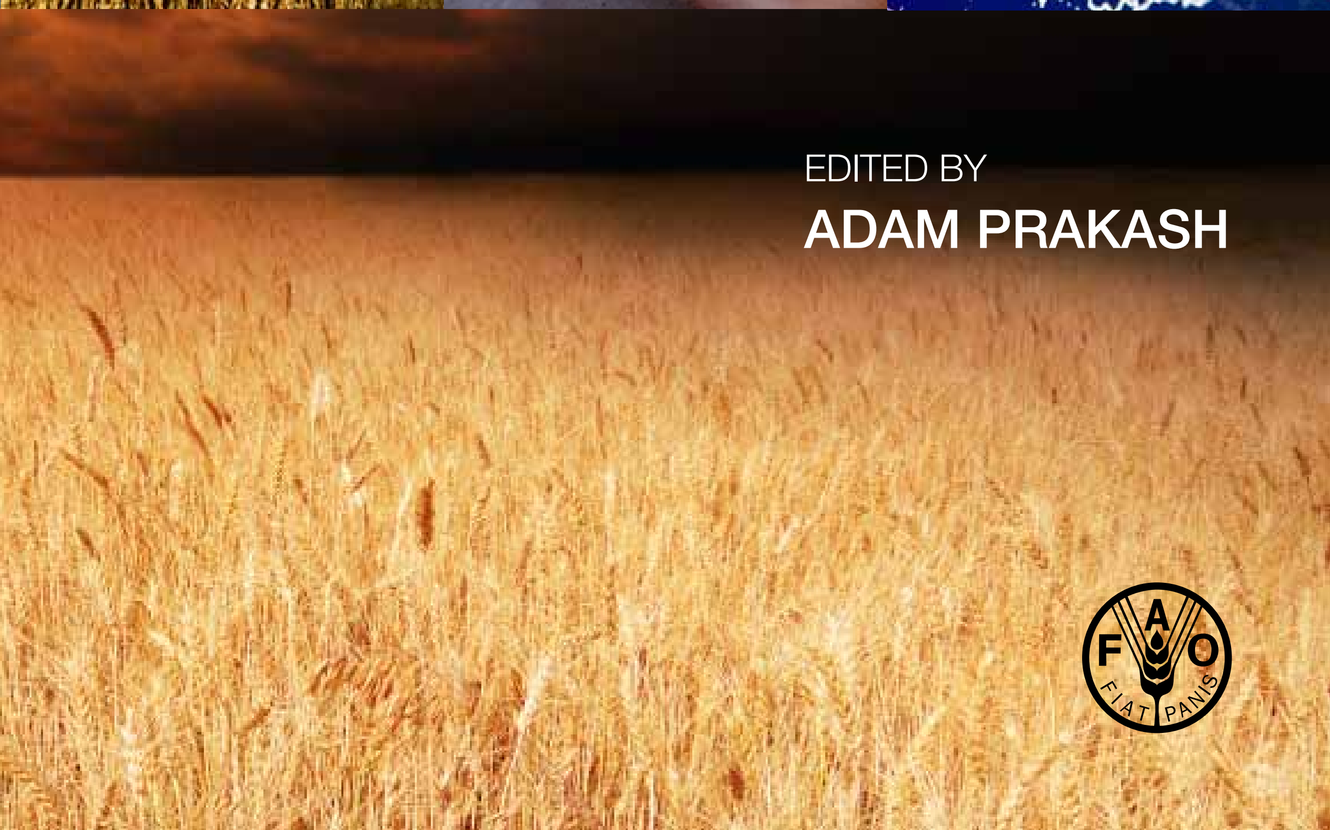
SAFEGUARDING FOOD SECURITY IN VOLATILE GLOBAL MARKETS





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Safeguarding food security in volatile global markets

Edited by Adam Prakash

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Chapter 4

Rising vulnerability in the global food system: environmental pressures and climate change[1]

Global Perspectives Unit (FAO) and Natural Resources Department (FAO)

This chapter extends the arguments made in Chapter 3 by examining the resilience of agriculture to cope with a changing climate in an already pressured ecological environment that will be subject to further demands. Recall that in the four decades leading to 2050, global food supply must rise 70 percent to meet the population's dietary needs, and that the increase needed in developing countries amounts to 100 percent. However, achieving food security for a rapidly-rising population is not the only factor behind the necessary growth. Agriculture will increasingly need to meet the demands of the emerging bio-based economy, especially in bioenergy and in markets for renewable and sustainable industrial products.

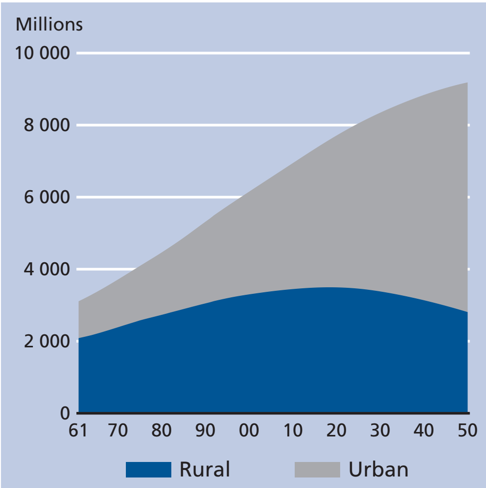
Both new and traditional demands for agricultural produce will put increased pressure on already-scarce agricultural resources. And while agriculture will be forced to compete for land and water with mushrooming urban settlements, it will also be required to serve on other major fronts: agriculture will have to adapt and contribute to the mitigation of climate change, help preserve natural habitats, protect endangered species and maintain a high level of biodiversity. If this were not challenging enough, in most regions fewer people will be living in rural areas, and even fewer will be farmers. They will need new technologies to grow more on less land, and with fewer hands.

The current momentum of rising agricultural production and productivity has been accompanied by adverse effects on the agricultural resource base, which have put its productive future potential in jeopardy. Among these effects are, for example, land degradation, salinization of irrigated areas, over-extraction of underground water, growing susceptibility to disease and build-up of pest resistance favoured by the spread of monocultures and the use of pesticides.

This backdrop of adverse effects and the observation that weather induced disturbances in major cereal producing countries have triggered past crises expose the growing fragility of the world's food production systems and agricultural markets to a changing climate. The pressures on agriculture are therefore immense. It seems that small deviations from the task of feeding more, that bring about scarcity through supply instability will lay the groundwork for further episodes of extreme volatility and crises.

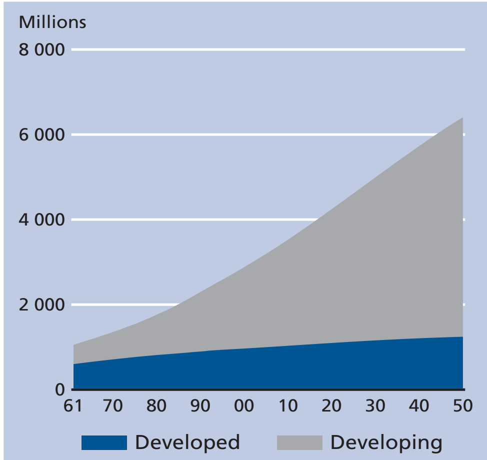
[1] This chapter is based on material from Bruinsma (2003), FAO (2009a) and FAO (2009b).

