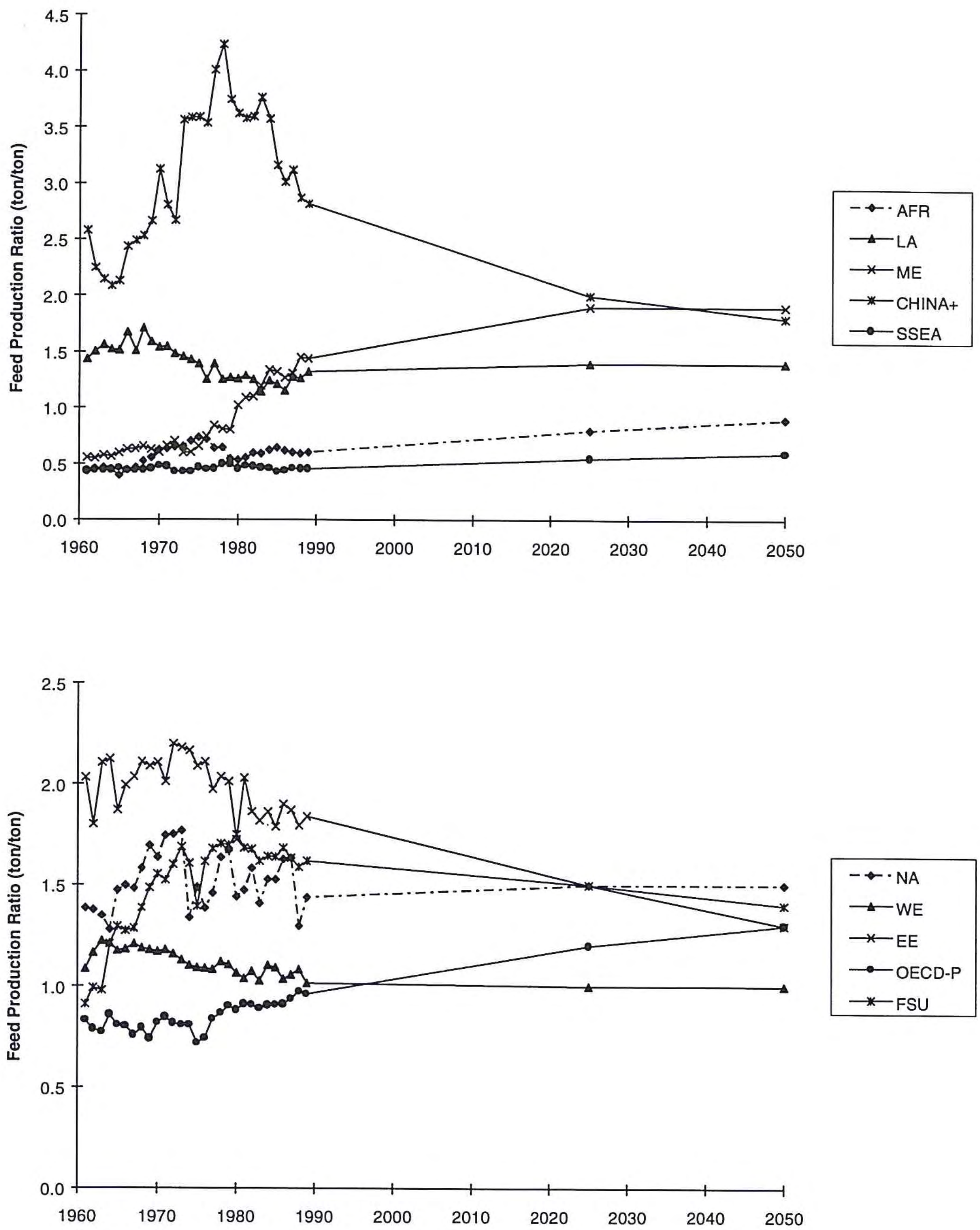


Figure 2.9. Feed production ratio: 1961 - 2050.

2.3.2 *Seafood*

Fish and other aquatic products play a very small part in the diets of all regions except OECD Pacific (which includes Japan). In 1989 they contributed only 1% to global dietary calories. However, they are important sources of protein and fats in some cultures and their contribution to human diets has risen in every region (see Table 2.3). About one-third of the global fish catch is fed to animals or otherwise lost to human consumption.

The scenario assumes that future demand will be limited by problems of fishery supplies. The contribution of seafoods to the human diet declines so that during 1989-2050 global consumption as food increases by only 44%, from 73 Mt to 105 Mt. The use of fish for animal feed is also constrained so that total demand for fish and other seafoods increases by only 38% during the scenario period, from 106 Mt in 1989 to 146 Mt in 2050.

These assumptions are in line with widespread fears that the present world catch of marine fish plus shellfish may be close to the sustainable limit. This catch has declined slightly from a peak of 85 Mt in 1989 with indications of stress or decline in major fishing zones (Brown, Kane & Roodman, 1994). Output of fresh water fish has grown rapidly in the same period to reach about 16 Mt/year in 1991, or 16% percent of total fish production. The projected fish demand could be met by holding marine production at today's level while increasing production from other sources at one-third of the historic rate of increase.

2.4 Final Demand and Required Supply

The sum of human food, animal feed and other uses gives the *final demand* (FD) tonnage for each region, year and crop group. However, two more steps must be taken in the consumption chain before we can see what level of production is required for each commodity. The first is to incorporate the various distribution and processing losses, and seed requirements (plus stock changes for the baseline year), which are estimated in the FAO Agrostat Supply Accounts and Food Balance/Utilisation Accounts. These must be added to *final demand* to give a *required supply* for each product. In some cases the combination of losses and seed use is very large: for example, in 1989, it amounted to 28% of final demand for wheat and coarse grain (C11) in the former Soviet Union; 46% of final demand for rice in North America; and 42% of final demand for roots and tubers in Eastern Europe. Second, the net trade outflow of products - or *net exports* (exports less imports) - must be added to required supply to give an estimate of the quantity of each product that must be produced in each region; that is, *required production*.

In fact the calculation procedure differs slightly from this description because it is assumed that seed use is a function of crop production, not of required supply (production minus net exports). The first of two calculation steps handles losses other than for seed, the second handles seed use and trade (all data in million tons or as fractions):

1. required supply (less seed use) =
final demand x (1 + WPFRAC) + stock change
or: RS = FD x (1 + WPFRAC) + SC
where WPFRAC = distribution plus process losses as a fraction of FD and SC is assumed zero in scenario projections.

2. required production =
(required supply + net exports) / (1 - SEEDFRAC)
or: RP = (RS + NE) / (1 - SEEDFRAC)
where SEEDFRAC = use for seed as a fraction of production in baseline year 1989.

Required supply measures how much food a region needs to have available. It is worth looking at how these needs are made up from its components - human food, animal feed, other uses and losses - and the dramatic differences between more and less developed regions in this respect. Some outline data for 1989 are shown in Table 2.6 and Figure 2.10.

Most strikingly, average total needs in the MDC regions (8,153 kcal/cap/day) were 2.5 times greater than in the LDCs with an average of 3,262 kcal/cap/day. Putting this another way, whereas the ratio of total supply of potential human food to human food itself was 1.32 in the LDCs, in the MDCs it was 2.39, mainly because of very much greater levels of animal feed but also because of larger non-food ("other") uses and process and distribution losses. Because of these large differences, the full adoption of today's MDC supply levels and patterns by the LDCs would put more very much greater pressures on global food production requirements than population growth alone.

Table 2.6. Structure of required supply (daily per capita kcal): 1989.

Region	Human food	Animal feed	Other uses & losses	Total supply
Africa	2,351	190	433	2,974
Latin America	2,729	1,015	863	4,607
Middle East	2,869	780	526	4,175
China+	2,618	485	386	3,489
S & SE Asia	2,307	118	301	2,726
N America	3,641	4,376	1,517	9,536
W Europe	3,426	2,505	1,088	7,019
E Europe	3,450	4,502	1,784	9,736
OECD Pacific	2,971	1,379	577	4,927
Former USSR	3,372	4,451	1,890	9,713
LDCs	2,477	366	419	3,262
MDCs	3,410	3383	1,360	8,153
World	2,703	1,097	647	4,447

Other uses & losses: other (industrial) uses, process & distribution losses, seed use.

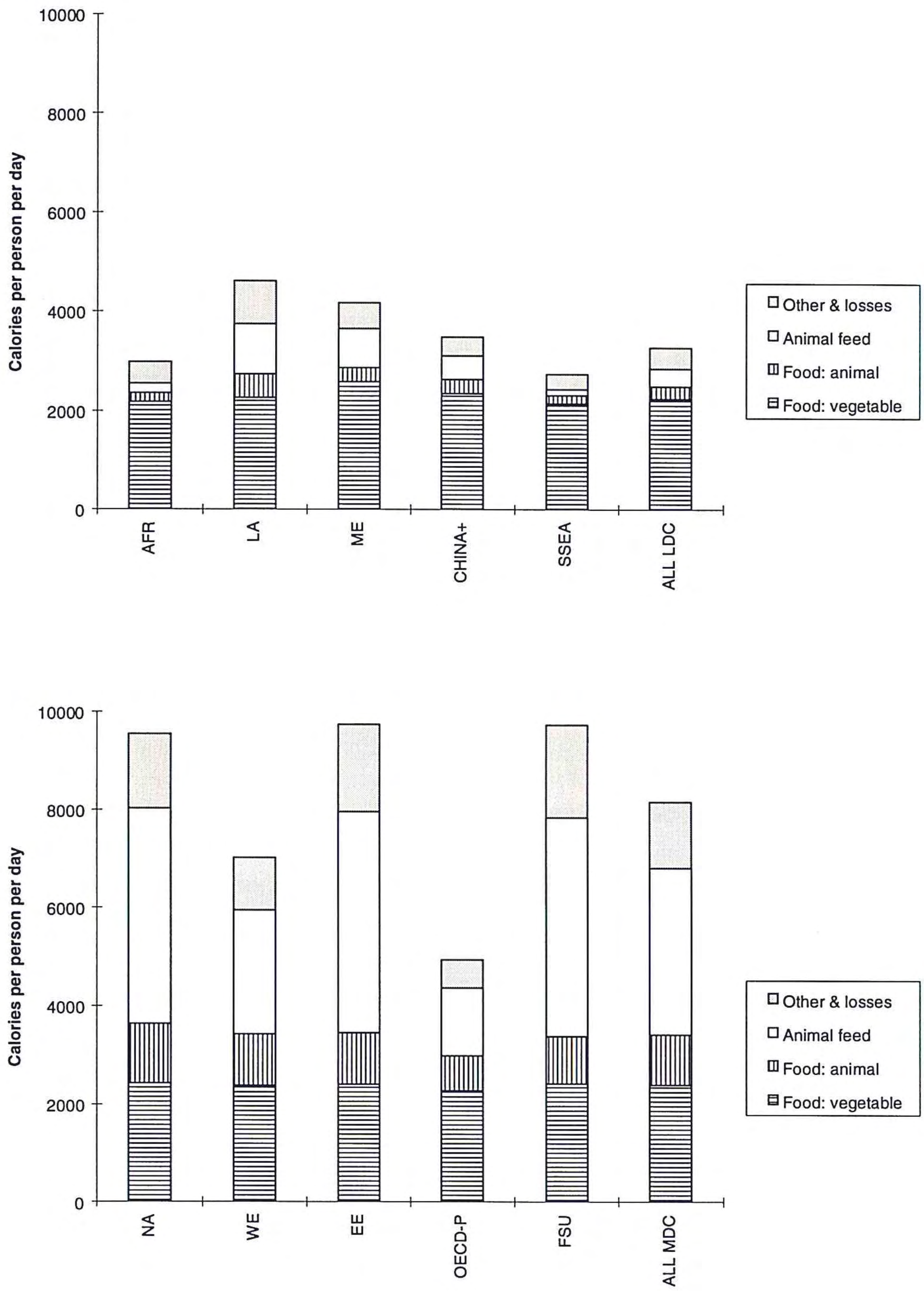


Figure 2.10. Structure of supply: human food, animal feed, other uses and losses: 1989 (per capita daily calories).

Other and losses: other (industrial) consumption, process losses, distribution losses, use for seed.

2.4.1 Final Demand and Required Supply: Scenario Projections

We are now in a position to see how the foregoing assumptions build up to define future requirements for agricultural products. As one would expect, in most LDC regions the scenario assumptions about population growth and better dietary standards combine to give very large increases in requirements both for human food and animal feed. In the MDCs, on the other hand, much slower population growth coupled with little change in already high nutritional standards leads to much smaller increases. As a result, although global requirements increase by what appear to be daunting amounts in absolute terms, growth rates for the broadest product groups are actually lower than for the past three decades.

Some comparisons for 1989, 2025 and 2050 are provided in Tables 2.7 and 2.8 for human food and Tables 2.9 and 2.10 for required supply, which includes animal feed, other uses and losses as well as human food. If we consider that required supply gives the best estimate of total commodity demand, we find that during the scenario period 1989-2050 globally the required supply of cereals increases by a factor of 1.99, other crops increase by 2.27, and animal products increase by 2.37. These are large increases, but there are 60 years in which to achieve them. Indeed, over such a long period the annual rates of increase in consumption - namely 1.14% for cereals, 1.35% for other crops and 1.42% for animal products turn out to be quite low and, furthermore, substantially lower than the average rates over 1961-1992.[3]

For cereals the future growth rate assumed for the scenario is less than half that of the past three decades.

Of course, these global figures disguise much larger and more challenging increases amongst the less developed regions - notably Africa and the Middle East. In the LDCs as a whole, over the 1989-2050 period the required supply of cereals, other crops and animal products increase by factors of 2.6, 2.9 and 4.6 respectively. But in Africa we have equivalent increases of 5.1, 4.3 and 7.5; and in the Middle East 6.1, 4.9 and 7.5. While both regions have the highest projected rates of population growth, the scenario also assumes major increases in per capita consumption of animal products as well as the animal feed production ratio, so that the use of crops for animal feed soars upwards. In 1989, cereals fed to animals were close to 12 million tons each in Africa and the Middle East. In 2050 they are projected to be 155 and 119 million tons respectively.

For the MDCs, the scenario projects quite modest increases in human food and total required supply. All told, human food demand rises by close to 15% during 1989-2050 for all the main product groups. In North America cereals increase by almost twice this amount because of the assumed substitution of cereals for declining per capita consumption of animal products. There are also larger than average increases for non-cereal crops in Eastern Europe, and of animal products in OECD Pacific as the Japanese diet becomes more like that of other high income regions today. Considering total required supply, the main differences from direct human food are the higher increases for cereals due to additional animal feed requirements. Total cereal requirements rise by 27% compared to 15% for human food alone.

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[3] The comparisons are for 1989-2050 global consumption data from the present report and 1961-92 global production data from the FAO report, The State of Food and Agriculture, 1993. Global production and consumption data differ only by relatively small stock changes. The 1961-92 annual rates of increase were 2.60% for cereals, 2.12% for all other food crops combined, and 1.82% for all animal products.

In the next chapter we consider how these increases in consumption can be met by the twin strategies of raising domestic production and, where necessary, imports. Since these options are closely linked and complementary, discussion of the scenario assumptions and results for both is deferred to that chapter, even though imports are in fact part of the consumption side of the scenario model (see Table 1.5). The remainder of this chapter merely completes the consumption chain for the 1989 baseline year by considering trade and, finally, the resulting required production of each commodity.

Table 2.7. Human food consumption, 1989, 2025 & 2050 (million tons).

	Cereals			Other crops			Animal products		
Region	1989	2025	2050	1989	2025	2050	1989	2025	2050
Africa	88.9	250	361	267.1	719	1,131	37.0	143	264
Latin America	57.8	92	106	314.0	557	653	67.6	157	201
Middle East	28.3	75	104	66.1	192	284	14.4	62	107
China+	273.9	352	348	289.9	586	848	57.0	159	220
S & SE Asia	267.1	490	568	510.8	1,067	1,486	92.8	267	415
N America	30.5	41	41	174.2	217	201	113.0	130	121
W Europe	61.5	68	69	299.0	322	301	155.3	175	165
E Europe	17.7	16	18	63.3	84	85	31.5	37	38
OECD Pacific	20.6	23	24	72.7	90	85	33.1	49	52
Former USSR	47.4	49	52	217.7	264	277	89.5	108	113
LDCs	716.0	1,258	1,487	1,448.0	3,120	4,402	268.8	788	1,207
MDCs	177.7	197	204	826.8	977	949	422.5	498	490
World	893.8	1,455	1,691	2,274.8	4,097	5,351	691.3	1,286	1,697

Table 2.8. Human food consumption: tonnage ratios 2025/1989 & 2050/1989.

	2025			2050		
Region	Cereals	Other crops	Animal products	Cereals	Other crops	Animal products
Africa	2.81	2.69	3.85	4.06	4.23	7.13
Latin America	1.58	1.77	2.32	1.83	2.08	2.98
Middle East	2.65	2.91	4.30	3.69	4.29	7.42
China+	1.28	2.02	2.79	1.27	2.93	3.85
S & SE Asia	1.83	2.09	2.88	2.12	2.91	4.48
N America	1.33	1.25	1.15	1.36	1.15	1.07
W Europe	1.10	1.08	1.12	1.13	1.01	1.06
E Europe	0.91	1.33	1.18	1.02	1.35	1.20
OECD Pacific	1.13	1.24	1.47	1.18	1.17	1.58
Former USSR	1.03	1.21	1.20	1.09	1.27	1.27
LDCs	1.76	2.15	2.93	2.08	3.04	4.49
MDCs	1.11	1.18	1.18	1.15	1.15	1.16
World	1.63	1.80	1.86	1.89	2.35	2.45

Table 2.9. Required supply, 1989, 2025 & 2050 (million tons).

Region	Cereals			Other crops			Animal products		
	1989	2025	2050	1989	2025	2050	1989	2025	2050
Africa	112.0	357	574	307.5	836	1,321	42.1	167	314
Latin America	113.1	241	296	542.2	866	998	76.7	177	227
Middle East	41.0	163	251	66.9	221	327	16.5	72	123
China+	353.1	521	554	400.7	838	1,161	62.3	168	232
S & SE Asia	321.2	599	744	552.8	1,189	1,695	109.7	319	509
N America	206.0	300	292	197.1	249	231	122.6	142	133
W Europe	199.2	239	240	426.5	459	433	200.3	223	213
E Europe	82.7	73	68	106.2	130	128	45.7	50	49
OECD Pacific	48.9	93	115	85.8	111	109	44.2	65	74
Former USSR	217.1	247	247	294.3	347	361	152.8	187	192
LDCs	940.3	1,882	2,419	1,870.1	3,950	5,502	307.3	903	1,405
MDCs	754.0	952	961	1,109.9	1,298	1,262	565.5	666	660
World	1,694.3	2,834	3,380	2,980.0	5,248	6,764	872.8	1,570	2,065

Table 2.10. Required supply: tonnage ratios 2025/1989 & 2050/1989.

Region	2025			2050		
	Cereals	Other crops	Animal products	Cereals	Other crops	Animal products
Africa	3.19	2.72	3.97	5.12	4.30	7.46
Latin America	2.13	1.60	2.31	2.62	1.84	2.97
Middle East	3.98	3.30	4.34	6.12	4.90	7.46
China+	1.48	2.09	2.70	1.57	2.90	3.72
S & SE Asia	1.87	2.15	2.91	2.32	3.07	4.64
N America	1.45	1.27	1.16	1.42	1.17	1.08
W Europe	1.20	1.08	1.11	1.20	1.01	1.06
E Europe	0.88	1.23	1.09	0.82	1.20	1.08
OECD Pacific	1.91	1.30	1.48	2.36	1.27	1.67
Former USSR	1.14	1.18	1.22	1.14	1.23	1.25
LDCs	2.00	2.11	2.94	2.57	2.94	4.57
MDCs	1.26	1.17	1.18	1.27	1.14	1.17
World	1.67	1.76	1.80	1.99	2.27	2.37

2.5 Trade and Required Production

Differences in climate and suitability for growing crops, as well as many other factors which affect comparative economic advantages of agricultural production, have always led to large international trade in agricultural products. In accounting terms, trade flows are reduced greatly if one only considers net exports (exports less imports) and trade across the borders of multi-country regions rather than the borders of individual countries. Yet even so the flows can be considerable. Obviously, dependence on importing rather than producing food oneself is an important strategy for feeding increased populations, provided that the imports are affordable and that some other regions are prepared to produce enough to export.

Table 2.11 summarises some major features of regional food production and trade in 1989. For highly aggregated product groups - cereals, other crops and all animal products - it shows regional production, net exports and the *self-sufficiency ratio* (SSR), defined here as (required supply + net exports)/required supply. The self-sufficiency ratio can also be measured, as in Table 2.11, by the equation SSR = production/(production - net exports), or SSR = P/(P - NE).

Considering cereals, we see that eight of the 10 regions were net importers, with North America and Western Europe the only net exporters. However, for rice (not shown here) OECD Pacific and S & SE Asia were net exporters and China+ just achieved self-sufficiency (SSR = 1.0). As with most food products, the Middle East had the lowest self-sufficiency ratio. For cereals this was only 46%, meaning that it imported slightly more than it produced. Africa was the next lowest, with 79%. In the LDCs as a whole, cereal production fell short of needs by about 83 million imported tons (SSR = 0.91), which were supplied by the MDCs with a combined SSR of 1.12.

Table 2.11. Production, net exports and self-sufficiency ratios: 1989.

