CHAPTER

13

Climate change and agriculture: physical and human dimensions

13.1 Introduction

There is a wide scientific consensus that global climate is changing in part as a result of human activities (IPCC, 2001b), and that the social and economic costs of slowing it down and of responding to its impacts will be large (OECD, 2001a). In the past there has been a steady rise in average global temperature: the 1990s were around 0.6°C warmer than the late 1890s. The 1990s were the warmest decade since the beginning of instrumental record-keeping in 1860, and the warmest in the past thousand years on the basis of tree rings and other proxy measurements. Moreover, there has been an increase in the number of heat waves and a reduction in the frequency and duration of frosts in many parts of the world. It is now generally accepted that this climate change is the result of increasing concentrations of carbon dioxide, methane, nitrous oxide and other greenhouse gases (GHGs) in the atmosphere (IPCC, 2001a).

However, there are large uncertainties as to when and where climate change will impact on agriculture production and food security. Climate models can now simulate part of the natural climate variability well enough to give confidence in their projections of future changes outside the natural range (IPCC, 2001b). The latest predictions for the year 2100 are slightly higher than earlier ones and suggest that global average temperatures could progressively rise by up to 6°C under the business-as-usual scenario of the Intergovernmental Panel on Climate Change (IPCC). These predictions are less clear as to the magnitude and timing of the changes and impacts at the regional, subregional and national level, and this uncertainty will remain for some time to come (IPCC, 2001c). Continuing development of global circulation models (GCMs) since the IPCC's 1995 report has resulted in some markedly different conclusions regarding spatial and temporal shifts in climate. In some regions at least, e.g. in Europe, climate change impacts until 2050 seem likely to be less than those arising from natural variability (Hulme *et al.*, 1999), but there will be substantial differences within Europe (Parry, 2000).

It is generally agreed that agricultural impacts will be more adverse in tropical areas than in temperate areas. Developed countries will largely be beneficiaries: cereal productivity is projected to be higher in Canada, northern Europe and parts of the former Soviet Union compared with what it would have been in the absence of climate change. By contrast a number of today's poorest developing countries are likely to be negatively affected

(IPCC, 2001c). Here the next 50-100 years will see widespread declines in the extent and potential productivity of cropland (Fischer *et al.*, 2001) particularly in sub-Saharan Africa and southern Europe (Parry, 2000; Parry *et al.*, 1999). Some of the severest impacts seem likely to be in the currently food-insecure areas of sub-Saharan Africa with the least ability to adapt to climate change or to compensate for it through greater food imports.

Around the rising trend in average temperature and rainfall, interannual and seasonal variation will increase. This will result in more frequent and more intense extreme events, and in greater crop and livestock production losses. Climate variation is already the major cause of year-to-year fluctuations in production in both developed and developing countries, and of food insecurity in developing countries (FAO, 2001f). For the period up to 2030, alterations in the patterns of extreme events will have much more serious consequences for chronic and transitory food insecurity than shifts in the patterns of average temperature and precipitation. There is evidence that extreme events were already becoming worse towards the end of the 1990s, and there is rising confidence in projections that they will increase in frequency and severity well before 2030 (Easterling *et al.*, 2000; IPCC, 2001b, 2001c). These extreme events have a disproportionately large impact on the poor because their crops, livestock, homes, food stores and livelihoods are at risk from floods and droughts and they have few or no savings to carry them through bad periods. Such impacts can be missed by GCMs operating at broad spatial and temporal scales, since extreme events commonly result in short-term and relatively localized food shortages that are masked by shifts in national production stemming from normal climate variability.

This chapter is devoted primarily to a review of climate change and food security issues and interactions. It examines how climate change may alter the agriculture and food security outcomes expected in the absence of climate change. The chapter's assessment of the possible impacts of climate change on food security should be considered in the context of the following limitations and assumptions. The time horizon of this study is 2030. This chapter therefore does not cover the 2050-2080 period during which the IPCC and others project increasingly serious climate-change-induced shifts in food production potential in currently food-insecure areas (IPCC, 2001a, 2001b; Fischer *et al.*, 2001). Thus, the modest impacts on aggregate food production proposed here are a reflection of the shorter time frame, rather than of any undue optimism about the longer-term situation.

The emission of GHGs by agriculture is discussed in Chapter 12. In this chapter, four other dimensions of the interaction between agriculture and climate change will be considered. First, agriculture's role as an important moderator of climate change through the sequestration of carbon in the soil and in long-lived products, and through the growing of biofuels to replace fossil fuels. Second, the positive and negative impacts of climate change on agricultural production and on natural ecosystems. Third, the implications for food security. Household and national incomes will generally be rising, allowing people to be less reliant on subsistence agriculture and more able to buy their food needs, and allowing countries to compensate for domestic food deficits through greater imports. However, a significant number of countries and communities may continue to be bypassed by development. Fourth, the clear need for changes to agricultural policies and technologies which in the short term could combat climate variability and natural resource degradation, but would also reduce or avoid possible food security impacts of future climate change, for example, NT/CA (see Chapter 11). Such measures have gained in importance now that carbon sink projects will qualify for credits under the clean development mechanism (CDM) of the Kyoto Protocol.