Figure 4.1: Population growth to 2050



Source: UN, FAO.

Figure 4.2: Urban population growth to 2050



Source: UN, FAO.

Vulnerability of the natural resource base

Demographic-induced vulnerability

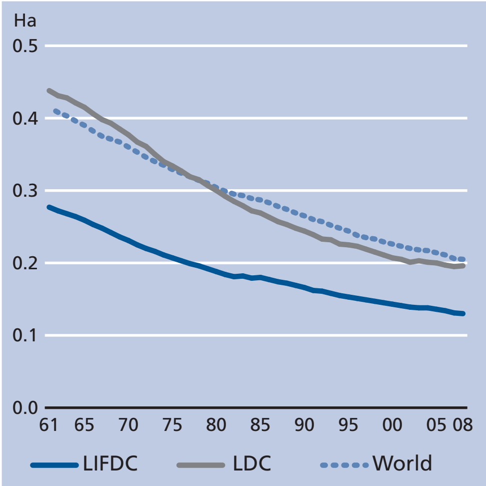
The exodus of rural inhabitants to towns and cities has resulted in a near explosion of urban populations. During 2008, the world's urban population was, for the first time, larger than the rural population. According to the latest UN forecasts, approximately 70 percent of the world's population is expected to reside in urban centres by 2050. Virtually all of this growth is foreseen to occur in developing countries, where, for instance, urban populations are expected to double over the next four decades and thus account for almost the entire increment in developing countries' population growth (Figure 4.1). But only part of this trend will be caused by increased rural-urban migration. Other reasons include the transformation of rural settlements into urban areas and, most importantly, natural urban population growth (Figure 4.2).

The process of urbanization does more than simply draw land resources away from food production. By lowering the pool of labour, urbanization has implications for agricultural wage levels and the composition of the remaining labour force. Typically the young, able-bodied, educated and skilled migrate, putting strain on current and future on-farm labour productivity.

In addition, such changes in population distribution will change the demand for fuel wood, especially charcoal, when incomes are insufficient to procure alternative sources of energy. Depletion of wood resources from areas supplying urban centres will results in major environmental problems such as soil erosion, soil infertility and danger of flooding. This trend is likely to persist during the decades to come unless alternative sources of energy are more widely available and accessible.

It is important to note that urban growth tends to occur on the best agricultural land. A 1987 estimate found that while 4 percent of potentially productive agricultural land would be lost to urbanization between 1975 and 2000, it would include a full quarter of the most productive land.

Figure 4.3: Per capita arable land availability (ha): 1961-2008



Source: UN, FAO.

Land-induced vulnerability

As populations grow, much good cropland is lost to urban and industrial development, roads and reservoirs. For sound historic and strategic reasons, most urban areas are situated on flat coastal plains or river valleys with fertile soils. Given that much future urban expansion will be centred on such areas, the loss of good-quality cropland seems likely to continue. In fact the losses seem inevitable, given the typically low economic returns to farm capital and labour compared with non-agricultural uses (Figure 4.3). Such losses are essentially irreversible, and in land-scarce countries the implications for food security could be serious.

Estimates of non-agricultural land use per thousand persons range from 22 ha in India (Katyal et al., 1997) to 15-28 ha in China (mainland) (Ash & Edmunds, 1998) and to 60 ha in the United States (Waggoner, 1994). The magnitude of future conversions of land for urban uses is not certain, nor is it clear how much of it will be good arable land. There is no doubt, however, that losses could be substantial. In China (mainland), for example, losses between 1985 and 1995 have been over 2 million ha, and the rate of loss to industrial construction has increased since 1980 (Ash & Edmunds, 1998).

Assuming that the conversion of land for non-agricultural purposes is an average of 40 ha per thousand persons, the projected loss on this account would be almost 90 million ha by 2050 (Table 4.1). Even if all of this land will have crop production potential, it still represents a fraction of the global balance of potential cropland that is as yet unused. However, in heavily populated countries such as China (mainland) and India that have very limited potential for cropland expansion, even small losses could be serious. In China (mainland), this issue has been of growing concern for a number of years.

Rising competition for land to pursue other economic activities poses a credible threat to the ability of food systems to meet allocative efficiency, especially for ensuring that supplies increase in response to high food price signals. The tenet of competitive markets is that the demand and supply of land will be governed by the economic returns to the factor of production. Notwithstanding the inelasticity of supply in the short run - land simply cannot

Table 4.1: Total arable land: data and projections

	Arable Land in Use						Annual Growth			Balance	
	1961/63	1989/91	2005	2005 adj.	2030	2050	1961-2005	1990-2005	2005-2050	2005	2050
	(mn ha)						*(% p.a.)*			*(mn ha)*	
sub-Saharan Africa	133	161	193	236	275	300	0.80	1.07	0.55	786	723
Latin America	105	150	164	203	234	255	1.01	0.64	0.52	861	809
Near East/North Africa	86	96	99	86	84	82	0.34	-0.02	-0.11	13	16
South Asia	191	204	205	206	211	212	0.15	0.07	0.07	14	7
East Asia	178	225	259	235	236	237	0.99	1.12	0.02	131	129
excluding China	73	94	102	105	109	112	0.85	0.71	0.15	78	75
Developing Countries	693	837	920	966	1040	1086	0.67	0.65	0.27	1 805	1 684
excl. China and India	426	536	594	666	740	789	0.75	0.66	0.39	1 730	1 609
Industrial countries	388	401	388	388	375	364	-0.02	-0.21	-0.15	486	510
World	1 375	1 521	1 562	1 602	1 648	1 673	0.30	0.17	0.10	2 576	2 503

Source: FAO.

be transformed from one productive activity to the next overnight - competition from the energy sector (namely biofuels and carbon sequestration) set aside for conservation and for rising urbanization as well as the building of new cities, can put the food sector on a poor competitive footing.

In many instances, however, the demand and supply of land for non-food activities is also being supported by policy mandates backed by subsidies and other incentives. Policy shifts that influence land utilization tend to be planned well in advance of their announcement and for the most part do not contribute to uncertainty. But their impacts do. Once resources are exhausted or degraded, little can be done.

A joint FAO-United Nations Environment Programme (UNEP) study has estimated the current extent of land degradation at 16 percent. Land degradation, which is a major threat to food security and has negated many of the productivity improvements of the past, is on the rise (Pimentel et al., 1995; UNEP, 1999; and Bremen et al., 2001).

Area of degraded land

The most comprehensive global assessment is the Global Assessment of Human-induced Soil Degradation (GLASOD) mapping exercise (Oldeman et al., 1991). The assessment is subject to a number of uncertainties, particularly regarding the impact of soil degradation on productivity, the rates of change in the area and the severity of degradation (Table 4.2).