	Production (P) (million tons)			Net exports (NE) (million tons)			Self-sufficiency ratio = P / (P - NE)		
Region	Cereals	Other crops	Animal prods.	Cereals	Other crops	Animal prods.	Cereals	Other crops	Animal prods.
Africa	95.1	296.9	33.9	-23.3	-7.3	-7.3	0.79	0.98	0.83
Latin America	106.6	684.0	80.7	-11.9	134.	7.0	0.89	1.25	1.09
Middle East	21.6	40.4	11.2	-22.1	-	-5.2	0.46	0.57	0.68
China+	400.8	416.3	59.9	-10.1	-	-1.5	0.97	0.97	0.98
S & SE Asia	374.7	662.8	102.5	-15.4	46.4	-6.4	0.95	1.08	0.94
N America	332.6	204.8	117.8	122.1	-2.5	-0.4	1.59	0.99	1.00
W Europe	231.1	372.1	204.6	25.0	-	8.6	1.13	0.91	1.04
E Europe	81.0	110.6	45.2	-2.7	-0.4	1.5	0.97	1.00	1.03
OECD Pacific	37.4	75.3	46.2	-14.6	-	3.8	0.70	0.88	1.09
Former USSR	201.3	250.6	148.5	-37.4	-	-0.9	0.83	0.79	0.99
LDCs	998.7	2,100.	288.3	-82.9	51.4	-13.5	0.91	1.07	0.96
MDCs	883.3	1,013.	562.2	92.3	-	12.5	1.12	0.90	1.02

Production as in FAO Agrostat, with its definitions (e.g. rice as paddy rather than husked grain).

Turning to non-cereal crops, self-sufficiency ratios were generally much less extreme. Interestingly, the positions of the MDCs and LDCs were reversed, with the LDCs as a whole acting as substantial net exporters (due entirely to Latin America and S & SE Asia) and the MDCs as net importers, giving SSRs of 1.07 and 0.90 respectively. Total world crop production was close to 5 billion tons, or just under one ton per person. Per capita production in the MDCs (1.50 tons) was almost twice as great as in the LDCs (0.79 tons), although in both cases with large differences at the regional level from these gross averages.

With animal products, trade generally plays a small role compared to production, with self-sufficiency ratios close to one. The main exceptions amongst importers were the Middle East (SSR = 0.68) and Africa (SSR = 0.83) and amongst exporters Latin America and OECD Pacific, both with SSRs of 1.09.

In the next chapter we look at how these food needs and production requirements have been met by the combination of expanding cultivated land areas and raising the productivity of that land. We also look at the crucial question of how the large future growths in food commodity requirements summarised above can be met by further gains of agricultural lands and productivity and - most importantly - how these gains look when compared to potential resources and practical limitations.

3 FOOD PRODUCTION

3.1 Introduction

In a Conventional Development future, world consumption of crop products might need to double or more by 2050. Most of this increase would be in today's less developed regions, where the pressures on land, water and other agricultural resources are already more severe than in the developed world. In the LDCs combined, the scenario outlined in Chapter 2 projected a 2.6 fold increase in the required supply of cereals between 1989 and 2050 and a 2.9 fold increase for non-cereal crops.

There is little question that these large production increases can be achieved in principle. As we shall see in this chapter, there are still large untapped resources of cultivable land - notably in Latin America and Africa - which could be brought into production by clearing forests, grasslands, wetlands and other land types. There is considerable scope for using farmlands more intensively by reducing fallows or increasing double-cropping. And there are large potentials for increasing crop yields, judging by the huge differences in present-day yields both between best practice countries and others and, within countries, the best farmers and the average. These yield gaps are partly explained by large differences in fertiliser use: in 1989 average use of nitrogen fertiliser per arable hectare stood at 114 kg in Western Europe but only 26 kg in Latin America and 13 kg in Africa.

The practical questions, though, are much more difficult. They are how to bring about these large production increases in an affordable and environmentally sustainable manner. In particular, can food production be more than doubled without serious and lasting damage to land, water and other vital natural resources? And how does one improve the incentives to farmers to grow more and grow it more productively without raising food prices and putting even the most basic foods beyond the reach of the poorest?

This chapter deals with the simpler questions regarding physical potentials and resources. It reviews past trends and makes projections for the variables which make up the model production chain which was summarised in Chapter 1. As a reminder, this chain links a small number of variables to produce an estimate of crop production for each region, year and crop group, $crop_i$. Assuming no stock changes:

cultivated area (Mha) x cropping intensity = harvest area (Mha)
harvest area (Mha) x harvest share$_{(i)}$ x yield$_{(i)}$ (ton/ha) = production$_{(i)}$ (M tons)
(and: production$_{(i)}$ - net exports$_{(i)}$ = required supply$_{(i)}$)
(production$_{(i)}$ / required supply$_{(i)}$ = self-sufficiency ratio$_{(i)}$)

Required supply calculated here must equal the required supply calculated in the consumption chain (see Chapter 1). This is achieved by altering the production and trade variables until there is equality for each region, year and crop product. An additional constraint is that the sum of net exports$_{(i)}$ for all regions must equal zero. As there are many ways in which the variables might be altered, the following process is adopted. Cultivated area, cropping intensity and yield are considered as primary variables and are given initial values based on extrapolations from historic trends. Harvest share and the self-sufficiency ratio are set to the values of the previous time period and then altered as little as possible in the direction which will close any difference between the required supply terms. If closure is not achieved, the primary variables are altered, hopefully while staying within plausible limits.

3.2 Cultivated Land

In almost three decades, from 1961 to 1989, the world's cultivated land area increased by only 9%, or 124 million hectares. At the same time, global population rose by 69% and nutritional standards improved considerably.[4] Most of the huge increase in food consumption during the period was met not so much by expanding the land base but by using existing land more intensively and by increasing per hectare crop production, or yield.

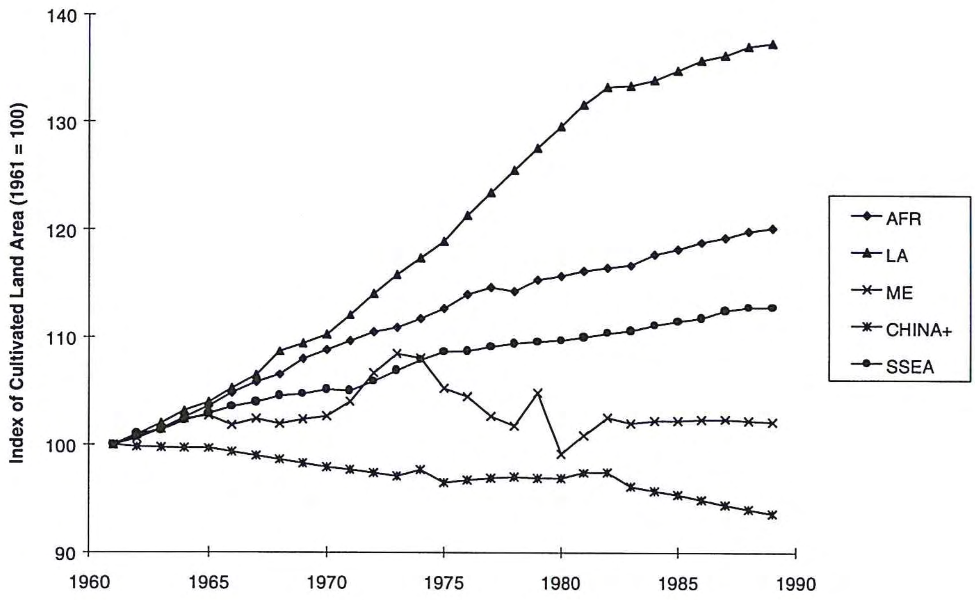
As one might expect, large regional differences occurred beneath this global trend. The largest proportional increase of cultivated land was in OECD Pacific, with 47%, followed by Latin America (37%), Africa (20%) and S & SE Asia (13%). In Latin America and Africa the expansion was very small compared to the remaining potential cultivable land but in other LDC regions it came much closer to exploiting all potentially productive land. Much of the expansion involved converting standing forest to more locally-valued uses such as farmland, as in Europe and North America centuries ago. In many cases this process would merely have returned the forest to previous use as cultivated and settled land (Wood, 1993). In other regions cultivated land increased very little or declined, as in China+ and Europe. In sum, while the cultivated area increased by only 2.9% in the MDCs, it rose by 15.4% in the LDCs, giving a global increase of 9.2%.

Also striking are the differences in per capita cultivated land area. In 1989 regional averages varied almost 10-fold, with China+ at just under 0.09 hectares per person and North America with 0.86 hectares. Nevertheless, while North America's land abundance helped it be a net exporter of crops, the China+ region managed to grow 97% of its crop requirements on its own densely-occupied land, largely by high levels of irrigation, fertiliser use and double- or triple-cropping.

Table 3.1 summarises the changes in cultivated area during 1961-89. Figure 3.1 presents annual data for the period and clearly shows that the rates of expansion or decline in cultivated land have in some regions varied considerably. For example, expansion in Latin America has slowed since 1982 and in Africa since the mid 1970s, although much less obviously. The long-established trend in China+ of declining cultivated land accelerated markedly in the early 1980s. Trends in the MDCs have been fairly steady, with very little change in area since the early 1970s in North America and the former Soviet Union. The very rapid increase in OECD-Pacific in the 1960s has slowed since, but the rate of expansion remains quite large.

It is important to appreciate that these trends are for the *net* changes in cultivated land areas. In other words, they are the result of year on year additions to and losses from the current area of actual land which is cultivated - changes which have rather different social and environmental implications.

[4] Cultivated area refers here to arable land plus permanent crop land, as defined by FAO land use statistics.



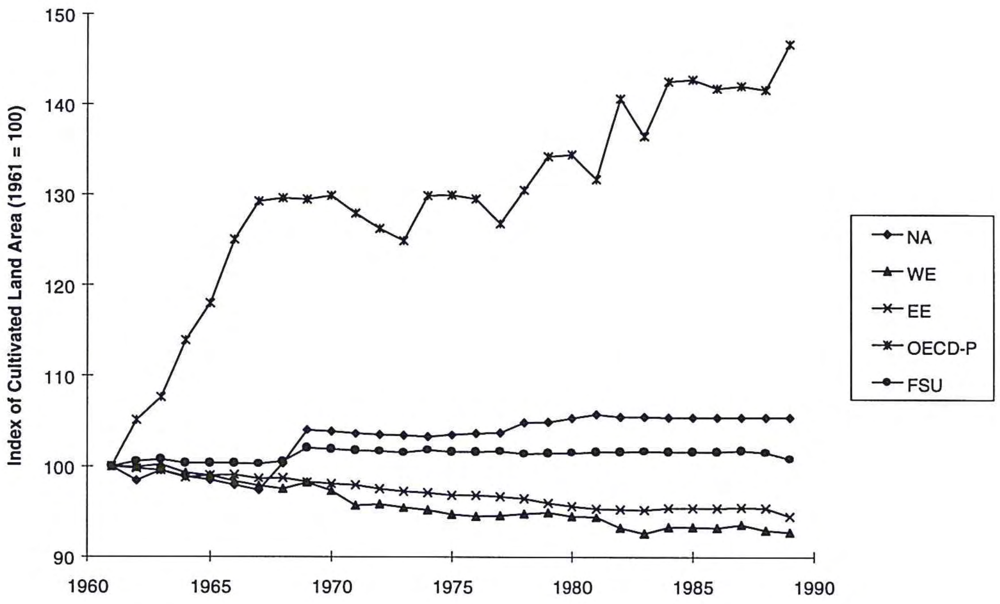


Figure 3.1. Index of cultivated land area: 1961-89.

Table 3.1. Cultivated land area: 1961 & 1989.

Region	Area (Mha) 1961	Area (Mha) 1989	Area change (Mha/year)	Area change (percent)	Area per capita (ha) 1989
Africa	155.7	187.0	1.12	20.1	0.300
Latin America	131.1	180.1	1.75	37.3	0.410
Middle East	38.6	39.4	0.03	2.1	0.276
China+	114.3	107.0	-0.26	-6.4	0.088
S & SE Asia	244.1	275.2	1.11	12.8	0.181
N America	223.8	235.9	0.43	5.4	0.860
W Europe	134.9	125.0	-0.35	-7.3	0.275
E Europe	42.7	40.4	-0.08	-5.5	0.406
OECD Pacific	37.7	55.3	0.63	46.7	0.377
Former USSR	228.8	230.6	0.06	0.8	0.803
LDCs	683.7	788.7	3.75	15.4	0.200
MDCs	667.9	687.2	0.67	2.9	0.545
World	1,351.6	1,475.9	4.42	9.2	0.284

Cultivated area = area of arable land + permanent crops (FAO definitions).

Cultivated land may be lost for several reasons. It can be converted to other uses which are judged to have a higher value, such as houses, factories, roads, quarries or golf courses. Or, it may be downgraded to a less productive form of agricultural land, such as rough pasture, or abandoned to become "wasteland", because it has become physically degraded or economically marginalised. Physical degradation may include soil erosion, soil nutrient depletion, salination, water-logging and other forms of physical or chemical deterioration of soils. Economic marginalisation means that the land is no longer worth working under existing economic conditions and may or may not be associated with physical degradation.

Additions to the cultivated land stock can be of two very broad kinds: (1) the conversion of other types of farm lands (such as pasture) to crop cultivation; and (2) the conversion of some kind of "natural" system, such as forest, woodland, grassland, wetland or low-productive "wasteland". These latter conversions may include bringing previously abandoned land back into cultivation. The second type of conversion in particular has important environmental implications, including possible losses of biodiversity and ecosystem productivity, and soil erosion if conversions are managed carelessly, and emissions of CO_2 and other greenhouse gases to the atmosphere. Unfortunately, data on these environmental issues and on the scale of different types of natural conversion processes now occurring or to be expected under various scenario assumptions are exceedingly weak. No attempt has been made in this report to quantify the environmental impact of these change processes, although there is further discussion about them in Chapter 4.

Besides these changes in cultivated land area, the "quality" or innate productive capacity of the cultivated land in use may also change due to human actions. World-wide, these changes are thought to add up to a massive process of human-induced land degradation. However, human action can also improve soil fertility and other aspects of land quality and is now increasingly known to do so even in places where it has been widely assumed that severe degradation processes were under way (English et al., 1994; Mortimore, 1993; Leach & Fairhead, 1994; and Phillips-Howard & Lyon, 1994). Again, data on these issues are extremely weak as well as disputed and contentious (Mortimore, 1993). However, it is important to note that historic changes in the quality of cultivated land are to a large extent captured by trends of crop yields. In other words, the actual change in yields achieved during 1961-89, which form the principal basis in this report for future yield projections, include the effects of any changes in the quality of cultivated land.

Also of importance to land productivity and yields is the amount of irrigated land within the cultivated land stock, especially in dry regions. This is not only because available water is such a strong determinant of crop yields; it is also because with adequate water it becomes worthwhile to raise yields still further by using better seeds and more fertiliser - the classic Green Revolution package. For this reason, production estimates here are wherever possible based on a breakdown of cultivated land into rainfed and irrigated areas. Some historical data on rates of change of these components are presented in Table 3.2, based on regressions of the 1961-89 data. Table 3.3 presents summary data on irrigated land in 1961 and 1989. One clear feature is the strong increase of irrigated areas in all regions, leading to a 60% rise in the LDCs combined and a near doubling in the MDCs. In six of the 10 regions, irrigated land areas have increased while rainfed areas have declined in absolute terms (see Middle East, China+, S & SE Asia, the two Europes and the former Soviet Union in Table 3.2). However, we shall see later that the first three of these regions are getting close to the limits of their possible expansion of irrigated land at reasonable costs.

Table 3.2. Changes in rainfed and irrigated cultivated land areas, 1961-89.

	Regression results				
	Rainfed land		Irrigated land		
Region	Annual % change	R^2	Annual % change	R^2	Remarks
Africa	0.61	0.96	1.35	0.99	
Latin America	1.18	0.98	2.60	0.98	
Middle East	-0.38	0.69	0.96	0.89	
China+	-1.28	0.96	1.60	0.89	Irrigated: little change since 1980
S & SE Asia	-0.12	0.50	2.20	0.99	
N America	0.20	0.61	1.19	0.72	Irrigated: no change since 1984
W Europe	-0.62	0.98	2.82	0.98	
E Europe	-0.61	0.99	4.68	0.98	Irrigated: slower change since 1985
OECD Pacific	1.03	0.79	0.52	0.46	
Former USSR	-0.18	0.83	3.51	0.97	Irrigated: slower change since 1985

3.2.1 Potential Cultivated Land

What is the scope for increasing cultivated land, especially in the LDC regions where it is generally most needed? Studies of crop suitability and production potentials in 91 developing countries by FAO and the International Institute for Applied Systems Analysis, Vienna (FAO, 1993; and Fischer, 1993) provide some answers. These are summarised for the PoleStar LDC regions in Table 3.4 in the form of the land areas actually cultivated circa. 1989 and potential cultivable areas, broken out by five classes of rainfed land productivity plus irrigated land. Also shown in the Table are indicators of the productivity of the land classes in terms of potential cereal yields relative to sub-humid land. Unfortunately, reliable data on 1989 cultivation by land class were not available for China, and hence the PoleStar China+ region. There were anomalies in some of the aggregated data for the

Middle East which resulted in actual cultivated areas in 1989 exceeding the potential cultivable area.

Table 3.3. Irrigated land (million hectares and % total cultivated area): 1961 & 1989.

	Area (million ha)		As % total cultivated area	
Region	**1961**	**1989**	**1961**	**1989**
Africa	7.8	11.2	5.0	6.0
Latin America	8.2	15.8	6.2	8.8
Middle East	9.7	13.1	25.1	33.3
China+	31.9	48.8	27.9	45.6
S & SE Asia	44.6	79.7	18.3	29.0
N America	14.4	18.9	6.4	8.0
W Europe	8.3	17.8	6.2	14.3
E Europe	1.6	5.7	3.8	14.2
OECD Pacific	4.0	5.0	10.7	9.1
Former USSR	9.4	21.1	4.1	9.1
LDCs	102.2	168.6	14.9	21.4
MDCs	37.7	68.6	5.6	10.0
World	139.9	237.2	12.6	19.8

Table 3.4. Potential cultivable land by productivity class: circa. 1989.

	Arid & Semi-arid	Moist Semi-arid	Sub-humid	Humid & Other	Naturally Flooded	Total Rainfed	Irrigated
Cultivated 1989 (Mha)							
Africa	37.1	37.5	50.6	44.2	6.5	175.9	11.2
Latin America	3.8	21.1	77.3	56.5	5.6	164.3	15.8
Middle East	8.3	8.8	2.8	3.8	2.7	26.2	13.1
China+						58.2	48.8
S & SE Asia	14.8	47.5	54.0	56.3	23.3	195.9	79.7
Potential cultivable (Mha)							
Africa	92.8	178.4	280.8	311.6	108.9	972.5	12.4
Latin America	15.1	56.0	169.0	583.4	120.2	943.7	21.9
Middle East	4.8	7.1	1.8	2.6	4.1	20.4	15.6
China+	0.1	4.1	51.6	102.7	31.7	190.2	-----
S & SE Asia	27.0	78.5	73.8	91.3	45.8	316.4	95.0
Potential / Cult. 1989							
Africa	2.50	4.76	5.55	7.05	16.75	5.53	1.11
Latin America	3.97	2.65	2.19	10.33	21.46	5.74	1.39
Middle East	0.58	0.81	0.67	0.68	1.52	0.78	1.19
China+						3.27	-----
S & SE Asia	1.82	1.65	1.37	1.62	1.97	1.62	1.19
Crop suitability [a]							
Africa	0.31	0.88	1.00	0.61	0.75		2.2
Latin America	0.31	0.88	1.00	0.64	0.66		2.2
Middle East	0.31	0.88	1.00	0.85	0.78		2.2
S & SE Asia	0.31	0.88	1.00	0.54	0.77		2.2

[a] Crop suitability roughly reflects potential cereal yields relative to sub-humid land (FAO, 1993).

The Table clearly shows that there are huge theoretical potentials for increasing *rainfed* cultivated land in Africa, Latin America and China+ (by factors of 5.5, 5.7

and 3.3 respectively over the 1989 cultivated area) and to a lesser but still sizeable extent - a factor of 1.6 - in S & SE Asia. The Middle East appears to have little if any potential for expanding its cultivated area.

However, the scope for increasing *irrigated* cultivation at reasonable costs is very much more restricted. According to these data and the criteria on which they are based, an increase from 1989 of only 11% is possible for Africa, 19% for the Middle East and S & SE Asia, and 39% for Latin America.

Over the next few decades the criteria which determine both the physical and economic feasibility of irrigation are likely to change substantially, perhaps most of all in regions such as the Middle East which face mounting population pressures on limited land resources but which are also likely to have the spare wealth to invest heavily in the land. For example, water conservation methods such as spot and trickle irrigation can greatly increase irrigated areas relative to surface or underground water resources; investments in water distribution over greater distances can probably tap considerable resources that are now mostly unused; and in some regions the desalination of salt or brackish water may well become economically feasible. Vegetable production by water-conserving methods such as greenhouses and hydroponics, often with very high yields, is also increasing in dry regions.

3.2.2 Cultivated Land: Scenario Projections

The scenario assumptions for future cultivated areas are given in Table 3.5 and, with the historic 1961-89 trends, in Figure 3.2. The scenario projections are closely linked to other major factors of food production and supply, such as crop yields and trade, which are discussed below. They also reflect some radical geo-political and economic decisions which might have to be made if the scenario as a whole is to come about; in particular if the growth in LDC food consumption summarised in Chapter 2 is to be met. For example, despite the large assumed increases in crop yields and other productive factors outlined below, Africa is unable to meet its growing food demand without a massive expansion of crop land as well as food imports. The Middle East, S & SE Asia and OECD-Pacific also have to increase food imports, in the first case by very large amounts.

Table 3.5. Cultivated land area: 1989, 2025 & 2050.