13.2 Agriculture as a moderator of climate change

Chapter 12 (Section 12.3.1) discussed the important role of agricultural activities as a driving force for climate change through the emission of GHGs. At the same time there is a growing appreciation of agriculture's positive contribution to climate change mitigation through carbon sequestration and the substitution of biofuels for fossil fuels. These contributions are likely to be of growing economic and environmental importance in the context of the Kyoto Protocol.

The benefits of carbon sequestration. In the past, attention has been focused on the role of forestry in carbon sequestration. This role will remain important in the future (see Chapter 6). In addition, however, crop and livestock production can also play a significant role through the sequestration of substantial amounts of carbon as soil organic matter (SOM) derived from crop residues, manure and better-managed grasslands. The additional benefits of this sequestration will diminish with time.

Global estimates of the potential contribution of cropland to carbon sequestration are in the range of 450-610 million tonnes of carbon p.a. (equivalent to some 1 640-2 220 million tonnes of carbon dioxide) for the next 20-30 years (GCSI, 1999). There is, however, considerable uncertainty about the potential gains from improved crop and livestock management practices (Lal and Bruce, 1999). In the United States changes in cropping practices (particularly conservation tillage and crop residue management, improved cropping systems and land restoration) could sequester about 140 million tonnes of carbon p.a. – nearly 10 percent of total United States emissions of all GHGs (Lal *et al.*, 1999). United States and United Kingdom studies show that permanent set-aside could sequester large amounts of carbon if it is forested or unmanaged (Cole *et al.*, 1996; Cannell *et al.*, 1999). Thus improved land management can enhance the role of agricultural soils as a major sink for carbon dioxide (CO_2) and as a compensating mechanism for agriculture's contribution to GHG emissions (Lal, Kimble and Follet, 1998) although it may be a decade or more before cultivated land is transformed from a net source to a net sink of carbon. Improved land management can therefore help countries to meet their obligations under international agreements to reduce net emissions of GHGs. Moreover, under the provisions of the CDM of the Kyoto Protocol, international support for improved land management to sequester carbon could also further sustainable agriculture and rural development (SARD) by providing other environmental and economic benefits (FAO, 2000c). The latter include reduced soil erosion and nitrate leaching, greater rainfall infiltration, higher soil moisture levels and lower energy costs.

Many of the required technological and land management changes could take place over the period to 2030. These could include shifts in land use, for example reversion of cropland in industrial countries to managed forests and pastures or to natural ecosystems as part of permanent set-aside; changes in cropping patterns, e.g. biomass cropping; adoption of NT/CA with improvements in tillage practices and residue management (see Chapter 11); better soil fertility and water management; and erosion control. All of these land management changes are based on known technologies and husbandry practices that have other benefits, including improved soil moisture availability to crops and higher yields, or reduced fossil fuel use as in the case of NT systems.

The crop production projections of this study, together with earlier FAO work on the biomass yield of different crops (FAO, 1978), give an estimate of the biomass of crop residues left in the field. Total global non-harvested residues (primarily crop stalks and roots) for 15 of the most important crops were around 4.7 billion tonnes p.a. in 1997/99 and are projected to rise to 7.4 billion tonnes by 2030. Depending on the region, these residues amount to between 2.4 and 6.2 tonnes per harvested hectare. These values are higher than those used for other global estimations (Lal and Bruce, 1999), but similar to those found in studies for Australia, Canada and the United States (Dalal and Mayer, 1986; Douglas *et al.*, 1980; Voroney, van Veen and Paul, 1981). Under tropical conditions, residues can be much higher. Cowpeas, for example, produce up to 24 tonnes of residues per ha (Diels *et al.*, 1999).

There are significant crop and regional differences in the proportion of crop residues that are left on the soil surface or incorporated in it. For most crops it is assumed that 25-50 percent of residues are returned to the soil as organic matter, and that half of this biomass is carbon. With these assumptions, gross carbon sequestration by the 15 crops could rise from 620-1 240 million tonnes p.a. to 960-1 910 million tonnes p.a. by 2030 (Table 13.1). If this is scaled up to include the harvested area for the remaining crops, the global estimate for 2030 rises to 1 170-2 330 million tonnes of carbon. Taking into account that these estimates refer to gross carbon sequestration, they are fairly close to other recent estimates (GCSI, 1999; Lal and Bruce, 1999; Batjes, 1999).