There is no clear consensus about the area of degraded land, even at the national level. In India, for example, estimates by different public authorities vary from 53 to 239 million ha (Katyal et al., 1997). Land degradation is quite variable over small areas; owing to differences in soil type, topography, crop type and management practice impacts are highly site-specific. Some forms of degradation are not readily visible, e.g. soil compaction, acidification and reduced biological activity. Lack of data and analytical tools for measuring such differences prevents or limits estimation of their impact on productivity, and makes scaling up to the national or regional level problematic. Furthermore, there are no internationally-agreed criteria or procedures for estimating the severity of degradation. Few if any countries make systematic assessments at regular intervals that would help estimate the rates of change.

Table 4.2: Global assessment of human-induced soil degradation (GLASOD) million ha

Region	Total Land Affected	Percentage of Region Degraded	
		Moderate	Strong and Extreme
Africa	494	39	26
Asia	747	46	15
Australasia	103	4	2
South America	243	47	10
Central America	63	56	41
Europe	219	66	6
North America	96	81	1
Total	1 964	46	16

Source: FAO.

Impact of degradation on productivity

Does degradation have a serious impact on on-farm productivity and offsite environments through wind and water soil dispersal? Because degradation is normally a slow and almost invisible process, rising yields caused by higher inputs can mask the impact of degradation until yields are close to their ceiling. Yields thus hide the costs of falling input efficiency to farmers (Walker & Young, 1986; Bremen et al., 2001).

Water-induced vulnerability

A very small proportion the planet's water is available for human use (Table 4.3); around 2.5 percent of the world's water is fresh, and two-thirds of this is inaccessible (locked away in glaciers, and as snow, ice and permafrost) and much of the remainder is aquifer, leaving 0.4 percent of the world's total freshwater accessible on the surface (Evans, 2009). Global demand for water has risen sharply within the last century. At the beginning of the twentieth-century, each person used 350 m^3 of water on average per year. By 2000 this had risen to 642 m^3, while total annual water withdrawal rose from 579 to 3 973 km^3 over the same period. In the future, the impact of water stress and water scarcity is likely to grow significantly (*ibid.*).

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

Historically, irrigation has been crucial for gains in food production, either from productivity or from acreage. Irrigation reduces drought risk, encourages crop diversification and enhances rural incomes. An important step in estimating the pressure of irrigation on water resources is to assess irrigation water requirements and withdrawals. Precipitation provides part of the water crops need to satisfy their transpiration requirements. The soil, acting as a buffer, stores part of the precipitation water and returns it to the crops in times of deficit. In humid climates, this mechanism is usually sufficient to ensure satisfactory growth in rain-fed agriculture. In arid climates or during the dry season, irrigation is required to compensate for the deficit resulting from insufficient or erratic precipitation.

Table 4.3: Annual renewable water resources and irrigation water withdrawal: data and projections

	Precipi-tation	Renew-able water resources	Water use efficiency ratio		Irrigation water withdrawal		Pressure on water resources due to irrigation	
			2005/07	2050	2005/07	2050	2005/07	2050
	mm p.a	*cubic km*	*%*		*cubic km*		*%*	
Developing countries	990	28 000	44	47	2 115	2 413	8	9
sub-Saharan Africa	850	3500	22	25	55	87	2	2
Latin America & Carribbean	1530	13 500	35	35	181	253	1	2
Near East/North Africa	160	600	51	61	347	374	58	62
South Asia	1 050	2 300	54	57	819	906	36	39
East Asia	1 140	8 600	33	35	714	793	8	9
Developed countries	540	14 000	42	43	505	493	4	4
World	800	42 000	44	46	2 620	2 906	6	7

Source: FAO.

Accordingly, critical issues in water management have arisen in recent decades. These issues include: competition with the urban and industrial sectors for available water supply; poor irrigation water-use efficiency; over-extraction of groundwater; reduced infiltration of rainwater into soils and reduced water recharge because of deforestation and land degradation; declining crop yields and water quality related to waterlogging and salinization; contamination of groundwater and surface water from fertilizers, pesticides and animal wastes; and the risk of greater aridity and soil moisture deficits because of climate change.

Over-extraction

The over-extraction of groundwater is widespread in both developed and developing countries. It arises when industrial, domestic and agricultural withdrawals of water exceed the rate of natural recharge. In some areas, particularly in the Near East/North Africa region, irrigation draws on fossil aquifers that receive little or no recharge at a level that is not sustainable (Gleick, 1994). In many areas of China (mainland) and India, groundwater levels are falling by one to three metres per annum. The economic and environmental consequences are serious and will get worse in the absence of appropriate responses. Irreversible land subsidence, especially in urban and peri-urban areas, causes serious structural damage to buildings, drainage systems, etc. Over-extraction in coastal areas causes saltwater to intrude into freshwater aquifers, making them unfit for irrigation or drinking water without costly treatment. Lowering of the water table increases pumping costs. It will take many years to achieve the investments and other changes required to limit over-extraction, so several million ha of irrigated land may either go out of production or be faced with unsustainable operating costs.

Waterlogging and salinization

Irrigation mismanagement is often related to the problems of waterlogging and salinization. The former restricts plant growth. It arises from over-irrigation and inadequate drainage, and in many cases precedes salinization. Over ten million ha of land is estimated to be affected by waterlogging (Oldeman et al., 1991). Salinization results from the build-up of dissolved solids in soil and soil water, and can occur in rain-fed areas with inherently susceptible soils (e.g. parts of Australia) as well as in irrigated areas. The UNEP considers salinization to be the second largest cause of land loss. Estimated impacts, however, vary considerably. Oldeman et al. estimate the total affected area to be over 76 million ha. It seems possible that some 20 percent of total irrigated area is affected, and some 12 million ha of irrigated land may have gone out of production (Nelson & Mareida, 2001).

In some semi-arid countries, 10 to 50 percent of the irrigated area is affected to a greater or lesser degree (Umali, 1993; FAO, 1997b and FAO, 1997a) with average yield decreases of 10 to 25 percent for many crops (FAO, 1993; Umali, 1993). Unfortunately there are little or no time series data to allow reliable estimates of the rates of change in the salinized area. It could be 1-1.5 million ha per annum and increasing (Umali, 1993), but this is difficult to quantify. Of particular concern are those irrigated areas in semi-arid regions that support large rural populations, such as the western Punjab and Indus valley where large areas of waterlogged saline land are spreading through the intensively irrigated plains.

Climate change

Climate change magnifies the threat to food security by increasing the frequency of climate hazards, diminishing agricultural yields and production in vulnerable regions and increasing water scarcity. The potential for intensifying conflicts over even more scarce resources will likely lead to new humanitarian crises, as well as increased urbanization, migration and displacement (IPCC, 2007).

At the same time, local production declines will significantly impact the income opportunities and the purchasing power of developing countries. Worldwide, 36 percent of the total workforce - two-thirds in sub-Saharan Africa - is employed in agriculture and depends on productivity growth within smallholder agriculture to improve their incomes and food security (FAO, 2009b). Low-income countries with limited financial capacity to trade, high dependence on their own production to cover food requirements, and high-demand growth are hence likely to face difficulties in ensuring that their populations will have access to food that will be available on global markets (*ibid.*).