	Area (million hectares)			Change: 1989 - 2050		Area per capita (ha)
Region	1989	2025	2050	(Mha/year)	(percent)	2050
Africa	187.0	267.2	294.2	1.76	57.3	0.13
Latin America	180.1	207.1	216.9	0.60	20.4	0.27
Middle East	39.4	41.3	42.0	0.04	6.6	0.08
China+	107.0	110.5	109.5	0.04	2.3	0.06
S & SE Asia	275.2	283.7	291.6	0.27	6.0	0.09
N America	235.9	228.1	227.1	-0.14	- 3.7	0.71
W Europe	125.0	122.5	122.8	-0.04	- 1.8	0.26
E Europe	40.4	39.2	39.5	-0.01	- 2.2	0.33
OECD Pacific	55.3	62.8	65.4	0.17	18.3	0.42
Former USSR	230.6	224.4	224.2	-0.10	- 2.8	0.64
LDCs	788.7	910.0	954.1	2.71	21.0	0.11
MDCs	687.2	677.4	679.1	-0.13	- 1.2	0.48
World	1,475.8	1,587.4	1,633.2	2.58	10.7	0.16

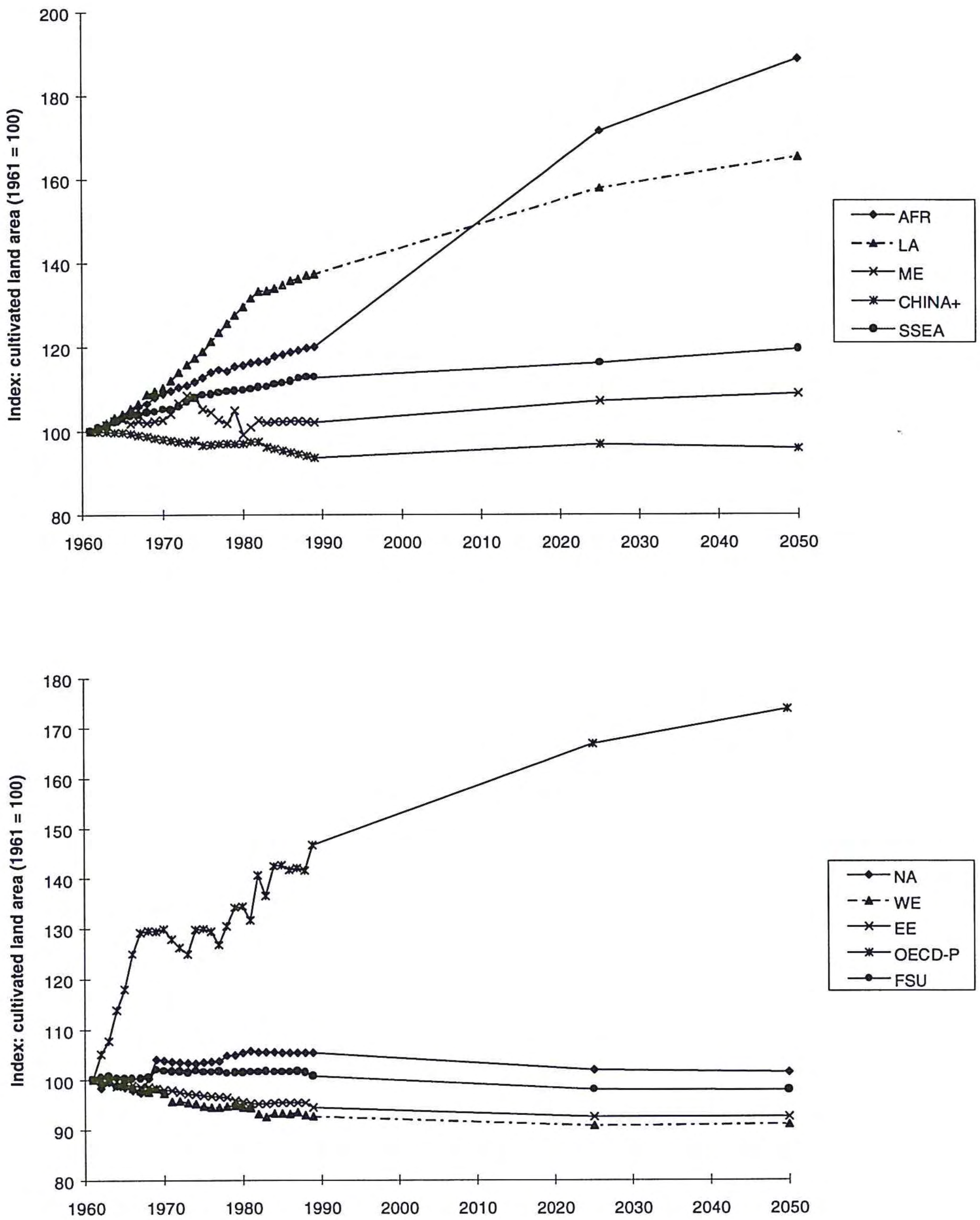


Figure 3.2. Index of cultivated land area: 1961 - 2050.

The large additional food exports can come only from the present MDC regions and Latin America with its abundance of spare land. It is hard to see how the present MDC major exporting regions - North America and Western Europe - can greatly expand their exports in the next century, even with continually rising crop yields, unless present planned reductions of farm land are slowed or reversed, and unless their export burdens are shared by Eastern Europe and the former Soviet Union. Reductions in farm land in these regions will also have to be slowed and reversed. At the same time, the large expansions of farmland which are needed in Africa and Latin America will continue to deplete forest stocks, even while yields increase very substantially and the land under cultivation is used ever more intensively. Continued forest clearance may have to be accepted as a vital weapon in a global strategy to feed humanity.

This background helps to explain the key features of the scenario assumptions shown in Table 3.5 and Figure 3.2, such as:

- The acceleration of crop land expansion in Africa. Running at just over 1.1 million hectares per year from 1961 to 1989, this rises to 1.76 million hectares a year from 1989 to 2050.
- Continued expansion of crop land in Latin America, S & SE Asia and OECD-Pacific, but at much slower than historic rates. In the Middle East, a small expansion of cultivated land is assumed in response to rapidly increasing food demand and imports, in contrast to a slight decline in area since the early 1970s.
- A sharp reversal in the China+ region to the recent rapid decline in cultivated area, largely due to urbanisation and other infrastructure development in China itself. As noted above, according to FAO there is spare cultivable land in the region which could be brought into production to offset these recent declines.
- With the exception of OECD-Pacific, the MDC regions experience small but steady declines in cultivated area. These trends should be compared to little change in area in North America and the former Soviet Union since the late 1960s, and a slow but steady decline in Western and Eastern Europe.

Taken together, these changes result in global cultivated land increasing by only 11% during 1989 to 2050. However, this rise is made up of a 21.0% increase in the LDC regions and a 1% reduction in the MDCs. In the LDCs the cultivated area increases by 0.31% per year during 1989-2050, rather slower that the 0.51% rate of the 1961-89 period. Globally, the average annual increase of 4.4 million hectares during 1961-89 slows during the next 60 years to only 2.6 Mha/year. This slow-down is explained mostly by the limited potential for expansion in S & SE Asia and the Middle East, the implausibility of a very large expansion in China+ after its recent decline, even though spare land is available, and the small projected reductions in cultivated area for most of the more developed regions.

For *irrigated land* (see Table 3.6 and Figure 3.3) the projections are strongly constrained by the limited potential for expanding irrigation discussed above. In the LDCs, quite rapid historic increases in irrigation are assumed to slow very substantially because of these constraints. In these regions, irrigated area is used in the model calculations explicitly to help define crop yields through the use of separate yield assumptions for irrigated and rainfed land. In the MDCs irrigated area is not used in the model calculation, due to lack of national data from FAO and IIASA on yields for rainfed and irrigated land. For illustrative purposes only, it is assumed that the rapid historic growth in Europe and the former Soviet Union slows drastically while in the other two regions, where there has been little change in the irrigated area for well over a decade, little change is assumed in future.

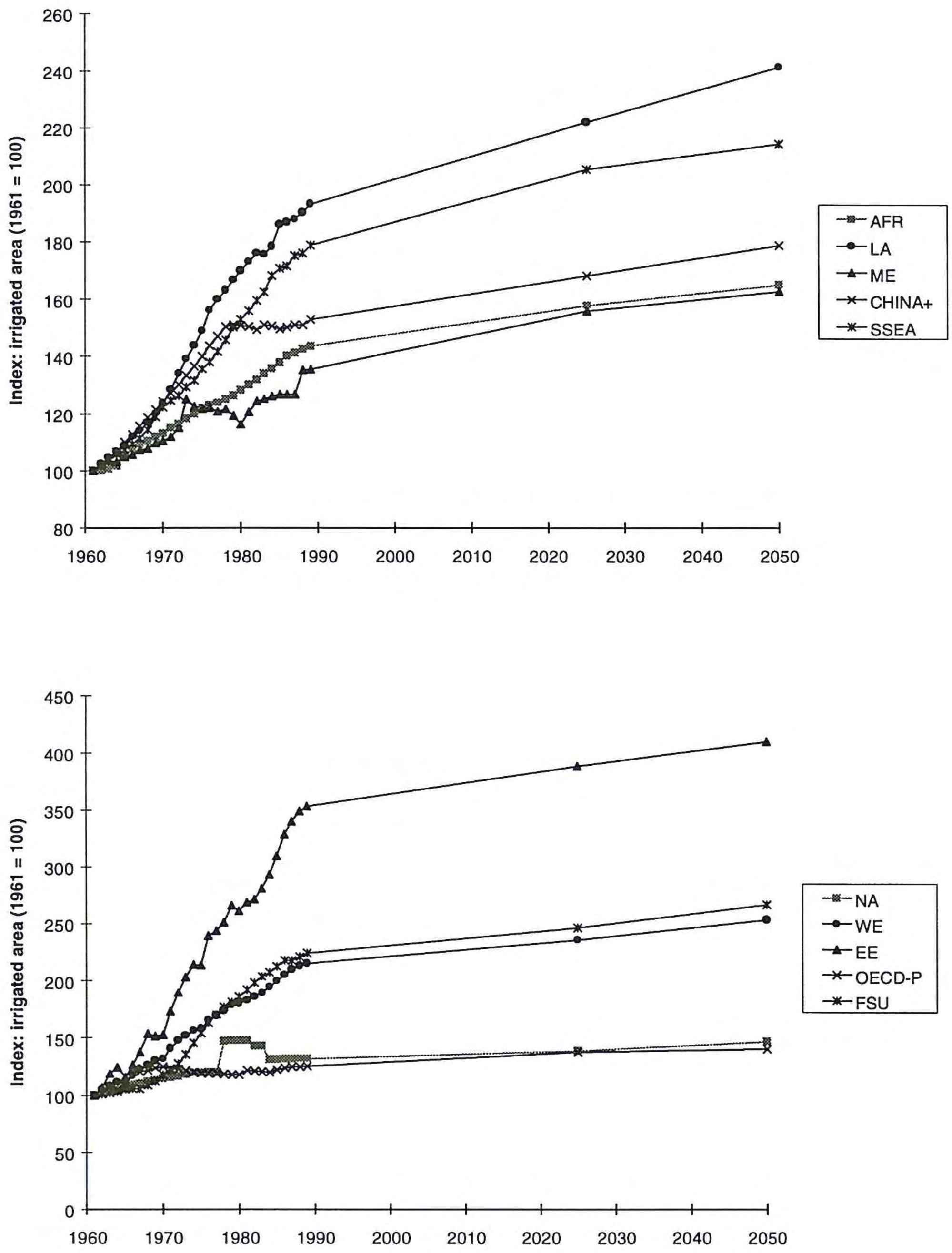


Figure 3.3. Index of irrigated land area: 1961 - 2050.

3.2.3 Fertilisers

Although fertiliser use is not at this stage an explicit part of the food production model, the vast differences in present levels of usage do obviously have strong bearings on the scope for future increases in crop yields, especially in fertiliser deficit regions like Africa.

Table 3.6. Irrigated area (million hectares): 1989, 2025 & 2050.

	Irrigated area			Area change	
Region	1989	2025	2050	1989-2025	1989-2050
Africa	11.2	12.3	12.9	1.10	1.15
Latin America	15.8	18.2	19.8	1.15	1.25
Middle East	13.1	15.1	15.8	1.15	1.20
China+	48.8	53.7	57.1	1.10	1.17
S & SE Asia	79.7	91.7	95.7	1.15	1.20
N America	18.9	19.9	21.0	1.05	1.11
W Europe	17.8	19.6	21.0	1.10	1.18
E Europe	5.7	6.3	6.6	1.10	1.16
OECD Pacific	5.0	5.5	5.6	1.10	1.12
Former USSR	21.1	23.2	25.1	1.10	1.19
LDCs	168.6	190.9	201.1	1.13	1.19
MDCs	68.6	74.5	79.4	1.09	1.16
World	237.2	265.4	280.5	1.12	1.18

Figure 3.4 shows the dramatic regional differences - and rates of increase in some regions - of fertiliser usage, represented here by average kg nitrogen fertiliser per hectare of total arable land. The increase was most impressive in China+, where during 1961-89 N fertiliser rates rose 34-fold from 5.7 to 194.6 kg/ha, according to FAO statistics. China+ is not shown in Figure 3.4 because it goes so far off the scale. S & SE Asia also raised average nitrogen applications massively, from 2.8 to 78.8 kg/ha. The other LDC regions lagged well behind these leaders - especially Africa, where what little rise there was in fertiliser use in the 1960s and 1970s almost ceased in the 1980s. In contrast, the Middle East witnessed very rapid increases in N-usage and has now reached over half of the S & SE Asia level. In the MDCs, the high N-usage in land-short, well-watered Western and Eastern Europe stands out as does the very low application level in OECD-Pacific, where cultivated area is dominated by the relatively arid zones of Australia. Also notable is the slow-down in the growth of N-fertiliser use in all regions, with actual declines in North America and the former Soviet Union.

The sometimes dramatic effect on crop yields of increasing fertiliser dosages is illustrated for wheat and maize in Figure 3.5, based on FAO's "global technology matrix" which is in turn based on farm-level data collected over many years (FAO, 1993). The plots show how yields increase with nitrogen fertiliser applications for different land quality classes; i.e. the classes based on water availability used in Table 3.4. Most importantly, the returns from additional fertiliser applications at very low usage levels - as in much of rainfed Africa, for instance - are enormous. For example, with wheat in arid zones, going from no fertiliser to a mere 5 kg per hectare could increase yields more than 4-fold, with a further 2.4 fold increase to be had from stepping up the application to 40 kg per hectare - about one-quarter the average application in Western Europe. With maize, the move from one extreme (arid land, no fertiliser) to irrigation with high fertiliser use, typically increases yields by a factor of over 20, from around 300 kg to 7 tons per hectare.

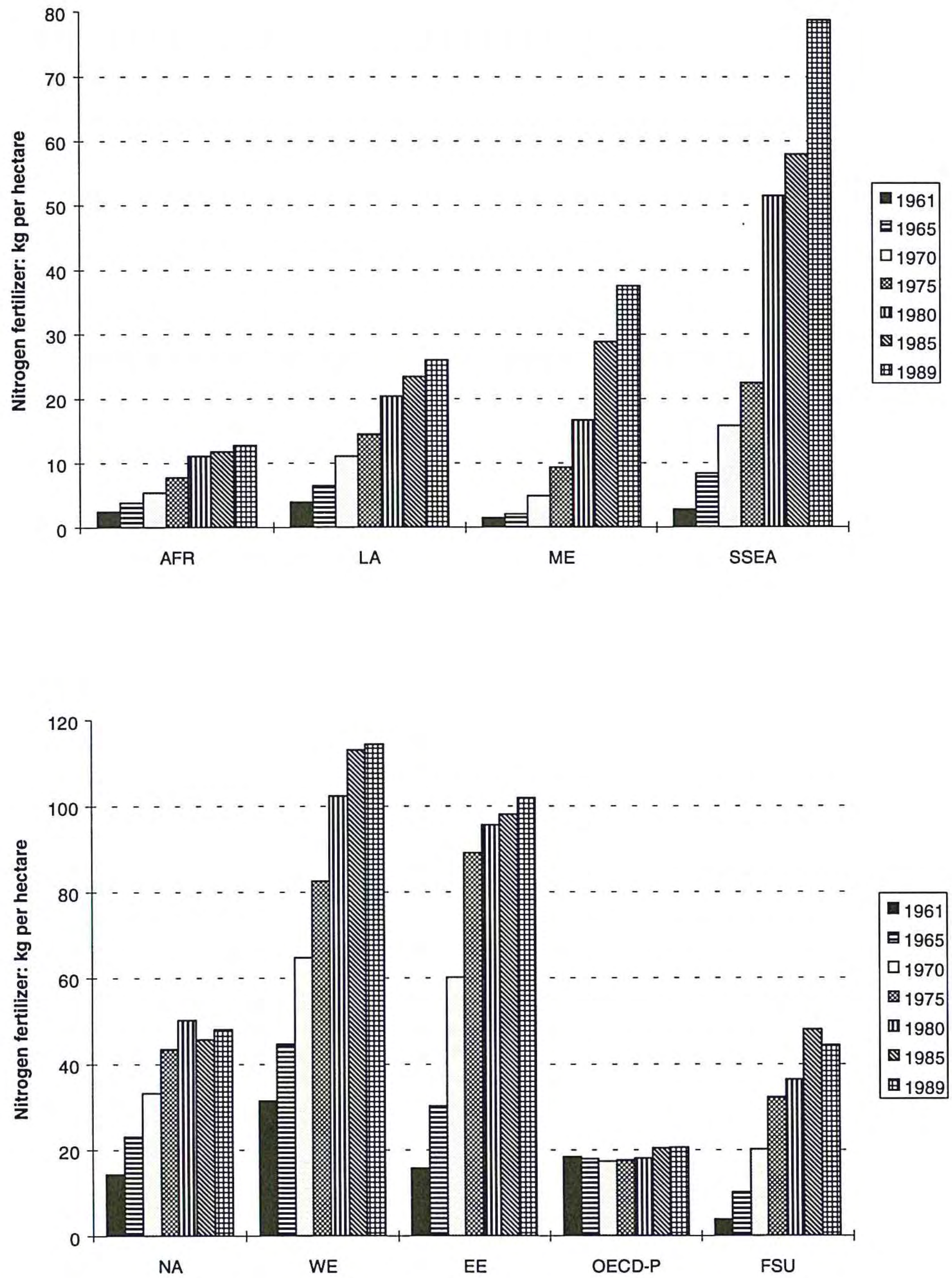
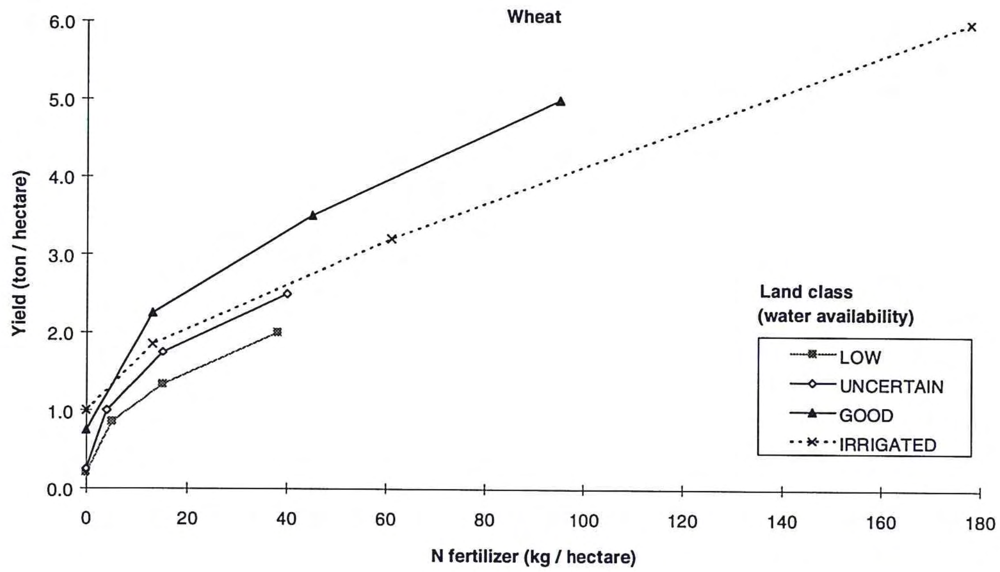


Figure 3.4. Average nitrogen fertiliser usage: 1961 - 1989.



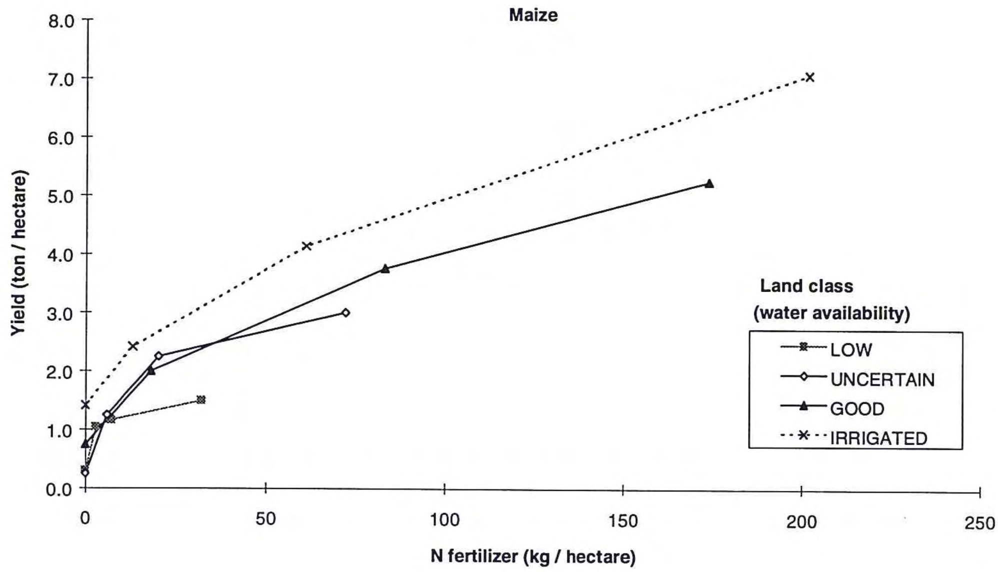


Figure 3.5. Wheat and maize yields with increased N-fertiliser and water.