Climate change is also likely to affect the utilization of food. Decreasing availability of food and water, high food prices, as well as more frequent extreme natural events will increase malnutrition. Diseases may spread to geographical areas where they have not previously been. This could initiate a vicious circle where infectious diseases, including water-borne diseases, cause or compound hunger, which in turn makes the affected population more susceptible to those diseases. Malnutrition and illness lead to declining labour productivity and incomes.

The IPCC fourth assessment report

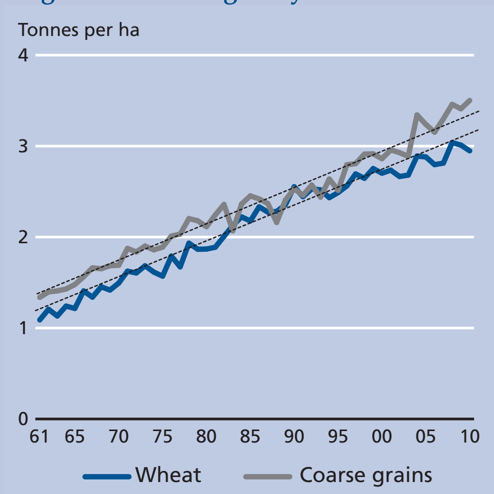
The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report provides the latest model-based projections and indicates that in the “best-case scenario” average surface air temperatures could rise by 1.8 °C (with a likely range of 1.1 to 2.9 °C) and sea level

Box 4.1: Do volatile crop yields portend climate change?

Average global yields of major grain crops have been particularly variable in recent years, as predicted by most climate-change impact models. It has also been predicted that greater weather variability will be one of the first signs of changing overall climatic conditions. However, when yields are further dissected into changes in individual countries and types of cereals, two interesting developments become clear.

First, the above-trend growth for grains as a whole is generally owed to exceptionally high yields for coarse grains and particularly rapid growth in maize yields in higher-latitude production systems. While it is too early to ascribe these changes to climate change, the observed effect is in line with the predictions under most climate change scenarios that foresee yield increase for temperate zone crops (higher latitudes). The expected changes in agro-ecological growing conditions (higher temperatures, increased average precipitation and CO2 fertilization) would suggest that higher average yields may remain a feature for the first decades of the twenty-first century. Second, a further differentiation between wheat and coarse grains reveals that wheat yields have become both lower on average and more variable across countries and years.

Figure 4.4 Global grain yields: 1961-2010



Source: Adapted from Schmidhuber (2006).

rise likely range (18 to 38 cm). On the other hand, in the "worst case scenario", temperatures could rise by 4.0 °C (with a likely range of 2.4 to 6.4 °C) and sea level rise likely range (26 to 59 cm).

Agricultural impacts, for example, will be more adverse in tropical areas than in temperate areas. Developed countries will largely benefit as cereal productivity is projected to rise in Canada, northern Europe and parts of the Russian Federation. In contrast, many of today's poorest developing countries are likely to be negatively affected in the upcoming decades owing to a reduction in the extent and potential productivity of cropland. Most

Box 4.2: The IPCC Fourth Assessment Report

The latest key findings of the IPCC regarding current research results on the state of climate change, its drivers and projections for the future include but are not limited to the following highlights (IPCC, 2007a):

- Warming of the climate system is now unequivocal
- The rate of warming in the last century is historically high
- The net effect of human activities since 1750 has been one of warming, due primarily to fossil fuel use, land-use change and agriculture;
- Most of the observed increase in globally averaged temperatures since the mid-twentieth century is very likely (greater than 90 percent) owing to the observed increase in anthropogenic greenhouse gas emissions
- Long-term changes in climate have already been observed, including changes in Arctic temperature and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and intensity of tropical cyclones leading to food supply disruption
- From 1900 to 2005, drying has been observed in the Sahel, the Mediterranean, southern Africa and parts of southern Asia
- Increased heat stress to crop and livestock; e.g. higher night-time temperatures, which could adversely affect grain formation and other aspects of crop development
- Increased evapo-transpiration rates caused by higher temperatures and lower soil moisture levels
- Concentration of rainfall into a smaller number of rainy events with increases in the number of days with heavy rain, increasing erosion and flood risks
- More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics
- Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the twenty-first century that will very likely be larger than those changes observed in the twentieth century
- Projections for the twenty-first century include a greater chance that more areas will be affected by drought, that intense tropical cyclone activity will increase, that the incidence of extreme high sea levels will increase (aggravated by subsidence in parts of some densely populated flood-prone countries, displacing millions) and that heat waves and heavy precipitation events will be more frequent
- Even if greenhouse gas concentrations were to be stabilized, anthropogenic warming and sea-level rise would continue for centuries owing to the timescales associated with climate processes and feedbacks.

severely affected will be sub-Saharan Africa owing to its inability to adequately adapt through necessary resources or greater food imports.

Problems facing farmers can be better understood if one considers the impact of climate change on weather or water. Precipitation, temperature and sunlight are the main factors behind agricultural production. Climate change can alter these factors and cause essential threats to water availability, reduce agricultural productivity, spread vector borne diseases to new areas and increase flooding from sea level rise and even heavier rainfall.

The IPCC Fourth Assessment Report addresses food security by discussing the foreseeable impacts on agricultural productivity and production in different regions around the globe. The report's collective comments suggest that some areas will benefit from global warming, at least during a transitional period, though most will be adversely affected. Significantly, the assessment emphasizes that those areas that will benefit from global warming in the near to mid-term will eventually also suffer from declining productivity. Various parts of the assessment also reference changes in the hydrological cycle that will affect agriculture in general and food security specifically.

Migrations forced by climate change (for example, excessive heat, increased evaporation rates, or prolonged drought-induced crop failures or flood) will further burden the already-stretched agricultural resources and food supplies of regions that have managed to sustain productivity.

According to an FAO study, a projected 2 to 3 percent reduction in African cereal production by 2020 is enough to put ten million people at risk. These impacts would require adaptation efforts that in many cases will hardly be affordable for people living with little access to the necessary resources or savings. In fact, the real impact will be in areas where food production is already marginal.

Aspects of vulnerability

About 25 years ago, a schematic diagram as shown in Figure 4.10 presented an idealized picture of a food production system where weather affects only crop yields. However, even at that time, the true impact of weather on many commodities was already well known.

The broader influence of weather is suggested in another version of the graph (Figure 4.11) where the box previously marked "weather" is replaced by "drought". In fact, lines in Figure 4.11 can be drawn from the drought box to many of the boxes in the diagram - even the "tastes" box - as humanitarian food imports of wheat or yellow maize, which, though not a staple in certain food importing regions, has been known to distort local food preferences. This situation has led to arable land being removed from traditional crop cultivation and given to the cultivation of non-traditional, climate-sensitive food crops.

In addition to what is already known or what will likely be the impact of episodes of extreme weather and climate on food production and, therefore, on food security, it is reasonable to speculate on the major impacts that might accompany global warming. In truth, such speculation has already been happening for several decades. The most legitimate assumption is that every box in the above graphic will be affected if the weather box were replaced by a "global warming" box.

Vulnerability patterns

Vulnerability is generally defined as a function of risk and exposure. Vulnerability with regard to climate change implies that people are exposed to aspects of climate that are changing in ways that will either generate or increase risk, which generally implies a potential loss of something valued.

For food security, there is higher risk of poorer nutrition or reduced access to food supplies than would be expected under "normal" climate conditions. The capacity to cope with the risky situations under a given exposure to hazards (both natural and human-induced) also shapes the pattern of vulnerability. As often is the case, this capacity is weak in parts of the world that suffer from food insecurity either intermittently or chronically.

Box 4.3: Modelling climate change impacts on regional agriculture: production

Climate change simulations are inherently uncertain. Two climate models - the National Centre for Atmospheric Research, the United States of America (NCAR) and the Commonwealth Scientific and Industrial Research Organization, Australia (CSIRO) - both of which apply the A2 scenario of the IPCC Fourth Assessment Report (temperature rise of 3.4 °C with a likely range of 2.0 to 5.4 °C), have been used to simulate future climate. The "wetter" NCAR scenario foresees average precipitation increases on land of about 10 percent, whereas the "drier" CSIRO scenario sees increases of about 2 percent.

Figure 4.5 Wheat production: climate change impacts

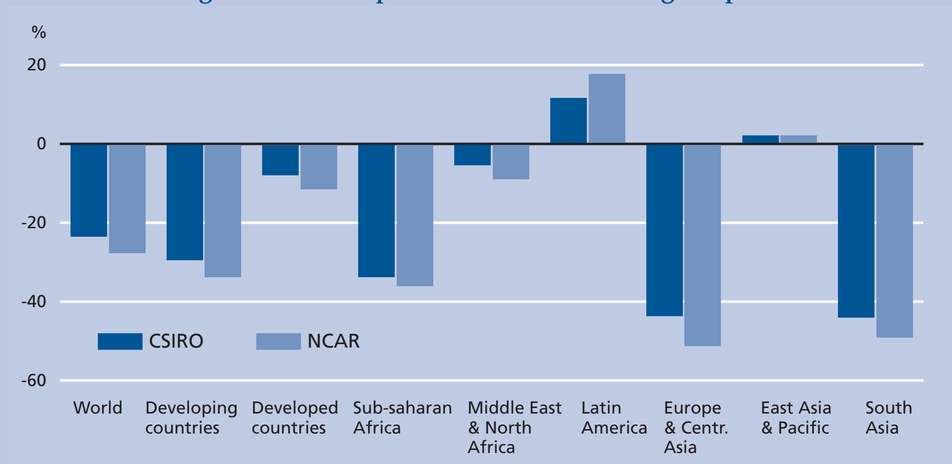


Figure 4.6 Maize production: climate change impacts

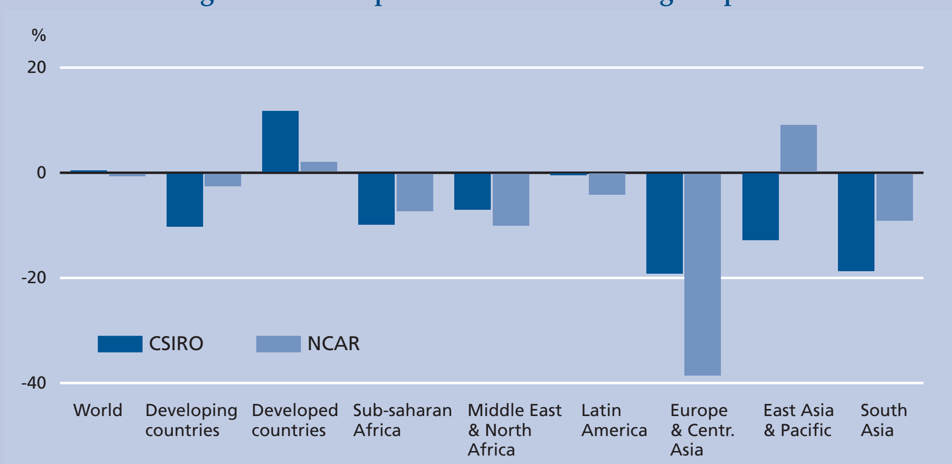
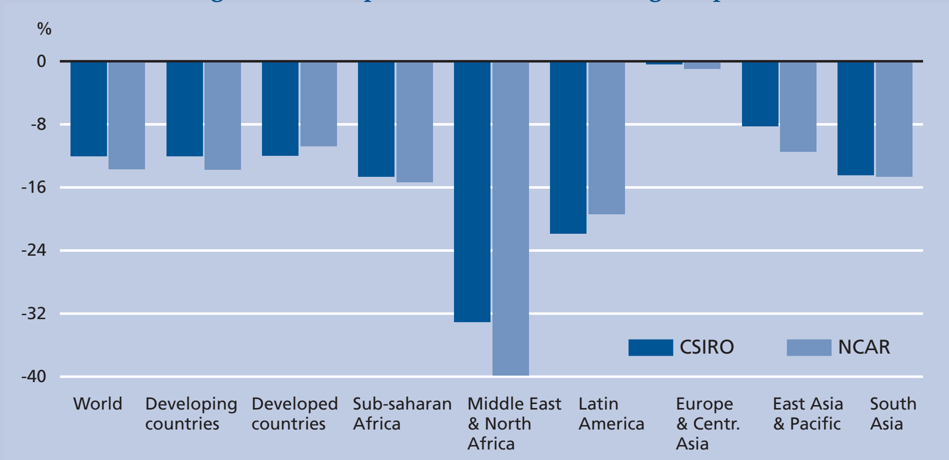


Figure 4.7 Rice production: climate change impacts



According to both models, in the case of no climate change, the production of all major crops will increase in developing countries. For example, in developing countries, production of rice increases by 17 percent, wheat by 76 percent and maize by 73 percent. Climate change reverses much of this increase, with the extent of the change depending on the region, crop and climate model. For example, in South Asia, maize production increases by 15 percent with no climate change, but is 9 percent below that level in the NCAR scenario and 19 percent below in the CSIRO scenario. In sub-Saharan Africa, maize production increases by 45 percent without climate change, but is 10 percent below that level with the CSIRO scenario and 7 percent lower with the NCAR.
Source: Nelson et al. (2009).

Rates and processes of change

Some of the most important factors of climate change are the expected shifts in the rates at which rainfall, temperature, relative humidity, cloudiness, evapo-transpiration (the process by which moisture is exchanged between the atmosphere and vegetation and soils) occurs. If the rates change incrementally and societies are aware of them, those societies may be able to adjust human activities accordingly. Within limits, some ecosystems will also likely be able to adjust to incremental changes. If, however, the rates of change are too rapid to be viable for adjustments such as shifting agricultural practices, changing crop rotations, developing new fodder regimes for livestock as grasslands dry out, then societies will be unable to escape with minimal impacts to their climate-sensitive activities and to the ecosystems on which those activities depend.