The combined effects of fertilisers, irrigation and management on yields of rice in the humid Asian tropics are illustrated in Table 3.7, based on data from the International Rice Research Institute (Gomez & Zandstra, 1982). Between the average rainfed farm and the best irrigated farm the yield per crop rises by a factor of roughly four, from 1.6 to 6.0 tons per hectare. But irrigation also opens up the possibility of multiple cropping, typically with other grain crops. With good management (and sufficient economic incentive) as many as four crops can be harvested per year on irrigated land. Consequently, the difference in yield per hectare per year increase to a factor of over 12, with a range from 1.9 to 24 tons. The maximum potential yield gives almost another doubling compared to yields on the best farms. In India during the 1970s the national average rice yield was fairly steady at around 1.5 tons/hectare/year while the average of national demonstration trials maintained a steady 6 t/ha/year and the best such trials achieved 12-15 t/ha/year - at least an 8-fold improvement on the national average (Yoshida & Oka, 1982).

Table 3.7. Effects of irrigation and management on rice yields.

Management / Water	Yield per crop (ton / ha)	Crops per year	Yield per year (ton / ha / year)
Maximum potential			
irrigated	11.0	4.0	44.0
rainfed	7.0	3.0	21.0
Best farm			
irrigated	6.0	4.0	24.0
rainfed	4.5	2.4	11.0
Average farm			
irrigated	3.0	2.0	6.0
rainfed	1.6	1.2	1.9

Data in the two right-hand columns include production from other grain crops grown in sequence with rice.

It is not hard to see from figures like these how the doublings or treblings of crop yields in the next 50-60 years which are assumed in some cases here (see Section 3.4) could be achieved - not so much by further research into more responsive cultivars and the like, but by improving in many ways the incentives and capabilities of farmers to grow more - from better credit and price regimes for crops and farm inputs to infrastructure improvements which allow more certain and timely access to inputs and product markets.

Large productivity increases can also be achieved without resort to high levels of technical inputs such as artificial fertiliser. Knowledge- and management-intensive farming methods which centre on resource conservation and recycling methods can greatly enhance crop yields with few or no inputs from outside the farm. Many such farming systems in Africa, Latin America and Asia have increased yields of food crops by as much as 200-300 per cent on so-called "marginal" land (Pretty, 1994 and 1995).

3.3 Cropping Intensity

A classic response to land shortage and/or high land prices has always been to intensify its use by shortening fallow periods or, water availability permitting, squeezing two or more crop production cycles instead of one onto a given parcel of land each year. While irrigation obviously facilitates this form of intensification, much can also be done on rainfed land through good management and methods such as mulching to enhance the soil's moisture-retaining capacity. In much of the S & SE Asia region, for example, the monsoon rains are adequate for growing two crops a year and, in many places with good moisture-holding soils, a third relatively drought-resistant crop (Hoque, 1984).

According to FAO statistics, however, such changes had little effect on the overall cropping intensity of the 10 PoleStar regions during 1961-89. This overall intensity is a coarse aggregate figure based on all crops and all the land on which they are grown; i.e. the total harvested area of all crops combined (where, for instance, the harvesting of two crops in a year on a hectare of land is counted as two harvested hectare) divided by total cultivated land, including arable land and permanent crop land. All these data are provided by or derived from the FAO Agrostat land use and crop production statistics (FAO, 1992).

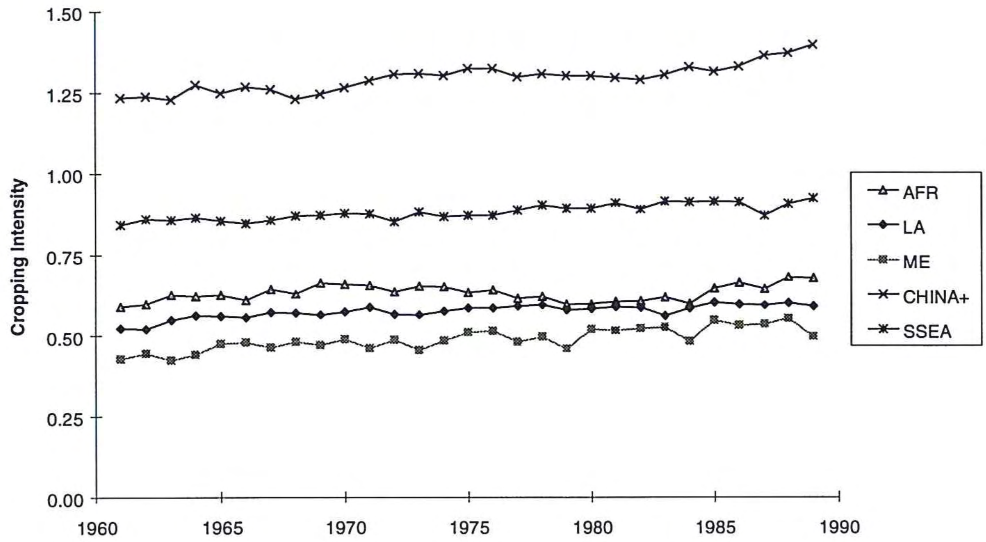
Figure 3.6 presents the historic trends for this aggregate cropping intensity. The change over the 30-year period has generally been very small. Also of note is the high value of around 1.3 for China+, followed by S & SE Asia and Eastern Europe with intensities in the 0.75 to 0.85 range, and the low value for OECD-Pacific because of the dominant influence of Australia.

3.3.1 Cropping Intensity: Scenario Projections

Projected values of the aggregate cropping intensity are shown in Table 3.8 and Figure 3.7. For the four LDC regions except China+, separate assumptions are made explicitly for rainfed and irrigated land; for all other regions the projections are for all land combined and take account of irrigation only in a qualitative manner. One major feature is the very small change assumed for the MDC regions, where there is also little change in cultivated land area and, in most cases, surplus crop production. Allowing also for environmental reasons for maintaining or increasing fallow lands, pressures to intensify the use of farm lands are likely to be small or non-existent. However, the opposite is likely to be the case in the LDC regions as population pressures on land resources increase and land values rise, especially in the Middle East and China+ where future land pressures seem to be the greatest. In most of these regions the fraction of cultivated land under irrigation is also assumed to increase, allowing higher intensities through more double- and triple-cropping.

Table 3.8. Cropping intensities: 1989 and 2025, 2050 relative to 1989.

	1989 actual			2025 relative to 1989			2050 relative to 1989		
Region	Rainfed	Irrig.	All	Rainfed	Irrig.	All	Rainfed	Irrig.	All
Africa	0.72	1.08	0.75	1.15	1.10	1.15	1.20	1.15	1.20
Latin America	0.69	0.97	0.72	1.15	1.10	1.15	1.20	1.15	1.20
Middle East	0.36	0.98	0.57	1.40	1.20	1.33	1.90	1.25	1.66
China+			1.47	1.10	1.10	1.10	1.20	1.15	1.17
S & SE Asia	0.95	1.20	1.02	1.10	1.07	1.09	1.20	1.15	1.18
N America			0.53			1.03			1.10
W Europe			0.76			1.00			1.00
E Europe			0.80			1.00			1.00
OECD Pacific			0.38			1.05			1.10
Former USSR			0.60			1.05			1.10



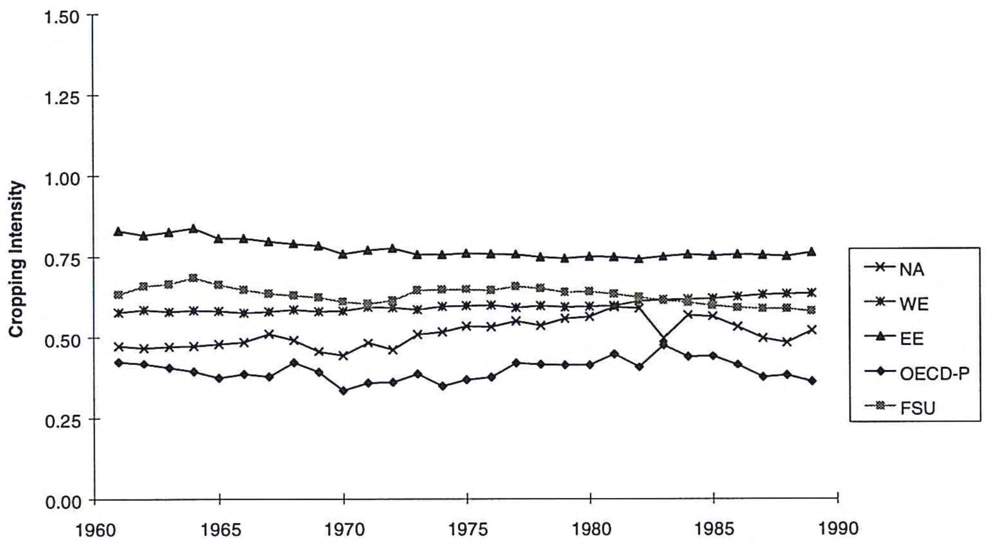


Figure 3.6. Cropping intensity: 1961-89.

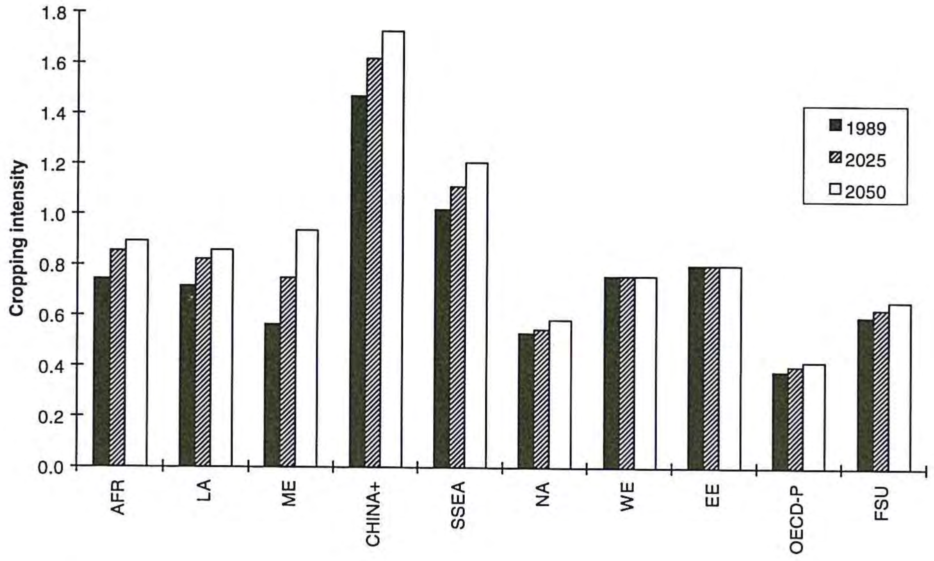


Figure 3.7. Cropping intensity: 1989, 2025, 2050.

For the LDCs in particular, the projections could well be very conservative. According to Hoque (1984) the highest intensity assumed here - 1.73 for China+ in 2050, compared to 1.47 in 1989 - was equalled 20 years ago in Taiwan and is little more than the national average in the early 1970s in Indonesia (1.61) and Bangladesh (1.49). The same author notes that the potential for increasing cropping intensity in the tropics is "tremendous" and that in many places, sunshine and other climatic factors are sufficient to grow three to five crops per year on the same land, depending on crop growth duration and water availability. The latter constraint can be greatly eased short of major irrigation schemes by many farm management techniques, including micro- and mini-scale water harvesting and storage methods, keeping the ground covered to reduce evaporation, and creating soil structures with good water infiltration and holding capacities.

3.4 Crop Yields

As we noted briefly above, the potential for increasing average crop yields is enormous, so much so that in most regions yield increase must be considered as the most important single strategy for increasing food production. We also saw in Chapter 1 that the yields which farmers have achieved in the past say little about the higher yields they could have achieved if there had been the incentives to do so. We can also assume that these incentives will generally increase in the longer term future in all of today's less developed regions, where pressures of rising population and better diets will impact increasingly on limited land and water resources.

Making projections of future crop yields is therefore rather problematic. Working from potentialities, one could assume very large increases on today. Trying to guess future realities raises the problem that for any crop and region actual outcomes will be the sum of millions of micro-level economic realities, including local prices for crops, land, labour, fertiliser and other farm inputs. Since it is impossible to model these adequately for the long-term future, the best one can do is make plausible future assumptions based on past and present experience coloured by present knowledge of bio-physical potentialities.

One strand of information which was used in making the projections here is the huge present day ranges of national average crop yields. This is shown in Figure 3.8 using 1990 data for five of the major crop groups considered here: wheat plus coarse grains (C11), rice (C12), roots and tubers (C2), pulses (C3) and sugar crops (C5). National average crop yield for all countries having over 5,000 hectares under the crop or crop group in question is plotted against cumulative national harvested area for the crop/group expressed as a percentage of the world harvest area. With all crop groups the plots account for over 99.8% of global harvest area for the group. The area under the yield curve is proportional to total production.

These yield distributions are summarised in Table 3.9. It is interesting to note that yields in the top-yield country exceed those in the lowest-yield country by about 10 times in the case of rice and sugar crops, 18 times for roots, 26 times for wheat and coarse grains and 51-fold for pulses. Some of these differences are accounted for by different mixes of crops with inherently different yields within crop product groups. Nevertheless there are clearly huge real yield differences between the highest and lowest ranking countries, much of them due to a combination of rainfall levels on rainfed land and/or irrigation, higher fertiliser use and better management.

Table 3.9. Distribution of national average crop yields (ton/hectare): 1990.

Crop groups	Top country	Top 10% of area	World average	Lowest 10% of area	Lowest country
Wheat & coarse grains	7.12	5.38	2.56	0.79	0.27
Rice [a]	8.21	6.05	3.56	1.76	0.85
Roots & tubers	40.7	24.9	11.9	4.51	2.21
Pulses	5.10	2.22	0.86	0.34	0.10
Sugar crops	115.3	82.2	52.4	22.0	9.8

[a] Rice yields as paddy (i.e. unhusked grain).

The remaining background information for the yield projections is best displayed with the projections themselves. This is done in the following section.

3.4.1 Crop Yields: Scenario Projections

Yield data for 1961-89 plus projections to 2025 and 2050 are shown for all crop groups and regions in Figure 3.9. They are summarised in Table 3.10 as actual yields and in Table 3.11 as annual rates of change in yield. The plots in Figure 3.9 show more clearly than the Tables the major features of the projections with respect to historic trends; i.e. where yields are assumed to increase faster, slower or at about the same rate as in the past. The plots also show where there have been major changes in the historic development of crop yields; i.e. where annual yield increases have changed from slow to rapid or, in some cases, turned into a decline. This important information is not available from the Tables but these do bring together in one place some key features of the scenario assumptions. Major features of the yield projections are:

- With many of the 80 region-crop group combinations there are sustained increases in yield over the next 60-odd years. Increases are generally largest in regions which face the greatest food-land pressures (Africa, Middle East) and where yields are now exceptionally low relative to other regions with comparable economic indicators (e.g. Eastern Europe and the former Soviet Union with some crops).

- Nevertheless, yields do not climb to exceptionally high levels during the next 60-odd years. For no region-crop combination does the yield in 2050 exceed or equal the highest national average yield in 1989. The top 10% yield range in 1989 (see Table 3.9) is exceeded in 2050 by only four out of the 10 regions for cereals, roots and tubers, and pulses, and three out of 10 for sugar crops.
- With the exception of China+ (where intensive irrigation and fertilisation produces high yields even today), yields in the LDC regions in 2050 are in most cases below those of the leading MDC regions today. For example, with wheat and coarse grains, LDC yields in 2050 are below those of North America, Western and Eastern Europe today; and with rice, below those of North America, Western Europe and OECD-Pacific. With roots and tubers, all LDC regions in 2050 have yields below those of present day North America and the two Europes. These assumptions contrast sharply with the potentialities for yield increases in most LDC countries. Bradfield (1972), for example, has argued on the basis of differences in temperature, insolation and forest productivity, that the tropical farmer could produce per unit area about four times as much dry matter as his counterpart in the temperate zones, provided he/she keeps a few layers of leaves between the soil and the sun throughout the year to reduce losses of soil moisture.

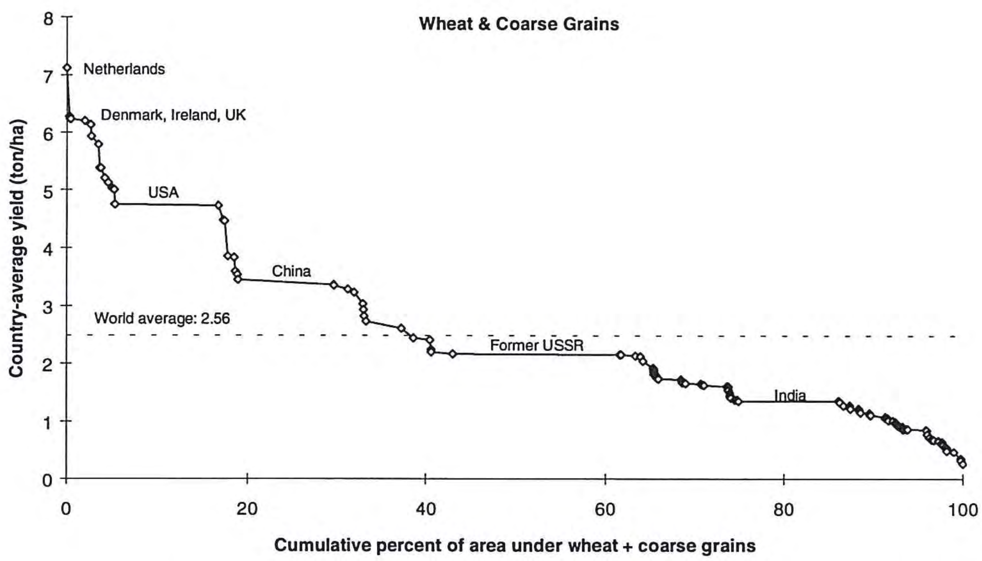


Figure 3.8(a). National average crop yield against cumulative percentage crop area: 1990 - wheat and coarse grains.

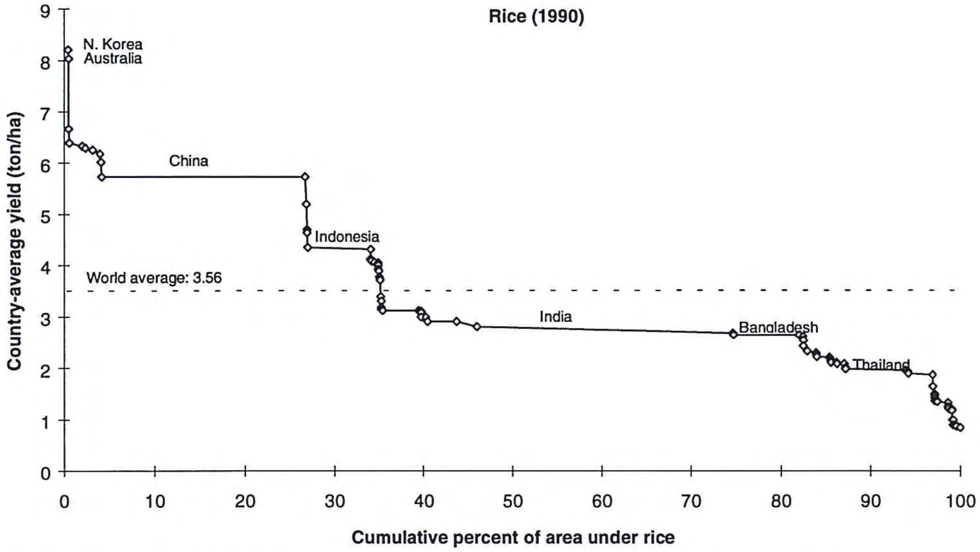


Figure 3.8(b). **National average crop yield against cumulative percentage crop area: 1990 - rice (paddy, or unhusked grain).**

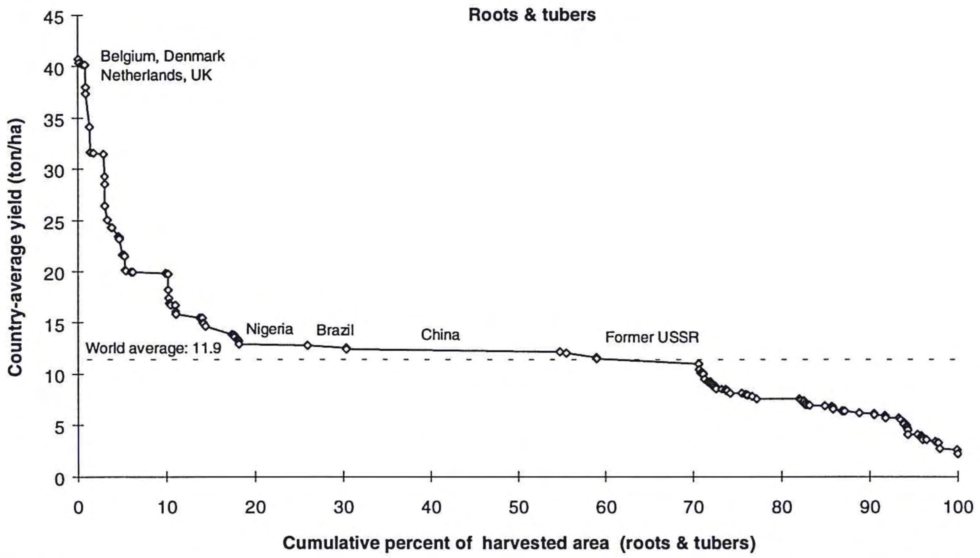


Figure 3.8(c). **National average crop yield against cumulative percentage crop area: 1990 - roots & tubers.**