Virtual water and ghost acres

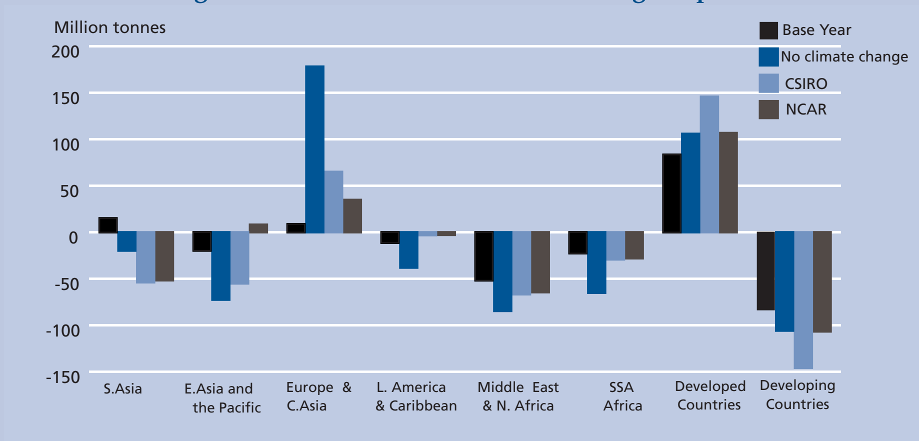
All reports on the hydrologic cycle suggest that it will intensify as the atmosphere warms, with some suggesting that the cycle could yield about 15 percent more precipitation per annum. At this point, however, conjectures based on global circulation model output are

[1] Originally from Morton (2007).

Box 4.4: Modelling climate change impacts on regional agriculture: trade

Regarding trade, under a no climate change situation, developed-country net exports increase from 83.4 mmt to 105.8 mmt between 2000 and 2050; an increase of 27 percent. Developing-country net imports mirror this change. With the NCAR results and no CO2 fertilization, developed-country net exports increase slightly (0.9 mmt) over no climate change. With the drier CSIRO scenario, on the other hand, developed-country net exports increase by 39.9 mmt

Figure 4.8 Cereal net-trade: climate change impacts



Regional results show (see above figure) important differences in the effects of climate change on trade and the differential effects of the three scenarios. For example, in 2000 South Asia is a small net exporter, and will become a net importer of cereals in 2050 with no climate change. Both scenarios result in substantial increases in South Asian net imports relative to no climate change. The East Asia and Pacific region is a net-importing region in 2000, and imports grow substantially with no climate change.

Depending on climate change scenario, this region has either slightly less net imports than with the no climate change scenario or becomes a net exporter. In Latin America and the Caribbean, the 2050 no climate change scenario shows increased imports relative to 2000, but both the CSIRO and NCAR climate scenarios result in smaller net imports in 2050 than in 2000.

Source: Nelson et al. (2009).

little more than speculation and educated guesses, not yet reliable enough to predict with any accuracy where the precipitation would fall, how it might fall, or when it will fall. Paradoxically, these reports also suggest that water scarcity in the next couple of decades is highly probable, with extreme shortages already appearing in various locations around the globe. As changes to the global water cycle become more pressing, policy-makers will have to scrutinize more closely where their limited water supplies will go and what they will be used for. The concepts of virtual water will become more and more relevant as these cycles continue to change.

Box 4.5: Climate impacts on food prices

Although the various climate change scenarios differ with regard to population and policy assumptions, most development paths essentially describe a world of robust economic growth and foresee real incomes rising more rapidly than real food prices. This suggests that the share of income spent on food should decline and that higher food prices are unlikely to create a major dent in the food expenditures of the poor. However, not all parts of the world perform equally well in the various development paths and not all development paths are equally benign for growth. Where income levels are low and shares of food expenditures are high, higher prices for food may still create or exacerbate a possible food security problem. A number of studies have measured the likely impacts of climate change on food prices (e.g. Fischer et al., 2002; Tubiello et al., 2006). The basic messages that emerge from these studies are:

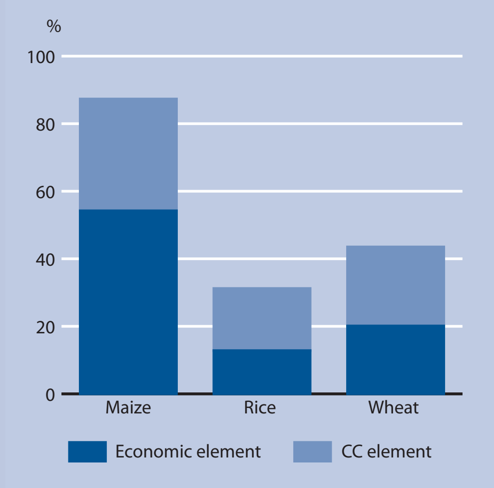
- On average, food prices are expected to rise moderately in line with moderate increases of temperature until 2050. After 2050 and with further increases in temperatures, prices are expected to increase more substantially.
- Expected price changes from the effects of global warming are, on average, much smaller than the expected price changes from socioeconomic development paths. For instance, in one scenario would imply a price increase in real cereal prices by about 170 percent.

Table 4.4 Climate change scenario impacts on food prices

	% price change, 2010 mean to 2050 mean		
	Maize	Rice	Wheat
Baseline	100.7	54.8	54.2
	(24.6; 0.104)	(4.2; 0.011)	(14.0; 0.060)
Optimistic	87.3	31.2	43.5
	(25.4; 0.114)	(2.0; 0.006)	(13.8; 0.063)
Pessimistic	106.3	78.1	58.8
	(25.5; 0.109)	(4.3; 0.010)	(15.3; 0.065)
	% price change, 2050 perfect mitigation to 2050 CC		
	Maize	Rice	Wheat
Baseline	32.2	19.8	23.1
Optimistic	33.1	18.4	23.4
Pessimistic	34.1	19.5	24.4

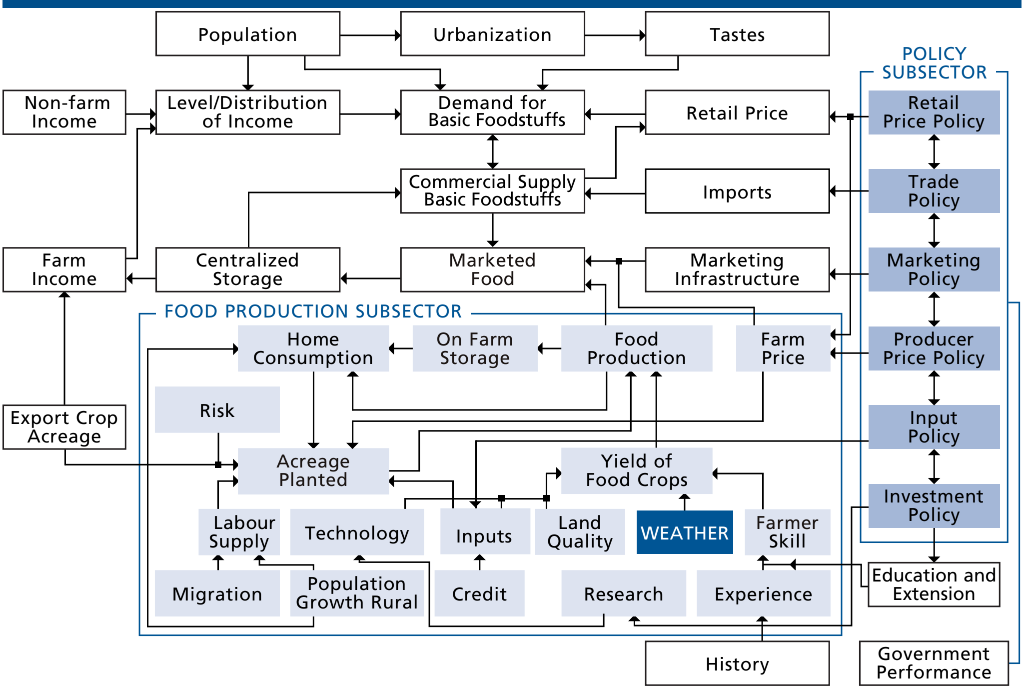
The additional price increase as a result of climate change would only be 14.4 percent. Overall, this appears to be the sharpest price increase reported and it is not surprising that this scenario would imply a persistently high number of undernourished people until 2080. Recently, Nelson et al. (2010), using scenario analysis based on four climate change models, found that relative to a world with perfect mitigation, prices in 2050 with climate change are higher by 18.4 percent (optimistic for rice) to 34.1 percent (pessimistic for maize). The authors' results are shown in the table above and the figure below(optimistic scenario only).

Figure 4.9 Percentage change in cereal prices (optimistic CC scenario)



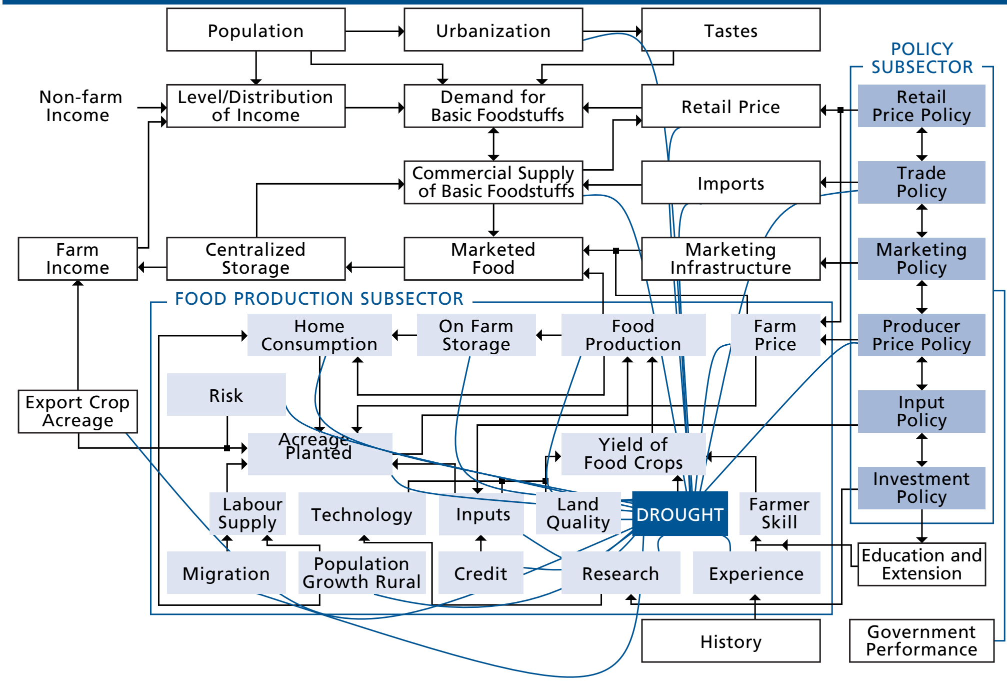
Source: Nelson et al. (2010).

Figure 4.10: An idealized food system



Source: Glantz (1987).

Figure 4.11: A food system under drought



Source: Adapted from Glantz (1987).

Similarly, the concept of ghost acres (or ghost hectares) was developed several decades ago. It was used to explain that food imports by Country A relied for those imports on the agricultural lands of Country B. In the same way, the "Green Revolution" also provided ghost acres in that the use of fertilizers and irrigation enhanced agricultural productivity and overall production from beyond what the land might have been able to provide in its natural state (Lang & Heasman, 2004). A country such as Japan, for example, would require several times more farmland than it has in order to produce an equivalent amount of protein to replace the amount it takes from the sea. The notion of ghost acres also applies to a country's food imports.

Global warming and disappearing seasons

The disappearance or even substantial changes in the overall characteristics of seasons is a concern. The problem is that over the past few decades, winters have generally become drier and warmer in many regions. Rainy seasons have become less so, not abruptly but incrementally over time. Both industrialized as well as developing economies and economies in transition live by the expected flow of the seasons, so no country will escape changes in seasonality with a warming atmosphere. Such changes will affect human settlements worldwide in ways that most communities are just beginning to consider. For example, researchers predict chronic water shortages worldwide (as in the eastern part of the Democratic Republic of the Congo), a shifting boundary between rangeland and farmland, recurrent and prolonged drought (as in various parts of sub-Saharan Africa, Australia and the southeast of the United States of America), a potential increase in the number and frequency

Box 4.6: The impacts of climate change on smallholder and subsistence agriculture

Although there has been much recent public discussion about the effects of climate change on rural areas of developing countries, not much of it has engaged with either the science of climate change impact on agriculture or the specificities of smallholder and subsistence systems.

Impacts on these systems should be considered in terms of hard-to-predict compound impacts highly specific to location and livelihood systems in different ecosystems and regions of the world. These livelihood systems are typically complex; they involve a number of crop and livestock species, between which there are interactions-for example, intercropping practices or the use of draught animal power for cultivation, and potential substitutions such as alternative crops.

Many smallholder livelihoods also include use of wild resources and non-agricultural strategies such as remittances. Coping strategies for extreme climatic events such as drought typically involve changes in the relative importance of crops, livestock species and non-agricultural activities, and the interactions between them. Positive and negative impacts on different crops may occur in the same farming system. Impacts on maize - the main food crop - will be strongly negative for the Tanzanian smallholder, whereas impacts on coffee and cotton - significant cash crops - may be positive.

There is evidence of increased risk of crop pests and diseases of crops under climate change, although knowledge of likely impacts in the tropics and on smallholder systems is much less developed. Modelling responses of both pathogens and (where relevant) insect vectors to rising temperatures and changing precipitation is complex, but there is cause for concern over possible spread of major diseases that attack smallholder crops in Africa: for example, Maize Streak Virus and Cassava Mosaic Virus in areas where rainfall increases, and sorghum head smut (a fungal disease) in areas where rainfall decreases. The latter would be compounded by farmers switching adaptively to sorghum in areas where maize becomes marginal. For diseases of livestock, modelling studies suggest overall slight declines in habitat suitable for tsetse-transmitted trypanosomiasis and East Coast Fever, although effects will be localized. Increased frequency of floods may increase outbreaks of epizootic diseases such as Rift Valley Fever and African Horse Sickness.