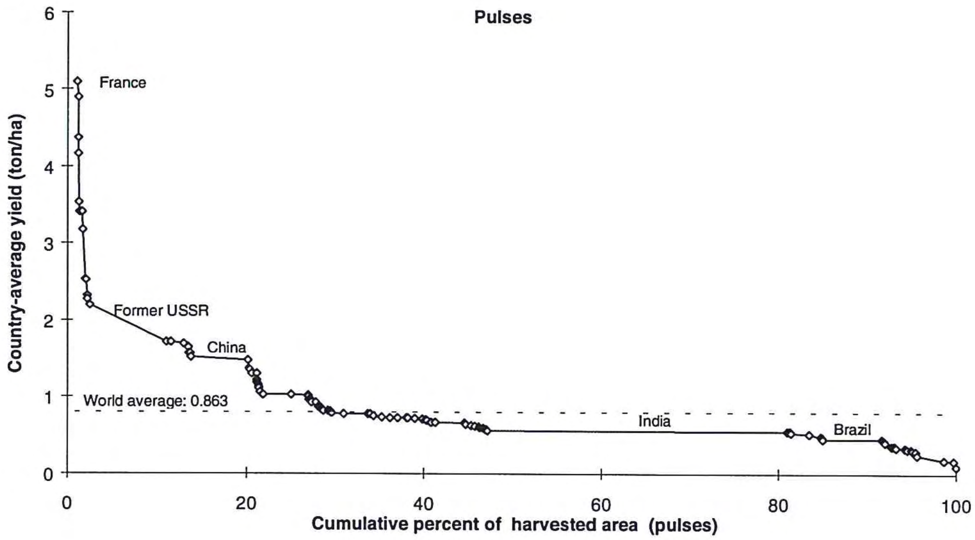


Figure 3.8(d). **National average crop yield against cumulative percentage crop area: 1990 - pulses.**

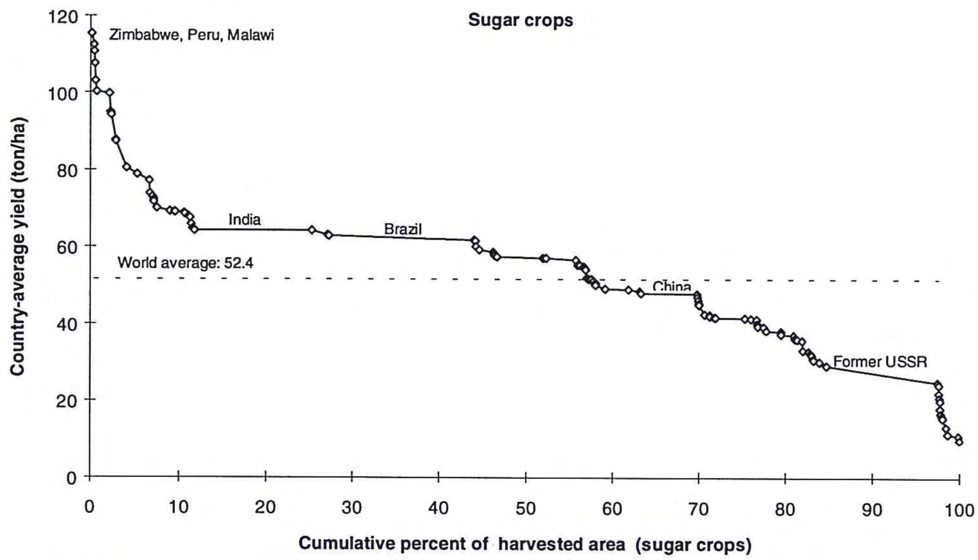


Figure 3.8(e). **National average crop yield against cumulative percentage crop area: 1990 - sugar crops.**

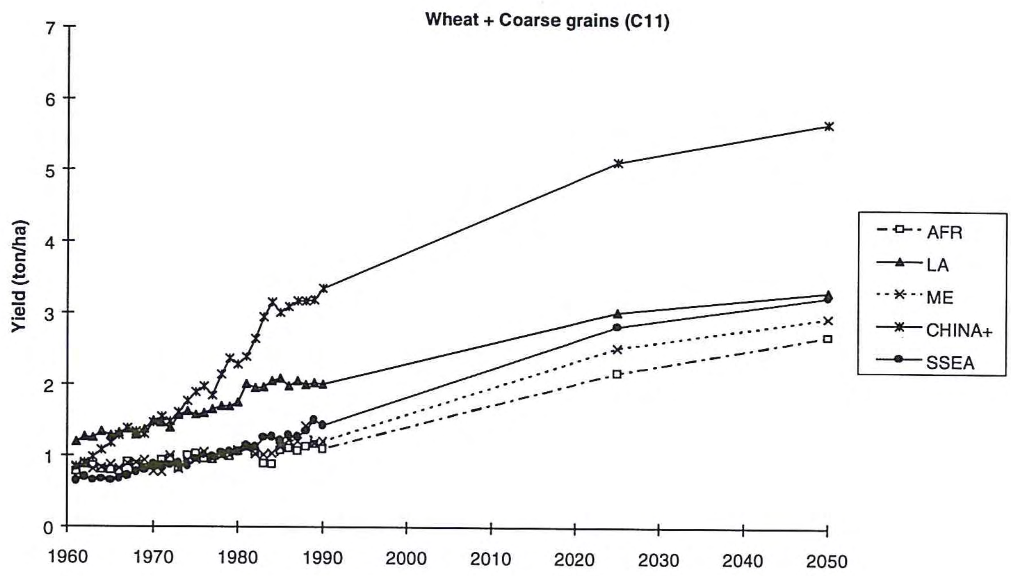
Table 3.10. Crop yields (ton/hectare): 1981, 2025, 2050.

	Wheat & coarse grains (C11)			Rice (paddy) (C12)		
Region	**1989**	**2025**	**2050**	**1989**	**2025**	**2050**
Africa	1.17	2.18	2.70	1.97	3.09	3.65
Latin America	2.03	3.03	3.32	2.59	3.55	4.32
Middle East	1.18	2.53	2.95	3.20	4.62	5.26
China+	3.19	5.13	5.67	5.30	7.03	7.39
S & SE Asia	1.50	2.83	3.24	2.79	4.88	5.54
N America	3.85	6.01	6.28	6.45	7.74	7.99
W Europe	3.87	6.04	6.27	5.70	7.12	7.41
E Europe	3.65	5.52	5.95	1.89	5.00	5.47
OECD Pacific	1.70	2.55	2.76	6.21	7.57	7.76
Former USSR	1.88	3.33	3.48	3.90	5.46	5.46
	Roots & tubers (C2)			**Pulses (C3)**		
Region	**1989**	**2025**	**2050**	**1989**	**2025**	**2050**
Africa	7.9	13.9	18.0	0.57	0.88	1.10
Latin America	11.4	17.9	22.0	0.51	0.90	1.10
Middle East	15.9	19.2	22.2	0.67	1.12	1.30
China+	9.0	18.1	22.0	1.05	1.80	2.01
S & SE Asia	12.0	19.7	23.2	0.59	0.89	1.09
N America	30.2	37.1	40.1	1.55	2.40	2.69
W Europe	24.2	33.1	36.0	1.68	3.00	3.50
E Europe	17.8	25.0	28.9	1.09	2.20	2.70
OECD Pacific	23.0	31.9	34.9	1.15	1.51	1.70
Former USSR	12.0	16.9	20.0	1.56	3.01	3.51
	Oil crops (non-tree) (C4)			**Sugar crops (C5)**		
Region	**1989**	**2025**	**2050**	**1989**	**2025**	**2050**
Africa	0.77	1.33	1.68	58.7	68.6	71.2
Latin America	1.34	2.00	2.30	65.3	86.3	92.5
Middle East	1.20	1.93	2.26	27.6	58.4	67.9
China+	1.52	1.99	2.30	40.5	68.1	76.2
S & SE Asia	0.82	1.40	1.69	61.8	79.2	90.0
N America	2.17	2.69	3.01	56.5	67.8	74.0
W Europe	2.16	2.71	3.00	49.2	69.9	80.2
E Europe	1.76	2.50	2.80	31.5	39.0	44.0
OECD Pacific	1.24	2.00	2.30	74.8	83.0	86.7
Former USSR	1.32	2.01	2.29	29.1	41.9	48.1
	Vegetables (C6)			**Tree crops (C7)**		
Region	**1989**	**2025**	**2050**	**1989**	**2025**	**2050**
Africa	14.8	20.0	24.7	2.68	3.9	5.2
Latin America	13.8	23.9	30.0	2.67	4.4	5.5
Middle East	18.0	29.1	34.8	6.79	8.9	10.0
China+	14.7	24.9	30.0	6.54	9.0	10.0
S & SE Asia	poor data	20.7	25.0	4.51	6.8	7.8
N America	28.3	37.9	42.1	12.1	15.1	15.5
W Europe	23.0	32.0	37.0	5.23	7.0	8.0
E Europe	16.7	28.0	35.0	5.46	8.0	9.0
OECD Pacific	23.2	32.0	37.1	8.89	10.7	11.5
Former USSR	20.1	29.9	35.0	3.29	5.8	7.0

Table 3.11. Annual percentage change in crop yields: 1961-89 and future projections.

	Wheat & coarse grains (C11)			Rice (paddy) (C12)		
Region	**1961-89**	**1989-2025**	**1989-2050**	**1961-89**	**1989-2025**	**1989-2050**
Africa	1.46	1.74	1.38	1.00	1.25	1.01
Latin America	1.90	1.12	0.81	1.31	0.88	0.84
Middle East	1.26	2.15	1.52	1.84	1.03	0.82
China+	4.79	1.33	0.95	3.34	0.79	0.55
S & SE Asia	3.03	1.78	1.27	1.96	1.57	1.13
N America	2.04	1.24	0.80	1.89	0.51	0.35
W Europe	2.69	1.24	0.79	0.42	0.62	0.43
E Europe	2.66	1.15	0.81	-0.83	2.74	1.76
OECD Pacific	0.85	1.14	0.80	0.87	0.55	0.37
Former USSR	2.03	1.60	1.02	2.25	0.94	0.55
	Roots & tubers (C2)			**Pulses (C3)**		
Region	**1961-89**	**1989-2025**	**1989-2050**	**1961-89**	**1989-2025**	**1989-2050**
Africa	1.18	1.58	1.36	0.62	1.20	1.08
Latin America	0.55	1.26	1.08	-0.64	1.60	1.27
Middle East	0.76	0.53	0.55	-0.45	1.44	1.09
China+	0.78	1.96	1.48	0.72	1.52	1.07
S & SE Asia	1.70	1.39	1.09	0.32	1.14	1.02
N America	1.48	0.58	0.47	0.39	1.22	0.91
W Europe	1.40	0.88	0.66	3.39	1.63	1.21
E Europe	0.82	0.95	0.80	3.55	1.97	1.50
OECD Pacific	1.01	0.92	0.69	-0.60	0.75	0.64
Former USSR	0.84	0.96	0.83	1.86	1.84	1.34
	Oil crops (non-tree) (C4)			**Sugar crops (C5)**		
Region	**1961-89**	**1989-2025**	**1989-2050**	**1961-89**	**1989-2025**	**1989-2050**
Africa	0.07	1.51	1.28	-0.38	0.43	0.32
Latin America	2.39	1.13	0.89	0.90	0.78	0.57
Middle East	1.31	1.34	1.04	1.08	2.11	1.49
China+	3.38	0.76	0.68	1.48	1.45	1.04
S & SE Asia	1.30	1.48	1.19	0.96	0.69	0.62
N America	0.97	0.60	0.54	0.18	0.51	0.44
W Europe	1.83	0.63	0.54	1.50	0.98	0.80
E Europe	1.44	0.98	0.76	0.87	0.60	0.55
OECD Pacific	-0.54	1.33	1.01	1.33	0.29	0.24
Former USSR	0.86	1.18	0.91	2.09	1.02	0.82
	Vegetables (C6)			**Tree crops (C7)**		
Region	**1961-89**	**1989-2025**	**1989-2050**	**1961-89**	**1989-2025**	**1989-2050**
Africa	0.50	0.83	0.84	1.11	1.05	1.09
Latin America	1.80	1.53	1.28	1.87	1.42	1.19
Middle East	1.42	1.34	1.08	1.20	0.75	0.64
China+	1.51	1.48	1.18	4.45	0.90	0.70
S & SE Asia	poor			1.86	1.13	0.90
N America	2.12	0.82	0.66	0.85	0.60	0.40
W Europe	1.49	0.92	0.78	0.19	0.81	0.70
E Europe	3.92	1.45	1.22	1.56	1.07	0.82
OECD Pacific	1.45	0.89	0.77	0.63	0.53	0.42
Former USSR	1.29	1.11	0.91	3.18	1.58	1.25

- The annual rate of yield increase during 1989-2050 is lower than during 1961-89 in all but 22 of the 80 crop-region combinations. In many cases the rate of yield increase is very much lower than in the past.
- In Africa the generally poor yield performance of the past is assumed to be reversed. With seven out of the eight crop groups, annual yield increases during 1989-2025 are greater than for 1961-89, with an equivalent score of six groups for 1989-2050. This fundamental shift is assumed to result from many factors including the fairly high growth of per capita income which is built into the Conventional Development scenario (and which must include substantial increases in farm incomes), and a variety of actions by policy makers, with the support of donor and lending institutions, designed to revitalise agriculture and reverse its recent stagnation and decline in many parts of the continent.
- In the Middle East there is a similar acceleration in yield growth, mainly as a response to mounting pressures on limited land resources from the assumed rapid growth in population and per capita food consumption. Annual yield increases are higher than for 1961-89 with four crop groups during the 1989-2025 period and three groups during 1989-2050.
- Yield increases accelerate in Eastern Europe and the former Soviet Union in cases where yields are presently low compared to Western Europe. This yield catch up is assumed to be driven by the privatisation of agriculture and the opening up of large new (European and world) markets to these regions.
- With some crops, yields in the LDCs are assumed to increase considerably faster than in the past as a result of recent scientific advances or specific opportunities to achieve greater productivity. This is the case for roots and tubers, where FAO considers that dramatic yield increases of two or three times on present values should be possible from greater fertiliser use plus use of new seeds (FA0, 1993). Faster yield growth is also assumed for pulses because of the recent development of new varieties (FAO, 1993).



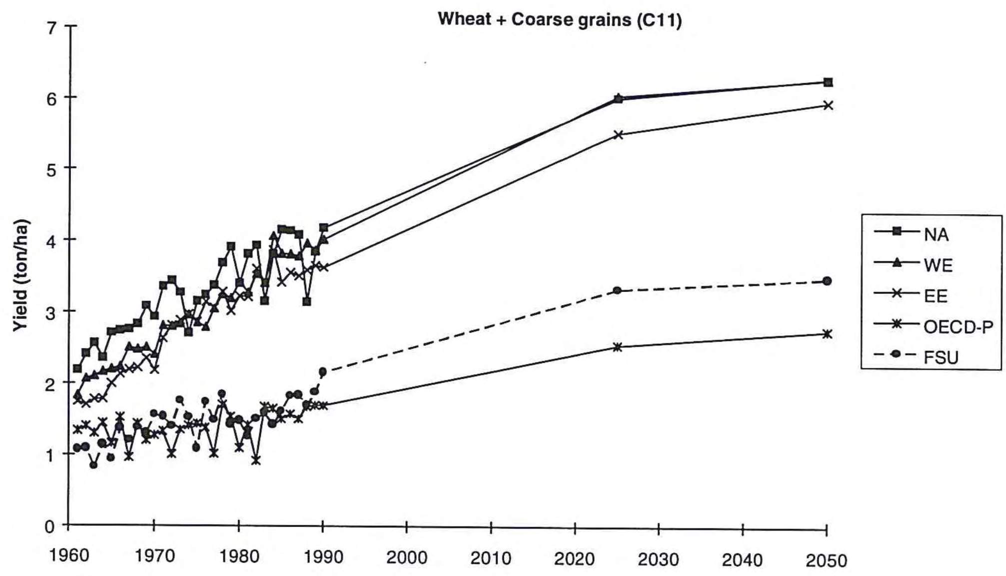
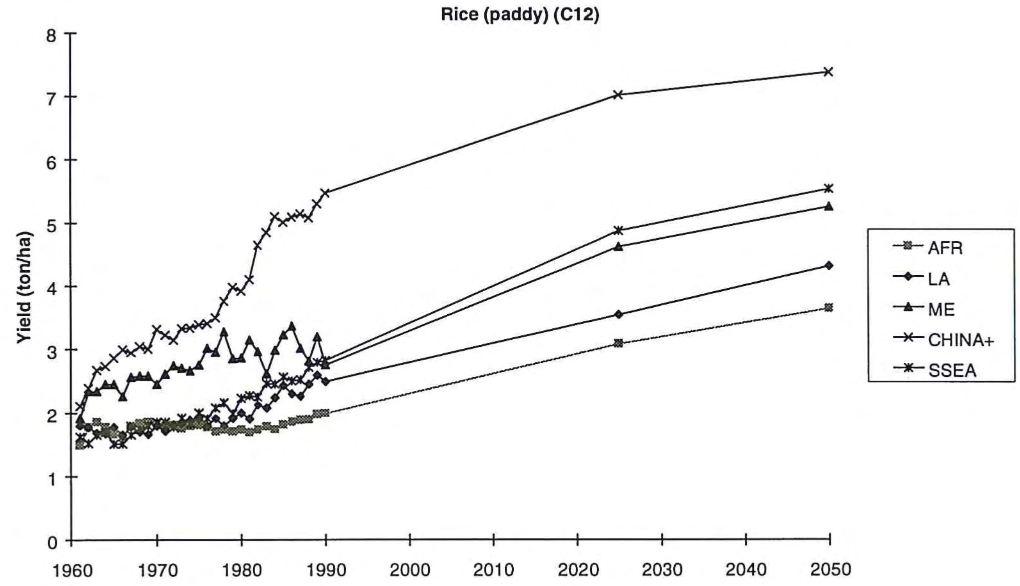


Figure 3.9 (a). **Crop yields: wheat & coarse grains, 1961 - 2050.**



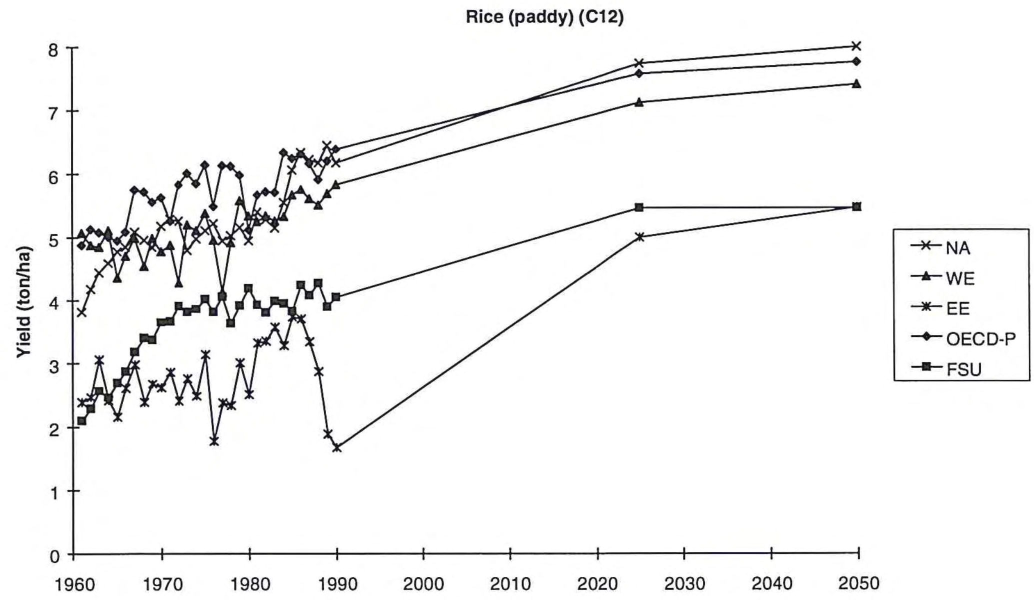
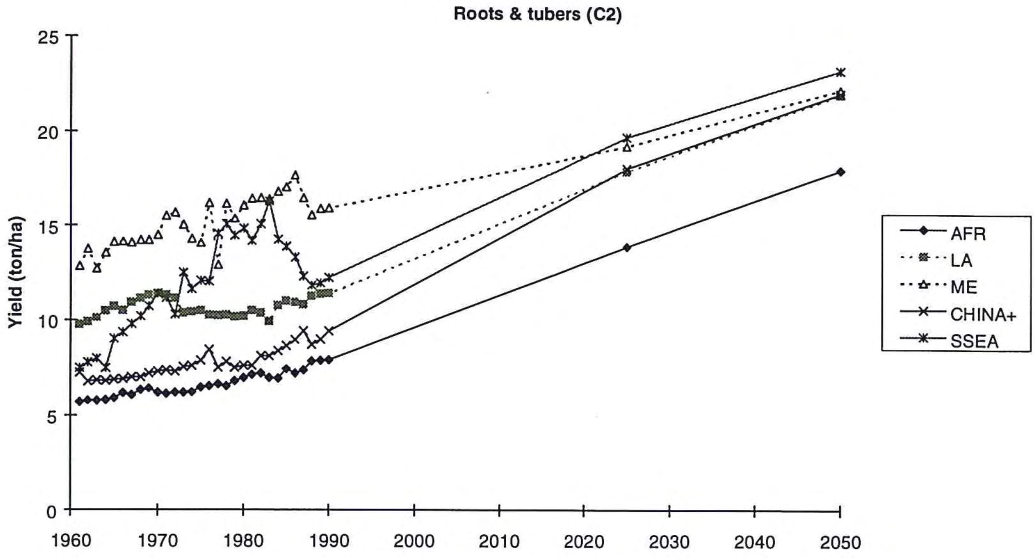