Another class of impacts is felt at the level of communities, landscapes and watersheds and has been less considered in literature on climate change and agriculture, although there is some overlap with consideration given to extreme events. One such impact is the effects of decreasing snowcaps on major irrigation systems involving hundreds of millions of smallholders, particularly in the Indo-Gangetic plain. As a result of warming, less precipitation falling as snow and earlier spring melting, there will be a shift in peak water supply to winter and early spring and away from the summer months when irrigation is most needed, with likely severe effects in areas where storage capacity cannot be expanded. Combined with increased water demand and the pre-existing vulnerability of many poorer irrigated farmers, such an impact could be catastrophic. Climate change effects on soil fertility and water-holding properties will also be important. Global warming and accompanying hydrological changes are likely to affect all soil processes in complex ways, including accelerated decomposition of organic matter and depression of nitrogen-fixing activity, resulting in increased soil erosion worldwide.

Source: Tubiello et al. (2008) – originally from Morton (2007).

of famines and perhaps a shift in their locations, and a shortening or lengthening of local and regional hazards related to climate, water and weather.

Forecasting by analogy: the future is here for those who wish to see it

Many of the adverse climate-change-related environmental scenarios being discussed, especially regarding the consequences of future human interactions with various types of ecosystems, from deserts (i.e. desertification) to mountain slopes (i.e. deforestation), have already been occurring for decades. Such scenarios should, therefore, no longer be viewed as speculation because the impacts of those changes have already been demonstrated, if not within one country, then in another. Even where there is a paucity of data for one particular area, the results of similar modifications to the natural environment have already been tracked and tested in other areas, yielding results that have demonstrated these modifications as being either good or bad for the environment, for society, or for both. Such correlations are at the heart of "forecasting by analogy".

The deforestation of mountain slopes, for example, will likely yield results in remaining forested mountain areas that are similar to those that have been witnessed in areas where such degradation has already taken place; in other words, the experiment of mountain slope deforestation has already been performed and the results are in hand, at least as far as the long-term impacts on the natural environment are concerned. When similar approaches to mountain forest management are attempted anew in a similar topographical setting elsewhere on the globe, therefore, similar results - soil erosion, rapid rainfall runoff, lower soil moisture recharge, sediment loading of streams, dams and reservoirs, faster snowmelt in the spring - should be expected.

Prolonged dry spells and especially-severe droughts expose inappropriate land use practices of farmers and herders; that is, practices that are inappropriate during periods of moisture stress but that are hidden or tolerated by nature during periods of favourable rainfall. A similar situation is likely to occur with regard to climate change, as the various characteristics of climate intensify or shift to locations where they had not been witnessed before. Policy-makers and individuals alike need to be alert to subtle changes in the environment or in the human interface with climate-sensitive ecosystems. It is also important to be aware that severe droughts can expose unsustainable land management practices.

The process of forecasting by analogy is valid when considering scenarios for other ecosystems, like the destruction of mangrove forests for the development of shrimp ponds or the irrigation of soils in arid areas without putting proper drainage facilities in place. While some governments have made sustainable changes to their environments, others have not. The point is that "new" scientific assessments of potential environmental impacts for each and every human interaction with the environment are often not necessary because the impacts of most human-induced environmental changes have already been sufficiently demonstrated.

Creeping environmental change

Quick-onset changes in climate and the environment are easy to see but difficult to cope with. Slow-onset changes, on the other hand, are difficult to see and even more difficult to cope with, at least in a timely way. Crop failure owing to drought occurs over a short period of time and is obvious to the observer. Decline in crop yield, however, is more readily detected over a longer time period. Governments in general tend to have considerable difficulty dealing with slow-onset, low-grade but cumulative changes to the environment.

The same holds true for similar creeping changes in both managed and unmanaged ecosystems as well as for changes in various aspects of climate, including subtle changes in temperature, rainfall, inter-annual variability, record-setting anomalies and so forth. Governments need to spend more attention coping with creeping changes in climate, water and weather because those incremental creeping changes eventually accumulate, leading to crises at some time in the future. For example, "famine" can be viewed as either an event or a process. Perceived as an event, famine is usually identified, on the one hand, in terms of the number of people forced to seek food in refugee camps. As a process, on the other hand, famine is identified by indicators of progress (change) that constitute subtle indicators along the path toward famine, such as increased sales of personal property, the drastic forced thinning of herds and unfavourable market behaviour of land, livestock, credit and water - each of which works against the scarce resources of poor farmers and herders.

Creeping changes, by their very nature, accumulate and eventually become major changes that usually materialize in environmental crises that interact with - if not create - other creeping environmental changes. For example, deforestation of mountain slopes can lead to soil erosion and increased runoff during heavy rains, intensifying the turbidity loads of rivers and streams. This silt continues to build up until it settles in reservoirs and behind dams, decreasing their utility and shortening their expected lifespan. This situation, in turn, reduces the amount of water that the dam or reservoir can provide to downstream users, while the increased runoff can lead to more serious and more frequent flooding of settlements and cultivated areas.

Summary

In summary, climate change multiplies existing threats and at the same time increases the vulnerability of individuals, communities and countries to food insecurity. Accelerated degradation of natural resources, coupled with more extreme weather events and growing food prices will further deplete the productive assets and income opportunities of the poor (World Bank, 2010). This reduces rural households' ability to produce or buy food as well as to recover from and build resilience to shocks, creating a downward spiral of eroding resilience.

Climate change may affect the physical availability of food production through shifts in temperature and rainfall; people's access to food by lowering their incomes from coastal fishing because of rising sea levels; or lowering a country's foreign exchange earnings by the destruction of its export crops because of the rising frequency and intensity of tropical cyclones. Some groups are particularly vulnerable to climate change: low-income groups in drought-prone areas with poor infrastructure and market distribution systems; low to medium-income groups in flood-prone areas who may lose stored food or assets; farmers who may have their land damaged or submerged by a rise in sea level; and fishers who may lose their catch to shifted water currents or through flooded spawning areas.

Other than foreseeing higher prices, current global assessments of climate change have been unable to quantify the likely climate change effects on price volatility. The main drivers of climate change induced price volatility would stem from impacts of extreme events such as drought and floods. That is, they have not considered the possibility of significant shifts in the frequency of extreme events on regional production potential, nor have they considered scenarios of abrupt climate or socioeconomic change and the upheaval cause by shifting production and trade zones. Such scenario variants are likely to significantly increase the already negative projected impacts of climate change on world food supplies (Tubiello et al., 2008).

Changing climatic conditions and degraded agri-environments are projected to adversely affect food systems on all scales, from a single household to the global level. It is essential for policy-makers to address the fundamental question of how to increase the resilience of present food production systems to the challenges posed by climate change.

To rephrase Evans (2009), do the issues discussed above imply, then, that humanity is inevitably heading for a Malthusian scenario as global population rises towards ten billion persons? The answer is a probable no. Looking back, history shows that a rapid escalation in population growth has always been accompanied by innovation, such as the "green revolution". However, the twinning of trends that point to supply scarcity with the demands of an ever-rising world population makes for a highly precarious situation that is full of uncertainty. Therefore, global solutions need to start with the clear recognition of that risk.

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