Figure 3.9 (b). **Crop yields: rice (paddy), 1961 - 2050.**



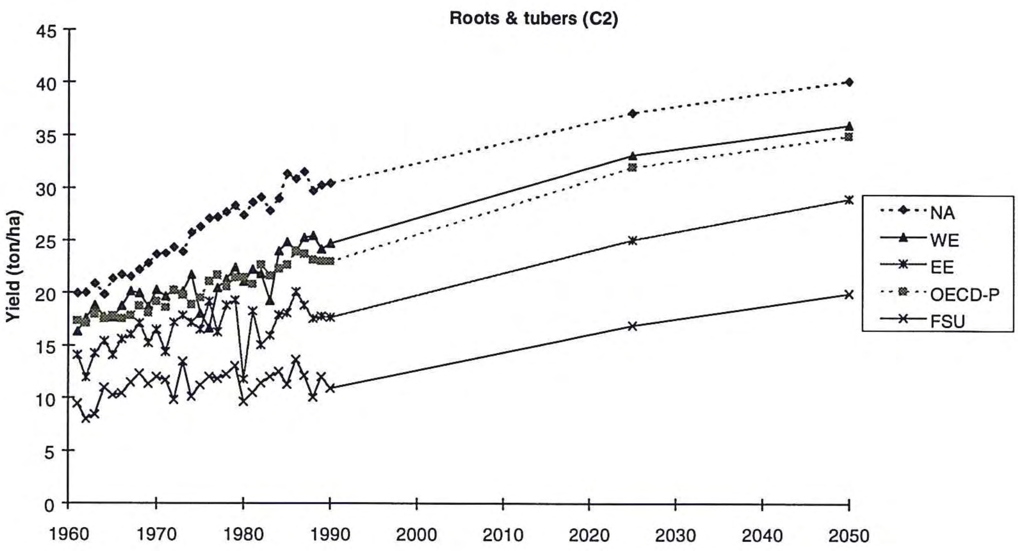
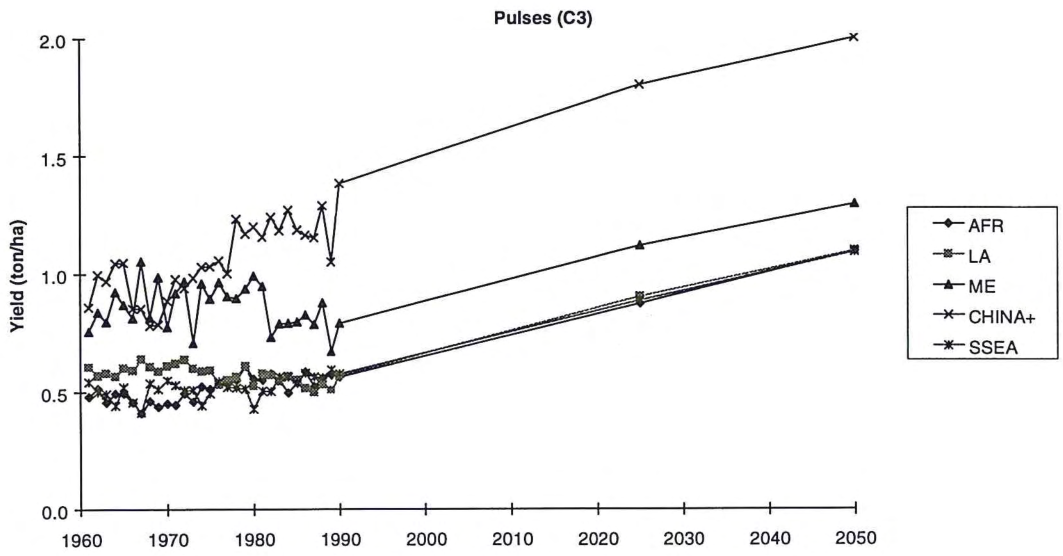


Figure 3.9 (c). Crop yields: roots & tubers, 1961 - 2050.



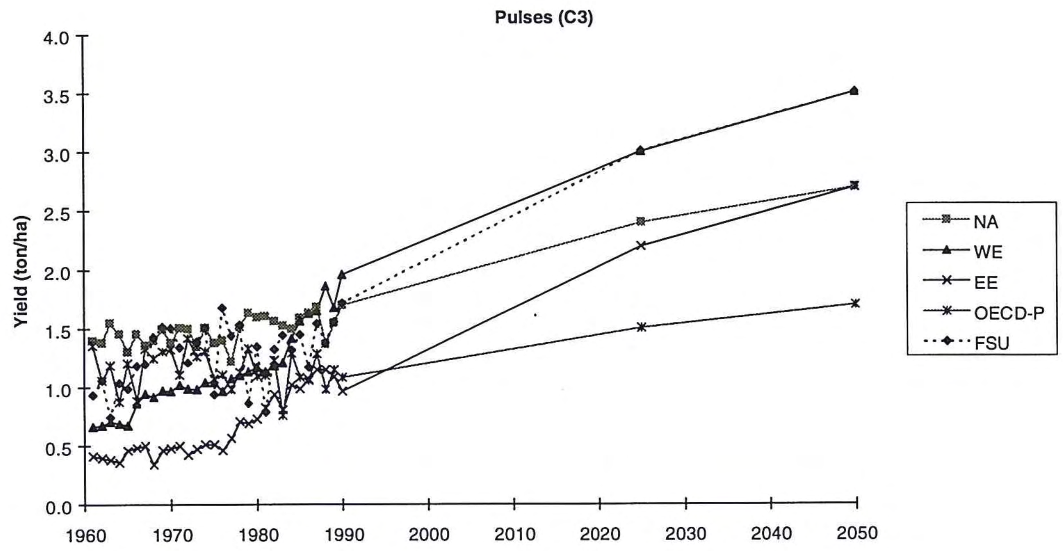
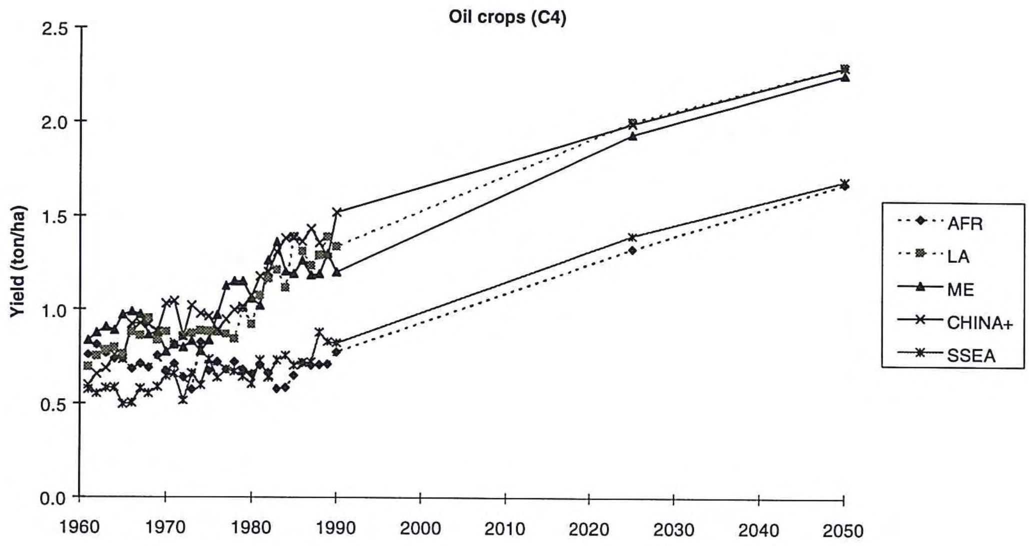


Figure 3.9 (d). Crop yields: pulses, 1961 - 2050.



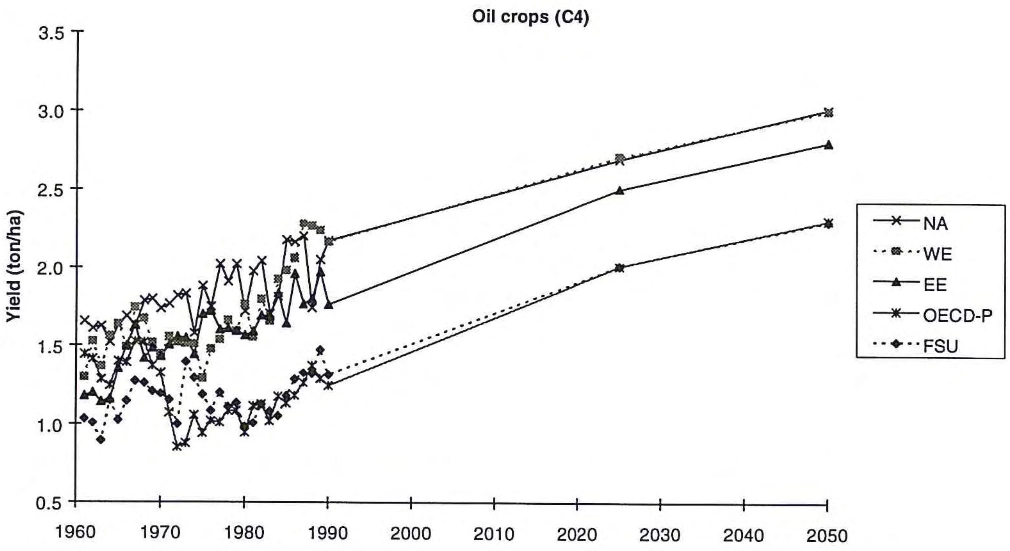
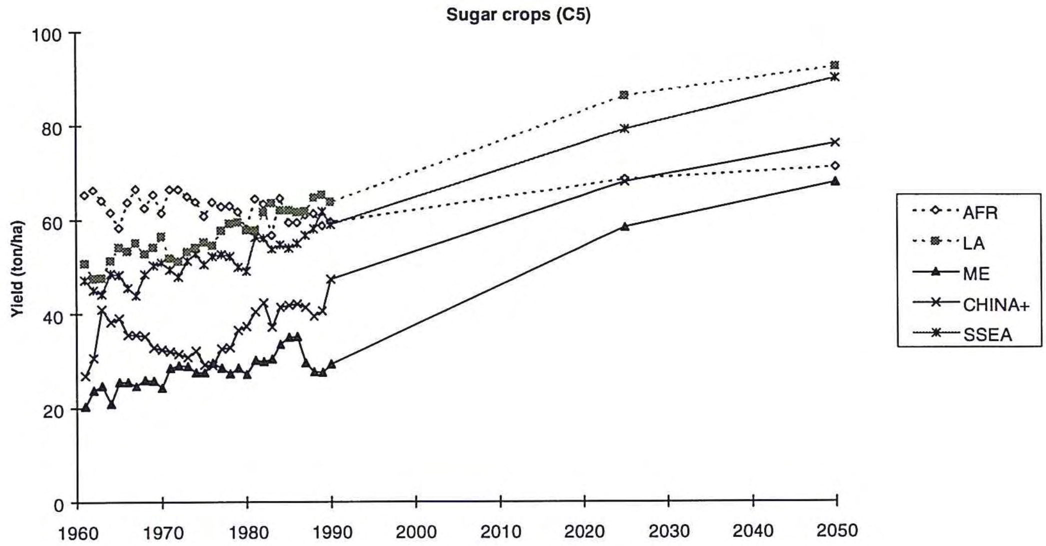


Figure 3.9 (e). **Crop yields: oil crops (non-tree), 1961 - 2050.**



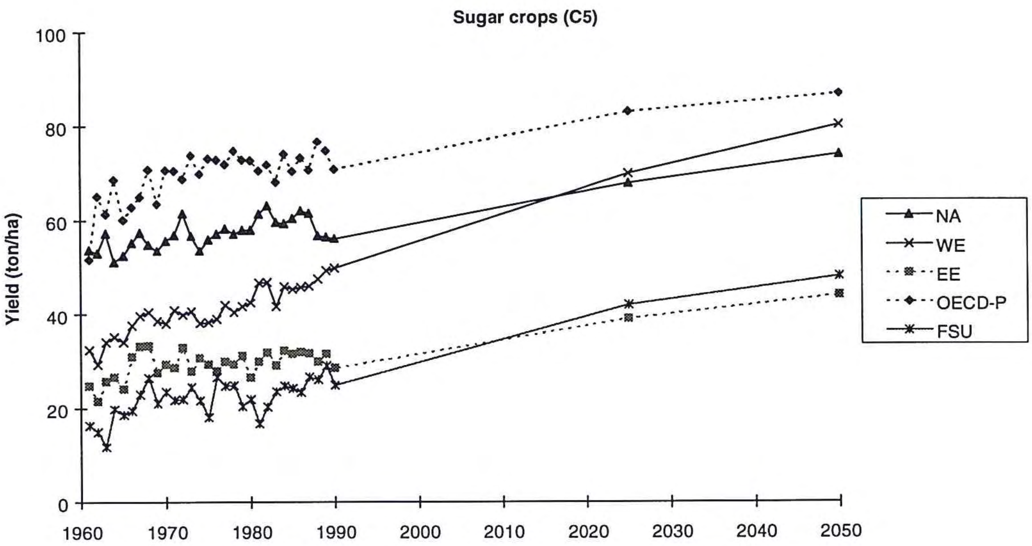
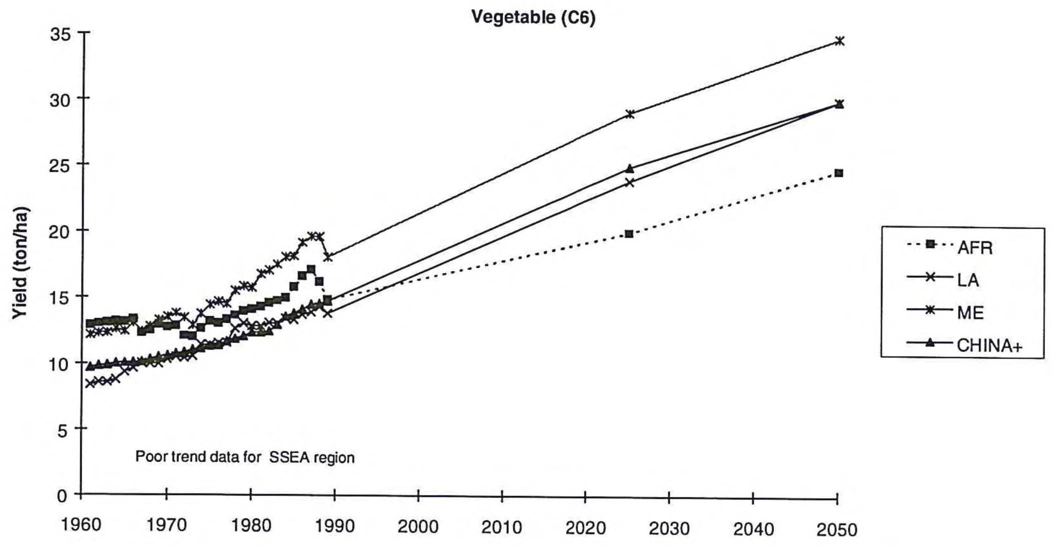


Figure 3.9 (f). **Crop yields: sugar crops, 1961 - 2050.**



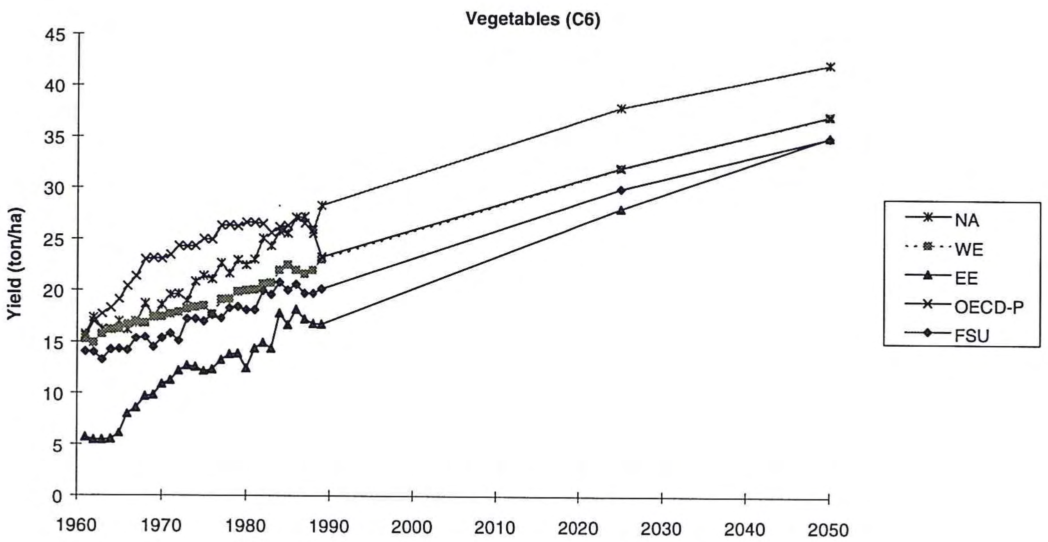
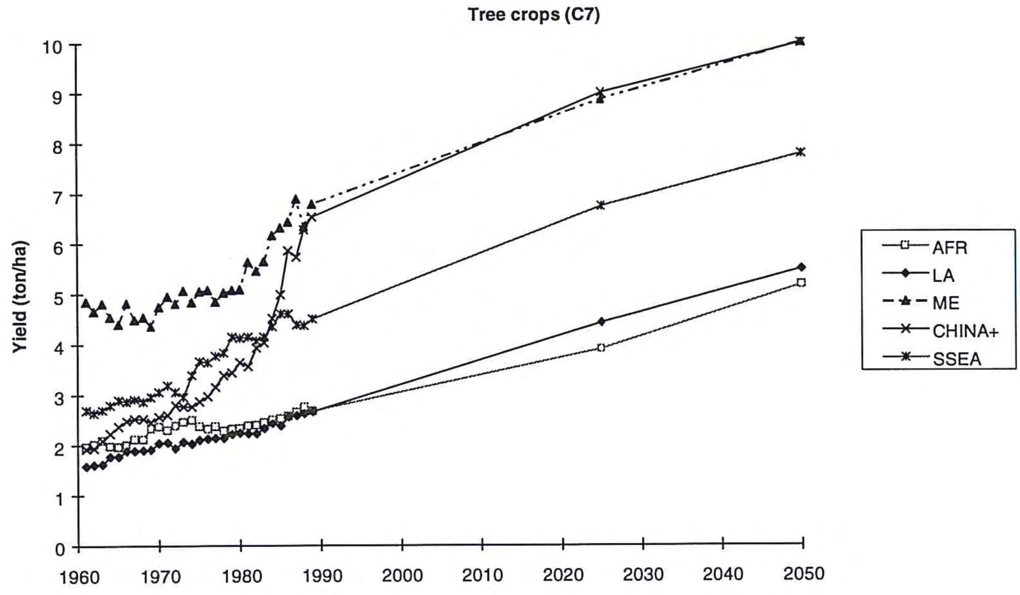


Figure 3.9 (g). **Crop yields: vegetables, 1961 - 2050.**



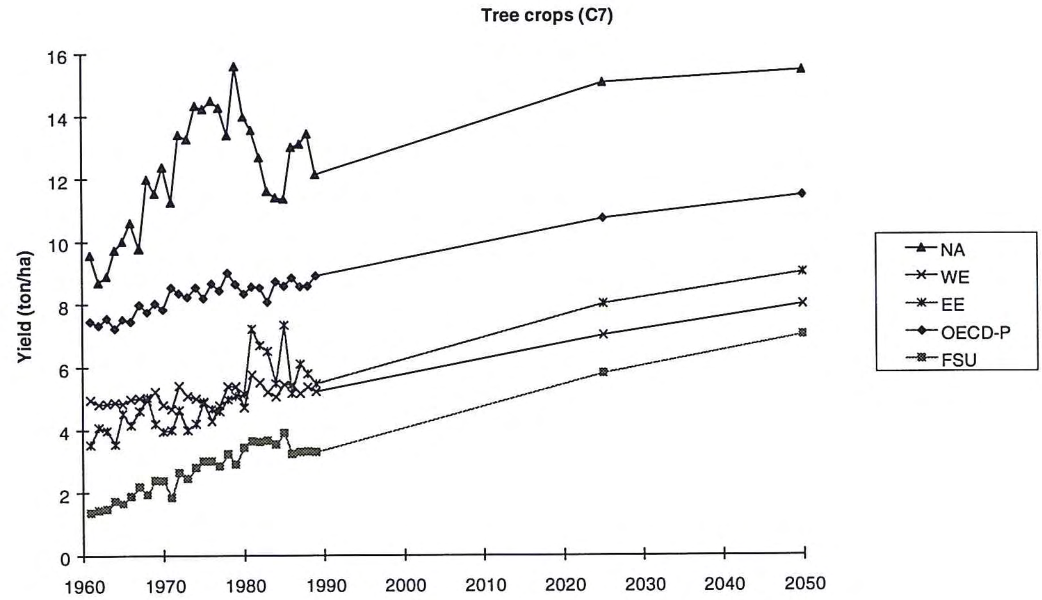


Figure 3.9 (h). Crop yields: tree crops, 1961 - 2050.

3.5 Harvest Shares

The harvest share of each crop group - the fraction of total harvest area devoted to the crop - is treated here as a secondary or balancing item. Together with the primary variables, total harvest area and crop yield, it defines the regional production of the crop group. This production level is itself a function of required supply, which is pre-determined by assumptions about population and food consumption (see Chapter 2), and another secondary variable, the self-sufficiency ratio. One constraint on the harvest shares is of course that in each region they must sum to unity.

Figure 3.10 presents the regional harvest shares in 1989, 2025 and 2050. The upper Figure (3.10a) is for the cereal groups: wheat and coarse grains (C11) and rice (C12). The lower Figure (3.10b) shows, in order, non-tree oil crops (C4), roots and tubers (C2), tree crops (C7) and the remainder combined; namely pulses (C3), sugar crops (C5) and vegetables (C6).

Generally speaking, changes in harvest shares are small. Cereals maintain their dominant position, taking from about 45% of total crop land in Latin America to 70% or more in the Middle East and all the MDC regions except Western Europe. The most notable changes in the scenario are the declines in China+, S & SE Asia and OECD-Pacific from 1989 to 2025, largely as a result of dietary shifts out of rice and into non-cereal foods. Latin and North America increase their shares of wheat and coarse grains, entirely to enlarge their exports to meet grain deficits in the LDCs. Amongst non-cereal crops, the largest change is the substantial increase of non-tree oil crops in all regions except North America (where the share was already very high at 27% in 1989), again due mainly to dietary changes.

3.6 Production, Self-sufficiency Ratios and Net Exports

To what extent do regions have to meet their food requirements by importing what they cannot produce themselves? And, conversely, by how much do some regions have to produce more than they need in order to export to deficit regions? The self-sufficiency ratio (SSR) holds the answers to both questions, since it links through trade the key components of food demand (required supply) and food production (achieved production). The SSR is defined here for each crop and region as achieved production divided by required supply, but also equals the term [1 + net exports/required supply].

To explore the assumptions and results for each region, it is easiest to begin with achieved production. This quantity is in fact the product of the various terms in the crop production chain which have been discussed in this chapter so far for each region, crop group and year, namely: Cultivated Area x Cropping Intensity x Harvest Share x Yield. Tables 3.12 and 3.13 present some key results.

It is clear that enormous production increases are demanded of some regions, even where net imports also increase. For example, in 2050, Africa and the Middle East have to produce over seven times more animal products than today; for LDCs as a whole the increase is 4.5 fold. For cereals, equivalent figures are factor increases of 3.7 to 3.8 for Africa and the Middle East and 2.1 for developing regions combined. For the world as a whole, production in 2050 needs to be nearly double the 1989 level for cereals, 2.3 times higher for other crops combined, and up by a factor of 2.4 for animal products.

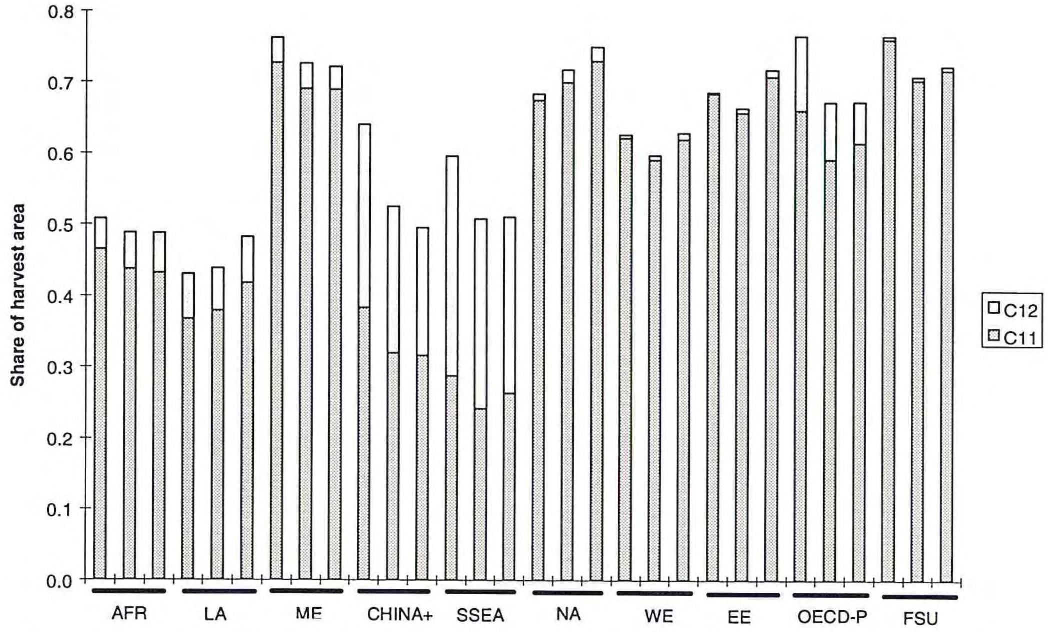


Figure 3.10 (a). **Share of harvest area, cereal crops: 1989 - 2050 (left, centre, right bars in each region are for 1989, 2025, 2050).**

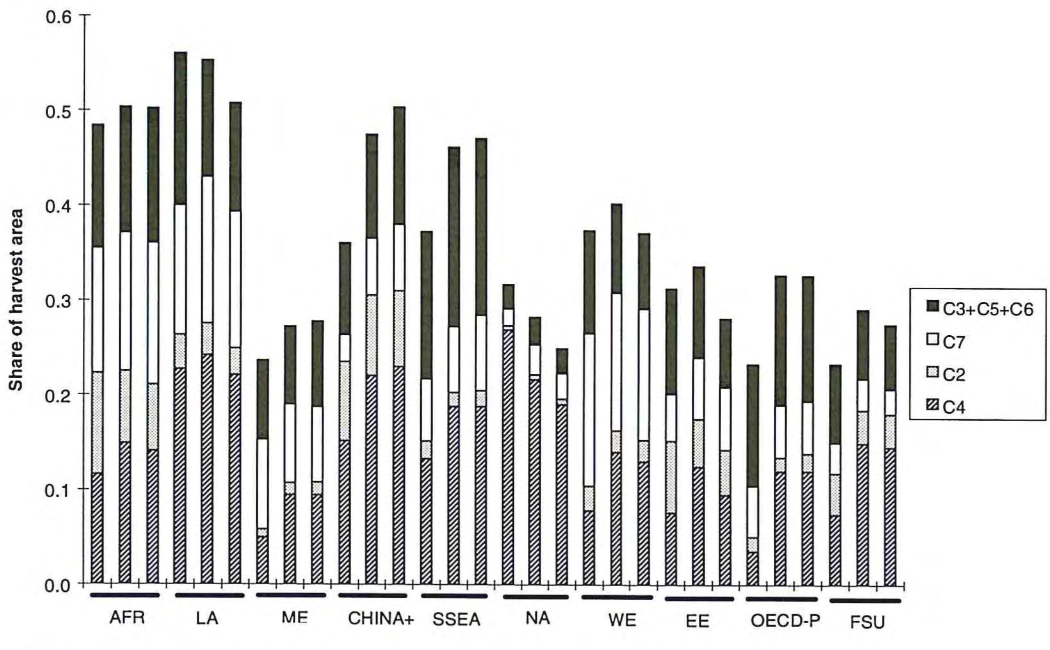


Figure 3.10 (b). **Share of harvest area, non-cereal crops: 1989 - 2050.**

Table 3.12. Achieved food production, 1989, 2025 & 2050 (million tons).

	Cereals			Other crops			Animal products		
Region	1989	2025	2050	1989	2025	2050	1989	2025	2050
Africa	95	253	354	297	752	1,230	34	134	256
Latin America	107	239	316	684	1,078	1,229	81	180	227
Middle East	22	57	81	40	107	147	11	48	81
China+	401	553	603	416	874	1,244	60	166	229
S & SE Asia	375	628	772	663	1,320	1,854	103	297	499
N America	333	549	632	205	284	285	118	151	145
W Europe	231	334	373	372	452	433	205	235	233
E Europe	81	117	136	111	131	129	45	52	52
OECD Pacific	37	53	59	75	94	113	46	75	88
Former USSR	201	335	380	251	378	400	149	201	212
LDCs	999	173	2,125	2,100	4,132	5,705	288	824	1,293
MDCs	883	138	1,580	1,013	1,339	1,358	562	712	729
World	1,882	311	3,706	3,114	5,470	7,063	851	1,536	2,022

Table 3.13. Changes in achieved food production relative to 1989.

	Cereals		Other crops		Animal products	
Region	2025	2050	2025	2050	2025	2050
Africa	2.66	3.72	2.53	4.14	3.95	7.55
Latin America	2.25	2.96	1.58	1.80	2.22	2.82
Middle East	2.65	3.75	2.65	3.65	4.27	7.17
China+	1.38	1.50	2.10	2.99	2.76	3.83
S & SE Asia	1.68	2.06	1.99	2.80	2.89	4.86
N America	1.65	1.90	1.39	1.39	1.28	1.23
W Europe	1.45	1.61	1.21	1.16	1.15	1.14
E Europe	1.44	1.68	1.18	1.16	1.14	1.14
OECD Pacific	1.42	1.58	1.25	1.49	1.61	1.90
Former USSR	1.67	1.89	1.51	1.60	1.35	1.42
LDCs	1.73	2.13	1.97	2.72	2.86	4.48
MDCs	1.57	1.79	1.32	1.34	1.27	1.30
World	1.66	1.97	1.76	2.27	1.81	2.38

Assumptions for self-sufficiency ratios (SSRs) are outlined in Figure 3.11 and Table 3.14. These show, for the years 1989, 2025 and 2050, the SSRs for all regions and four aggregate product groups: all cereals, all non-cereal crops, all crops and all animal products.

With cereals the dominant feature of the scenario is that the large present day differences in self-sufficiency ratios are widened: food deficit regions increase their deficits, food exporters have to export more. The Middle East in particular moves from a heavy to an acute cereal production deficit, with an SSR of 46% in 1989 and only 29% in 2050. Substantial deficits in the OECD-Pacific region and Africa also enlarge considerably; in the latter case the cereals' SSR moves from 79% to 60% during 1989 to 2050. The most populous LDC regions, China+ and S & SE Asia, which were both almost self-sufficient in cereals in 1989, experience only small reductions in their cereal SSRs by 2050. To counterbalance these mounting deficits all the MDC regions except OECD-Pacific are forced by the scenario assumptions to greatly increase cereal production and export volumes as compared to their domestic needs. The price and policy environment in which this is likely to happen is a major uncertainty of the scenario. While North America and Western Europe start the period as the only cereal net exporters and increase their SSRs by close to 30% each, Eastern Europe and the former Soviet Union begin in 1989 as importers but move rapidly into surplus production and substantial net exports. Latin America moves from being a net cereal importer to having a cereal SSR of 1.0 in 2050.

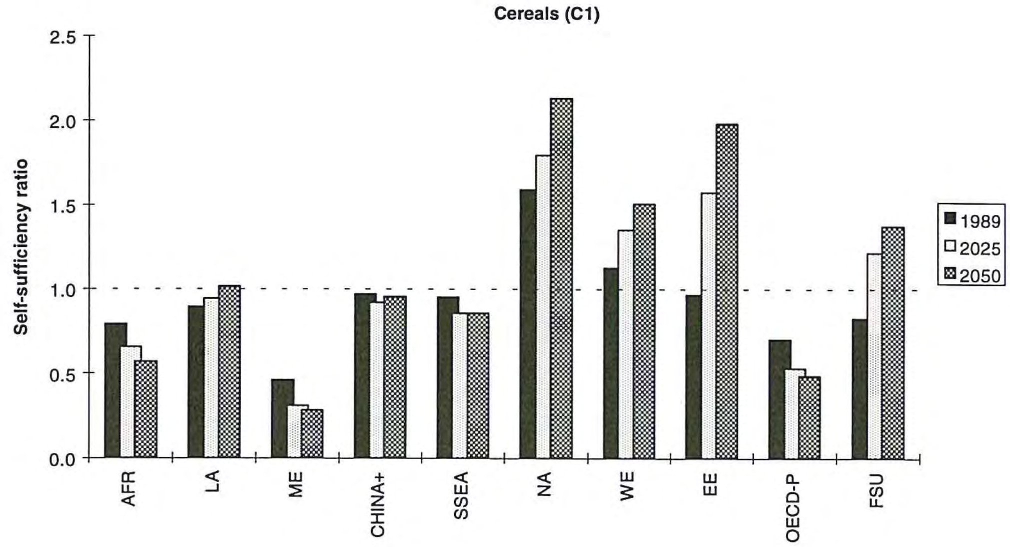


Figure 3.11 (a). Self-sufficiency ratio, cereal crops (C1): 1989 - 2050.

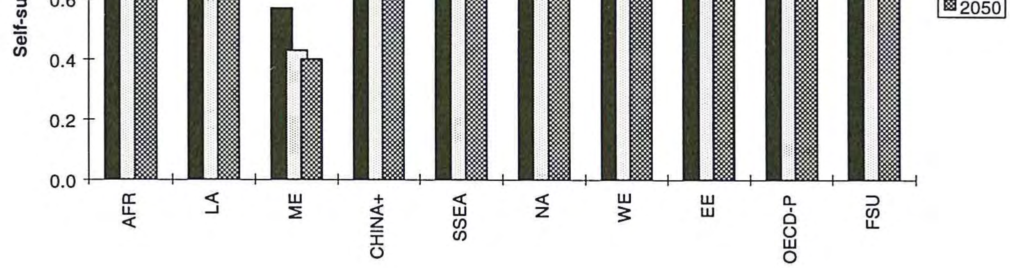


Figure 3.11 (b). Self-sufficiency ratio, non-cereal crops (C2 - C7): 1989 - 2050.

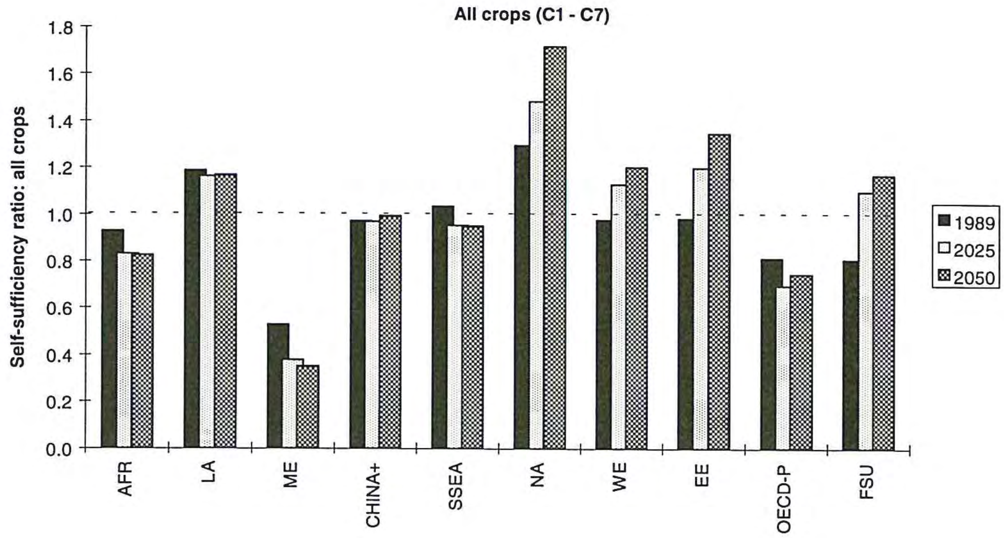


Figure 3.11 (c). Self-sufficiency ratio, all crops (C1 - C7): 1989 - 2050.

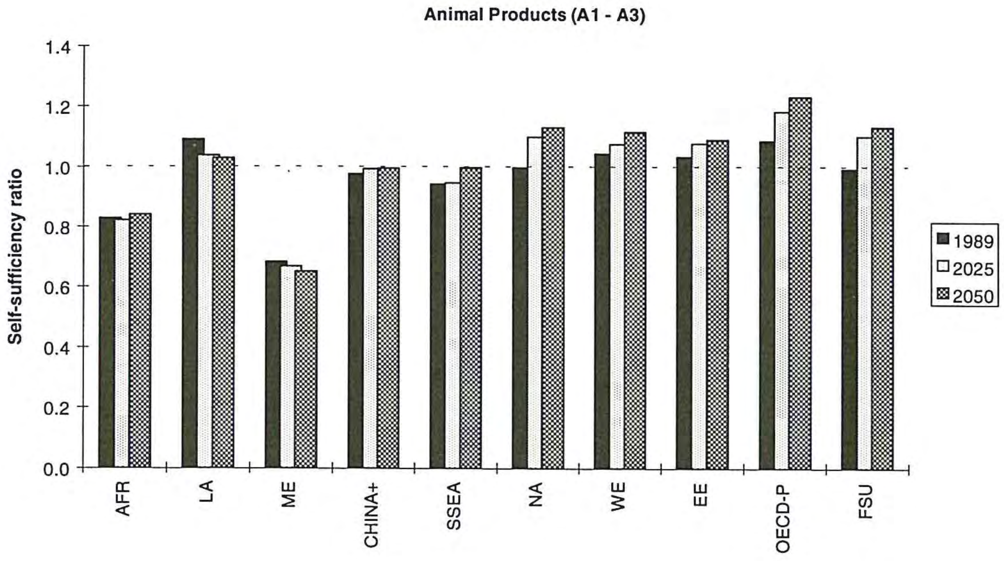


Figure 3.11 (d). Self-sufficiency ratio, animal products (A1 - A3): 1989 - 2050.

With non-cereal crops both the absolute differences and changes in the regional SSRs are far less extreme than with cereals. In 1989, apart from the large deficit of the Middle East and the large net exports of Latin America, all regions had SSRs within the 79% to 108% range. By 2050 the extreme positions of the Middle East and Latin America widen, with the SSR for the former region falling from 57% to only 36%. The deficit SSR worsens slightly in Africa, while S & SE Asia moves from a net surplus in 1989 (SSR = 1.08) to a substantial deficit in 2050 (SSR = 0.88). In all other regions, including China+ amongst the LDCs, net imports decrease or net exports increase so that the SSR rises.

Table 3.14. Self-sufficiency ratios.

Region	Cereals 1989	Cereals 2025	Cereals 2050	Other crops 1989	Other crops 2025	Other crops 2050
Africa	0.79	0.66	0.57	0.98	0.90	0.94
Latin America	0.89	0.95	1.02	1.25	1.22	1.21
Middle East	0.46	0.31	0.28	0.57	0.43	0.40
China+	0.97	0.92	0.96	0.97	1.00	1.01
S & SE Asia	0.95	0.86	0.86	1.08	1.00	0.99
N America	1.59	1.80	2.13	0.99	1.11	1.19
W Europe	1.13	1.35	1.51	0.91	1.01	1.04
E Europe	0.97	1.58	1.99	1.00	0.99	1.01
OECD Pacific	0.70	0.53	0.49	0.88	0.83	1.02
Former USSR	0.83	1.22	1.38	0.79	1.01	1.03

Region	Total crops 1989	Total crops 2025	Total crops 2050	Animal products 1989	Animal products 2025	Animal products 2050
Africa	0.93	0.83	0.83	0.83	0.82	0.84
Latin America	1.19	1.16	1.17	1.09	1.04	1.03
Middle East	0.53	0.38	0.35	0.68	0.67	0.65
China+	0.97	0.97	0.99	0.98	0.99	0.99
S & SE Asia	1.04	0.95	0.95	0.94	0.95	1.00
N America	1.30	1.48	1.72	1.00	1.10	1.13
W Europe	0.98	1.13	1.20	1.04	1.08	1.12
E Europe	0.98	1.20	1.35	1.03	1.08	1.09
OECD Pacific	0.81	0.70	0.75	1.09	1.18	1.23
Former USSR	0.81	1.10	1.17	0.99	1.10	1.13

With animal products there is relatively little change in the self-sufficiency ratios. In outline, they improve slightly in all the MDCs in order to balance off slight falls in Latin America and the Middle East. However, the effects of these changes on crop production requirements via crop-based animal feeds are very small indeed.

Combined with a two- to three-fold expansion in the volumes of world food consumption and production by 2050 these changes in self-sufficiency ratios give rise to some very large changes indeed in regional crop trade. Bearing in mind that we are considering here only *net* exports between regions, Table 3.15 provides aggregate regional trade data for cereals and non-cereal crops in 1989, 2025 and 2050.

Between them, the MDC regions have to increase their cereal exports more than 6-fold between 1989 and 2050 - from around 90 million to 552 million tons a year - to match the 6-fold increase in imports to the LDCs. Most of the latter is to Africa and the Middle East, where import tonnages increase 10-fold and 8-fold respectively. To correct this imbalance North America almost trebles its cereal exports from 122 to 330 million tons between 1989 and 2050. Western Europe more than quadruples its cereal exports from 25 to 122 million tons in the same period.

Table 3.15. Net exports (million tons).

	Cereals			Other crops		
Region	**1989**	**2025**	**2050**	**1989**	**2025**	**2050**
Africa	-23.3	-122.8	-246.6	-7.3	-81.4	-84.5
Latin America	-11.9	-13.2	4.7	134.5	192.9	211.3
Middle East	-22.1	-112.8	-179.8	-28.8	-125.9	-196.8
China+	-10.1	-41.0	-24.6	-10.5	-2.1	15.4
S & SE Asia	-15.4	-84.8	-105.9	46.4	-0.9	-19.0
N America	122.1	238.1	330.0	-2.5	27.1	45.0
W Europe	25.0	84.8	121.5	-40.1	5.3	15.3
E Europe	-2.7	42.2	66.6	-0.4	-1.5	1.0
OECD Pacific	-14.6	-43.8	-58.9	-10.5	-18.4	1.9
Former USSR	-37.4	53.4	92.8	-61.3	5.0	10.5
LDCs	-82.9	-374.6	-552.4	134.3	-17.5	-73.6
MDCs	92.3	374.7	552.1	-114.8	17.5	73.7

One obvious question is whether the LDC regions will be able to afford these enormous increases in food imports. A fair answer might be "yes, perhaps". If we consider the 10-fold and 8-fold increases in cereal imports to Africa and the Middle East, they turn out to be slightly less than the increases in regional GDP during the same period; i.e. by a factor of 10.9 for Africa and 9.9 for the Middle East (see Tables 1.2 and 1.3). *If* food prices (in real terms) do not increase significantly in the coming decades, the massive food imports in 2050 should account for no greater share of GDP than food imports today.

A second pertinent question is whether the food exporters will be willing to export in such vast quantities, bearing in mind current political pressures to reduce food production, farm subsidies and "surplus" crop land? However, if they do not export as assumed, future food deficits in the importing regions would have to be reduced. If we also assume for the moment that food demand as outlined in Chapter 2 is a given, the deficit reductions would have to be made through still greater increases in crop lands or in crop yields than assumed above, especially in the largest food deficit regions - Africa and the Middle East plus S & SE Asia for non-cereal crops.

From a Northern perspective both solutions raise manifold problems. Land expansion runs up against mostly Northern concerns about preventing forest clearance in the South - chiefly to "preserve biodiversity" and reduce greenhouse gas emissions from this source. Yield increases are therefore generally the more favoured solution. To the extent that these can be brought about by "more science" they are also the more painless solution: let the scientists and experts get on and do their thing and two ears of corn will grow instead of one. If, as seems much more likely, really large improvements in yield must come from a much broader package of measures, the yield improvement option will certainly not be painless. It will require a large range of tough political actions in developing countries with continued support, often in cash, from the traditional Northern donor countries. Substantial and permanent increases in basic food prices might also be required (after decades of steady decline) in order to increase farmer incentives. How that can be done without pricing food beyond the reach of many more millions of poor people than today - or by massive food subsidies for consumers - is a very large question indeed.

4 CHALLENGES AND RESPONSES

4.1 Introduction

The Conventional Development scenario presented in previous chapters assumes a continuity over the next 60 years in basic patterns and trends of food consumption and production. Dietary standards and patterns adjust gradually with rising incomes, average yields continue to improve, and there is a progressive expansion of agricultural (and settlement) areas at the expense of forests and other land. These trends ease off towards 2050 as the growths of population and per capita food consumption slow down. Generally speaking, the scenario can be said to represent a mid-range course between the pessimism which argues that world population already exceeds the carrying capacity of the agricultural system (Ehrlich, 1968), and the giddy optimism which sees no physical limits to food production (Simon, 1981).

This bland perspective does not mean that the future of food production raises no serious problems or can be left to unfold of its own accord. On the contrary, the scenario points to a number of serious environmental and other threats associated with the increased intensity of food production and the land area which must be devoted to it. It also assumes vigorous and sustained policy actions on several fronts in order to reduce these threats and secure the required food production and productivity gains. The encouraging conclusion, that there will be enough food over the scenario time horizon to meet expanding demand, may be undermined if institutional arrangements governing food supply and demand are not adjusted, if sustainable agricultural practices are not adopted and if land pressures and agrochemical pollution associated with expanded production are not ameliorated. Most importantly, the scenario exposes major food supply-demand problems in some regions, notably Africa and the Middle East, where the outcomes assumed are very far from guaranteed.

This chapter considers briefly the main environmental, resource and other forms of risk associated with the scenario and the policy responses which will be required to overcome or ameliorate them.

4.2 Land Resources

The population, economic growth and other assumptions of the scenario imply significant alterations in the use of land. Settled areas - the 'built environment' - will have to expand significantly to accommodate the growth of housing and services, commerce and industry, roads and other infrastructure. Cultivated lands will have to expand to compensate for agricultural land converted to the built environment and lost to soil and other forms of land degradation, as well as to meet the net increase required for food production, as detailed here in Chapter 3.

These changes will exert severe stresses on ecosystems which are now little affected by human pressures, such as wetlands and forests, as well as wildlife parks and other kinds of protected land.

Adding to these problems are the environmental threats to land and other resources arising from the growth of agriculture itself. To feed large populations with better diets, global crop production has to increase 2.2-fold by 2050 but has to grow by a factor of 2.5 in the developing world as a whole and 4-fold in Africa and the Middle East. Partly because of other pressures on land and shortages of undeveloped land which is good enough to farm, most of this huge production growth has to come not from expanding cultivated land but from greater crop yields as a result of more intensive land use, more irrigation, and more fertilisers. World-wide, cultivated land expands by only 11% between 1990 and 2050, with a 21% increase in the LDCs and a 1% fall in the industrialised regions. As a result, per capita farmland is squeezed tightly by population pressures, falling from 0.20 to 0.11 hectares in the developing regions as a whole, compared to 0.55 and 0.48 hectares in the developed regions. In South & East Asia, the Middle East and China+, the per capita cultivated area falls to as little as 0.09, 0.08 and 0.06 hectares, respectively in 2050.

This degree of intensification carries high risks of further degrading already over-stressed land, water and other natural resources (McCalla, 1994). As the scenario highlights, the daunting challenge is not only to more than double global food production on much the same land base as today but to do so sustainably while maintaining, and hopefully improving, vital land, water, fishery, forest and other natural resources. Few doubt that this challenge is immense and the risks of failure appreciable. As one World Bank report has put it: "The interaction between population growth, the environment and agricultural intensification raises the most compelling and most controversial issues currently facing developing countries" (Lele & Stone, 1989).

4.2.1 Land Degradation

Soil erosion and other forms of land degradation are generally agreed to present the most serious set of risks, although opinions differ widely on the scale, nature and causes of these problems. According to one authoritative source (CGIAR, 1994) globally about 2,000 million hectares of soil have become "degraded" due to human action since 1945 - an alarming annual rate of 40 million hectares or 1% of the world's cultivated and pasture area. Lack of terraces on steep slopes, failure to replace nutrients removed in crops and crop residues, and excessive irrigation or drainage did most of the damage to arable land, while overgrazing has been the main problem on rangelands. Brown (1984) estimated that global soil erosion was 23 billion tons per year, or 0.7% of the total soil inventory. At this rate (compounded) half the world's soils would be lost in a century. A more recent estimate puts the annual soil loss at treble this rate, or 75 billion tons, mostly from agricultural land (Myers, 1993).

Africa in particular, with its ancient, heavily-leached, nutrient-deficient and easily erodible soils, is thought to face severe and growing problems of land degradation and increasing aridity which threaten to undermine its present agricultural base (Yates & Kiss, 1992), let alone any large expansion of its crop and pasture lands (as assumed here). One major survey estimated that 72% of Africa's arable land and 31% of its pasture land are already degraded (Oldeman et al., 1991); another that 50% of the farmland and up to 80% of the pasture area shows signs of degradation (Cleaver, 1993).

Most of this degradation acts to reduce plant productivity so that farmers must put more into the land to get the same out of it, or must switch to new crop and livestock production systems. These impacts are to a large extent included in the historic trends of crop productivity and, based on these, the scenario assumptions about future crop yields (see Chapter 3). More extreme - and not explicitly modelled here - is soil damage so severe that once-productive land has to be abandoned more or less permanently. Estimates for such losses include 7 million hectares per year (Lampe, 1994); 10-11 Mha/year (Kendall & Pimentel, 1994); at least 10 million hectares per year including losses to the built environment (Pimentel et al., 1992); and 12 million hectares per year "destroyed" and abandoned because of non-sustainable farming practices (Lal & Stewart, 1990).

Such estimates are, it must be said, widely criticised as uncertain or exaggerated. For one thing, the data on which they are based are exceedingly weak and potentially misleading. Soil loss measurements on the same field by different teams can vary 100-fold or more (Seckler, 1987), and on the same small watershed by three to four orders of magnitude (Seckler, 1987; and Stocking, 1993). Extrapolation of soil losses from field measurements to large watershed or continental scales is likely to exaggerate 100-fold or more (Stocking, 1995). The complex relationships between soil changes and declines in land productivity are also "beset by enormous uncertainties and errors" (Blaikie & Brookfield, 1987). Equally serious is the frequent selective misuse of these poor data for political or propaganda reasons. It is therefore hardly surprising that large-scale estimates of soil and land degradation have been called uncertain, contentious and disputed (Mortimore, 1993); that some authors state baldly that on the large-scale rates of soil erosion are simply not known (Seckler, 1987; and Johnson & Lewis, 1995); and that the 1977 UN Conference on Desertification declared that "Statistics [on soil erosion and deforestation] are seldom in the right form, are hard to come by and even harder to believe, let alone interpret" (cited in Blaikie, 1985). However, none of these critics of alarmist estimates of soil erosion deny that soil and land degradation are real threats to the sustainability of productive land use and that corrective measures are urgently needed.

As a "worst case" working hypothesis we might assume that productive cropland is being lost to severe degradation and the built environment at a global rate of some 10 million hectares annually. This is just over twice the recent rate of cropland expansion, which averaged 4.4 Mha/year globally during 1961-89 (FAO, 1992). In future this disparity could be as much as five-fold. In the scenario presented here global cropland expansion slows to 2.6 Mha/year during 1989 to 2050 (2.7 Mha/year in the LDCs combined, of which 65% is accounted for by Africa and 22% by Latin America). Assuming that "permanent" land losses continue at 10 Mha/year, then world-wide some 12.6 million hectares of new cultivable land will have to be cleared each year just to provide for the assumed cropland expansion of 2.6 Mha/year. Additional new land will also be required to replace any losses of pasture land to degradation, the built environment and cropland, as well as to provide for net pasture area expansion.[5]

4.2.2 Impacts of Land Use Change

As in the past, this large-scale conversion of new land to human use carries serious risks for human societies and the environment. A good deal of this new land is likely to be of poor quality and hardly fit for productive use. For this reason alone, pockets of hunger, poverty and failure will persist beneath the broad regional assumptions of the scenario that average incomes, dietary standards and food production will increase. Environmental resources will inevitably be lost since this

[5] Pasture land is not modelled in the scenario due to severe data problems for animal feed and pasture requirements (see Section 2.2) and poor data on areas of pasture which are either in use and or presently idle reserves.

new land will be taken from a mix of forest and woodlands, grasslands and wetlands, depending on regional land endowments and pressures. The impacts will undoubtedly be large but they are also most difficult to quantify due to enormous data variations and uncertainties.

Major impacts will include continued losses of living space and livelihood for forest-dwelling people and of wildlife habitats. Biodiversity will be reduced and species driven to extinction. There will be continued pressures on wildlife reserves and other protected areas from local land-users and, increasingly, migrants from other land-scarce places. The many other productive values and ecological services of forests (and other biomes) will be diminished. Forest clearances will also produce greenhouse gas emissions, although total emissions related to agriculture could well be less than in the past due to the assumed slow down of cropland expansion.

However, it is important to recognise that all of these forest-related impacts will in many places be reversed by the regrowth of forest, woodland or shrubs on abandoned farm lands. Large areas of the world's tropical and temperate forests - including so-called "primary" forest - are known to have grown from once-settled cropland (Wood, 1993). In West Africa, for example, "much" of the closed forest is actually mature secondary forest which has grown from land cleared for agriculture and later abandoned (Gornitz & NASA, 1985). In at least one West African case this process has been so rapid that almost treeless cropland has reached the status of a protected world-class forest Biosphere Reserve in only a century (Fairhead & Leach, 1994).

4.3 Water Resources

Water shortages and greater competition for water between agriculture and rapidly growing urban and industrial demands are other serious impacts of and threats to agricultural growth. According to some authorities (CGIAR, 1994), competition will be particularly serious through much of Africa and the Middle East, where recent high rates of irrigation expansion appear to be unsustainable, and Asia, where the continuation of recent trends would require an investment of US$500-1,000 billion by 2025 and could exhaust the irrigation potential by that date. These and other issues of increasing water use and resource sustainability are examined in depth in a companion report of the PoleStar project.[6]

To help resolve problems of water shortage much greater attention will have to be paid on drylands to unfamiliar techniques such as small-scale water harvesting and, in all regions, to improved management of irrigation systems (CGIAR, 1994; and Srivastava & Alderman, 1993). With the latter, huge potentials exist all the way from the water source to the field and plant itself to reduce water losses and use water more effectively (Stanhill, 1986). These conservation techniques are rarely applied today because farmers typically pay very little for irrigation supplies. For example, in California the price of water to most farmers has been about 10% of the supply cost (Gottlieb, 1991); during the late 1980s in China, when there were chronic droughts and urban water shortages, the equivalent figure was 5-20% of costs (Smil, 1993). More expensive water will increase farm costs, but by helping to promote more efficient water use and reduce supply constraints, it could also help to increase crop yields and production.

[6] Raskin, P., E. Hansen & R. Margolis. 1995. *Water and Sustainability: a Global Outlook.* Stockholm: Stockholm Environment Institute.

4.4 Chemical Pollution

Pollution by fertilisers and pesticides are other serious environmental problems. Heavy fertiliser use in the intensively farmed lands of both the developed and developing regions is producing nitrate levels in drinking water which approach or exceed permitted levels, increasing the likelihood of government restrictions on fertiliser use (CGIAR, 1994). This is not yet a problem in much of the developing world where fertiliser use is very low, but could become so under the scenario assumptions that fertiliser use increases rapidly. These risks need to be balanced against the economic and environmental benefits of raising fertiliser usage: first, by increasing crop yields and so reducing the need to farm new fragile lands; second, by increasing crop residues and hence the likelihood that surpluses over demand will be used as soil-protecting green manures and mulches (Pinstrup-Andersen, 1993). Heavy pesticide use in developing countries is causing serious harm to human populations (CGIAR, 1994) with declining benefits to farmers as pest populations become increasingly resistant and their predators are killed off.

Techniques are being developed to counter both these pollution problems - including many biological approaches to nitrogen fertilisation and pest control - but they will require major investments for research, demonstration and implementation. Until these techniques are widely available at costs farmers can afford, these environmental impacts are likely to continue since their reduction will generally lead to lower food production and farm incomes.

4.5 The North-South Food Gap

One of the most crucial findings of the scenario is that even with large increases in crop areas and yields, some developing regions will have to turn increasingly to food imports from the industrial world. Production in the latter regions must be stepped up to meet these needs during a period when domestic demand is expected to stagnate or decline.

According to the scenario, for example, the developed regions have to increase their cereal exports more than 6-fold between 1989 and 2050 - from around 90 million to 552 million tons a year - to match the 6-fold increase in imports to the LDCs. Most of the latter increase is to Africa and the Middle East, whose import volumes increase 10.5-fold and 8-fold respectively. To correct this imbalance North America has almost to treble its cereal exports from 122 to 330 million tons between 1989 and 2050. Western Europe more than quadruples its cereal exports from 25 to 122 million tons in the same period. With other crops, net North-South trade is greatly reduced between 1989 and 2050, while regional roles are reversed. Overall, the LDCs turn from being net exporters to net importers and *vice versa* for the MDC regions combined (see Table 3.15).

As noted in Chapter 3, less developed regions should be able to afford these enormous increases in food imports if food prices do not increase by much. For example, the huge expansion of cereal imports by Africa and the Middle East is slightly exceeded by the growth of regional income (GDP, or Gross Domestic Product) in the same period: a factor of 10.9 in Africa and 9.9 in the Middle East (see Tables 1.2 and 1.3). *If* food prices (in real terms) do not increase significantly in the coming decades, the massive food imports in 2050 should account for no greater share of GDP than food imports today.

The more pertinent question is whether the developed regions will be prepared to become the world's food baskets to an even greater extent than today. Will they find it economic to grow and export cereals (and other foods) in such vast quantities? If not, will governments and the public be prepared to finance the required surplus production for export? With present cost and price regimes and political climates, the pressures in the two present-day food exporting regions - North America and Western Europe - are to reduce food production, farm subsidies, "surplus" crop land and hence potential exports which are surplus to domestic needs. However, if the developed regions do not increase their exports as assumed in the scenario, food deficit in the importing regions would have to be reduced. This might come about through lower nutritional standards than assumed in the scenario, or through still greater increases in crop land areas or crop yields than assumed.

Both alternatives raise many political problems for the industrialised regions. Land expansion runs counter to Northern environmental concerns about preventing forest clearance in the South - chiefly to "preserve biodiversity" and reduce greenhouse gas emissions from this source. Yield increases over and above the large increases assumed in the scenario would therefore generally be the more favoured solution. To the extent that these can be brought about by "more science" they would also be the more painless solution. But if, as seems likely, improvements on the scale required will also demand a much broader package of measures, this alternative might be far from painless for Northern governments and consumers. As noted in Chapter 3, the required measures include tough political actions in developing countries with continued support, often in cash, from the traditional Northern donor countries. They might also include substantial and permanent increases in basic food prices (after decades of steady decline) in order to increase farmer incentives. How that can be done without pricing food beyond the reach of many more millions of poor people than today - or by massive food subsidies for consumers - is a very large question indeed.

4.6 Policy Responses

The main elements of a strategy to greatly increase food production and do it sustainably are clear: do more to support the world's farmers - especially the resource-poor majority - with better research, information, infrastructures and incentives, within a broadly favourable and stable macro-economic environment.

The root problem is that poor farmers who lack access to productive resources are more likely to produce little and degrade land than the better endowed (Blaikie & Brookfield, 1987; Pinstrup-Andersen, 1993; and English, 1993). They will produce more if they are paid enough by markets they can reach (Sen, 1994). They are likely to produce more in a sustainable manner if they have secure rights to the land they manage. They might produce more, sustainably, by increasing external technical inputs such as artificial fertilisers to boost yields and green manures or some degree of mechanisation to alleviate labour shortages, if they can afford or get access to these. Or they might apply innumerable local, high-skill methods which can in many cases maintain soil qualities and double or triple crop yields with little or no use of external inputs (Pretty, 1994 and 1995).

Where population densities are low, as in much of Africa, both of these broad classes of developments might occur spontaneously due to population growth, which drives technical innovation and adoption as a result of evolving market forces (Boserup, 1965 and 1981). This process of "autonomous intensification" was a main engine of agricultural development in Europe and Asia (Lele & Stone, 1989). However, in many places these processes will no longer be sufficient to ensure sustainable agricultural and income growth and must be backed by a large array of public policies at every institutional level.

At the international level, global trade barriers and policies have cut the prices of many crops which are critical to the economies of developing countries and their farmers. Radical reforms of global food pricing and trading policies might be required to enable the large production increases which are needed. Crucially, these reforms must be based on a longer-term perspective than normally used by the market. The challenge to the industrial regions of the impending North-South "food gap" and the need to increase cereal production and exports, outlined above, is a prime example of why short-term market signals might have increasingly to be over-ruled by longer-term political considerations.

At the national level, civil strife, unstable governments, rigid state institutions and policies, weak agricultural support services, over-valued exchange rates, heavy taxes on agricultural exports and controls which reduce farm prices to a fraction of world market values, have combined with widespread neglect of rural infrastructures to undermine the entire agricultural enterprise - reducing farm profitability, increasing farmers' risks, preventing significant productivity gains and contributing to the persistence of rural poverty. In Africa particularly, poor roads, weak market structures and lack of credit facilities have greatly increased the costs of farm inputs such as fertiliser and reduced farm output prices, severely blunting incentives to switch from subsistence to market production and from extensive to intensive farming (Cleaver, 1993). At the same time, inequitable land ownership and tenure systems have discouraged sustainable land use practices.

These policy failures will not be corrected overnight, although most governments and donor agencies know that they require urgent and sustained attention. The political will to carry through with these policy reforms is essential, even though several key measures may be unpopular with some (predominantly urban) sections of the voting public.

In the meantime, there is a large and potentially most rewarding agenda for scientific research, education and dissemination to farmers of a host of more productive and environmentally benign agricultural technologies. Establishing their widespread use on the world's farms amounts to launching a new "doubly green" revolution which is more productive than the first green revolution and much greener in terms of conserving natural resources and the environment (CGIAR, 1994).

Most of these "new" techniques rely on improved information and skills rather than resource-intensive, material inputs. They include the selection and creation of improved animal and plant varieties; biologically-based pest control strategies; biological methods of increasing nutrient uptake by plants; more diverse and complex crop rotations; better spacing of crop plants; minimum tillage and green manure systems to increase yields and erosion-preventing ground cover; agroforestry systems which can simultaneously increase useful production, protect soils and enrich them with additional nutrients; the "fine-tuning" of fertiliser and water applications in space and time to maximise their effective use; and cheap soil testing methods to allow more precise correction of soil nutrient deficiencies and reduce unnecessary over-fertilisation (Serageldin, 1993; and Antholt, 1994).

Research has also to start from the real needs, constraints and opportunities of farm households in different environments and build up from there, rather than starting from the top down in research laboratories. The fruits of research must also be delivered to the people who need them: good information systems, targeted to local audiences and their needs, are vital tools for narrowing the huge gaps in yields and good husbandry practices between research stations, "best" farmers and average farmers. These requirements call for some fundamental changes to the structures and objectives both of international and national agricultural research centres and national agricultural advice and extension services.

Some have concluded that if the research goals outlined above are pursued vigorously, with substantially increased investments, future world populations can be adequately fed, malnourishment eliminated, environmental degradation prevented and natural resources conserved (CGIAR, 1994). A more sober conclusion might be that, while the potential for reaching this benign state of affairs is indeed enormous, the path towards it will certainly not be smooth. In a future of very rapid change and large uncertainties, we can expect both the Malthusian pessimists and the technical optimists to be right in different places and at different times, while we have to remain ignorant about the total outcome.

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Stockholm Environment Institute

The Stockholm Environment Institute (SEI) was established by the Swedish Parliament in 1989 as an independent foundation for the purpose of carrying out global environment and development research. The Institute is governed by an international Board whose members are drawn from developing and industrialized countries worldwide.

Central to the Institute's work have been activities surrounding the Rio UNCED conference, and previous to this, the Brandt and Palme Commissions and the work of the World Commission for Environment and Development. Apart from its working linkages with the relevant specialised agencies of the UN system, a particular feature of SEI's work programme is the role it has played in the development and application of Agenda 21, the action plan for the next century.

A major aim of SEI's work is to bring together scientific research and policy development. The Institute applies scientific and technical analyses in environmental and development issues of regional and global importance. The impacts of different policies are assessed, providing insights into strategy options for socially responsible environmental management and economic and social development.

The results of the research are made available through publications, the organisation of and participation in conferences, seminars and university courses, and also through the development of software packages for use in the exploration of scientific problems. SEI has also developed a specialised library which functions as a central catalyst in the short-term and long-term work of the Institute.

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- ❑ *Environmental Resources*, including energy efficiency and global trends, energy, environment and development, and world water resources;
- ❑ *Environmental Technology*, including clean production and low waste, energy technology, environmental technology transfer, and agricultural biotechnology;
- ❑ *Environmental Impacts*, including environmentally sound management of low-grade fuels, climate change and sustainable development, and coordinated abatement strategies for acid depositions;
- ❑ *Environmental Policy and Management*, including urban environmental problems, sustainable environments and common property management; and
- ❑ *POLESTAR*, a comprehensive modelling and scenario-based activity, investigating the dynamics of a world with 10 billion people by the middle of the next century.

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SEI STOCKHOLM ENVIRONMENT INSTITUTE

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