These estimates do not take account of the potential gains from NT/CA or from improved soil

Table 13.1 Estimated gross carbon sequestration per year by cropland soils

	Total carbon (million tonnes)		Carbon (tonnes/ha)	
	1997/99	2030	1997/99	2030
Sub-Saharan Africa	34-67	74-147	0.30-0.60	0.47-0.95
Latin America and the Caribbean	62-124	110-220	0.66-1.33	0.83-1.65
Near East/North Africa	27-54	46-91	0.52-1.04	0.75-1.50
South Asia	97-194	168-337	0.53-1.07	0.87-1.73
East Asia	182-363	267-534	0.84-1.69	1.17-2.34
Industrial countries	168-336	227-455	0.90-1.80	1.16-2.32
Transition countries	49-97	64-128	0.45-0.90	0.53-1.05
World	618-1 236	956-1 912	0.65-1.30	0.88-1.76

Source: FAO calculations.

erosion control. However, the switch to NT/CA systems, which started in the late 1960s in developed countries and in various developing countries in the 1970s, could add to the amount of carbon sequestered (Friedrich, 1996; Derpsch, 1998). The gains vary according to agroclimatic conditions: 0.5-1.0 tonnes of carbon/ha/p.a. in the humid temperate areas, 0.2-0.5 in the humid tropics and 0.1-0.2 in the semi-arid zones (Lal and Bruce, 1999). The NT/CA area grew very rapidly over the last few years, but compared to total arable land the area is still small. There are large areas of South and East Asia where NT/CA could be applied but as yet it is hardly used. On the Loess Plateau of China, for example, its use is barely out of the experimental stage, yet it could help to sequester some 4 million tonnes of carbon p.a. (CCICED, 1999).

Assuming that another 150 million ha of rainfed cropland will be using NT/CA by 2030, sequestering 200-400 kg carbon/ha/p.a. (Lal *et al.*, 1999), this would represent a further 30-60 million tonnes carbon/p.a. There would also be other environmental benefits in the form of reduced soil erosion and better water retention, plus savings in fossil fuel use (Frye, 1984). Even greater gains of 500-800 kg carbon/ha/p.a. could be achieved where marginal cultivated land is taken out of crop production and replaced by grass or legume forages (Lindwall and Norse, 2000). Moreover, degraded land that has gone out of production or contributes little to food security, e.g. saline soils, could be restored to sequester carbon at the rate of 100 kg/ha/year in temperate areas and 200-300 kg/ha/p.a. in tropical and subtropical areas (Lal, Kimble and Follet, 1998; GCSI, 1999). The total area of saline soils that could be restored to boost carbon sequestration is over 126 million ha (GCSI, 1999). Assuming that 2 million ha of saline lands are restored each year over the next 30 years, the total carbon sequestered each year could be about 12 million tonnes by 2030.

The rates of carbon sequestration presented above are only order of magnitudes. Potential rates of carbon sequestration in response to improved management vary widely as a function of land use, climate, soil and many other factors. The rate of sequestration gradually declines before reaching a limit and can be especially high during the first few years. As a result, short-term studies tend to overestimate the rate of carbon sequestration. For some of the activities sequestering carbon it may take 40 to 100 years before saturation levels are reached. However, the IPCC considers the estimates for most of these to be less reliable than estimates about many of the activities sequestering carbon over shorter periods. For NT/CA sequestration is particularly high during the early years. Should conventional tillage be reintroduced though, the sequestered carbon will be rapidly released (FAO, 2001h). Nonetheless, agricultural carbon sinks are needed to “buy time” in coping with CO_2 emissions.

Potential contribution of biofuels. Biofuels used for cooking and heating already make a significant contribution to GHG reduction. However, there is considerable uncertainty about the future rate of substitution of renewable biofuels for fossil fuels. The technological potential and environmental benefits are clear, and some modelling exercises have projected large increases in the area under biofuel crops. The uncertainty stems from economic and political factors. For the foreseeable future, the energy from biofuel crops will continue to be more expensive than that from fossil fuels. If, however, carbon taxes were imposed on fossil fuels so that their cost to consumers included the external costs of their use, including the costs of climate change, then biofuels would be much more competitive. In addition, if more governments introduced positive discrimination for biofuels, then their production could expand rapidly and make a significant contribution by 2030.

13.3 Climate change impacts on agriculture

13.3.1 Climate change to 2030

Global average temperatures are projected to rise by about 1°C by 2030 (i.e. well outside the natural range). Higher latitudes will warm more rapidly than lower ones, land areas will warm more rapidly than the oceans, and polar sea ice will decrease more in the Arctic than in the Antarctic. Consequently, average temperatures in the higher latitudes may rise by 2°C, possibly double the increase in the tropics. Projected changes in precipitation show even greater regional differences, with major grain-producing areas of South America showing increases and parts of Central America and South Asia suffering from decreased precipitation and higher soil moisture deficits (IPCC, 2001b).

Broadly speaking, climate change is projected to increase global mean precipitation and runoff by about 1.5 to 3 percent by 2030 (IPCC, 2001b). There will be greater gains in the higher latitudes and the equatorial region but potentially serious reductions in the middle latitudes. Parts of Central America, South Asia, northern and southern Africa and Europe could suffer appreciable falls in available water resources. Moreover, there could be significant subregional differences, e.g. northern and southern Europe are projected to undergo significant shifts in climate-change-induced runoff but not western and central Europe (Hulme *et al.*, 1999). Estimation of the impact of changes in precipitation is further complicated by the interplay of two effects: changes in precipitation and rises in water-use efficiency associated with the CO_2 fertilization effect.

13.3.2 Impacts on agriculture

Climate change will have a range of positive and negative impacts on agriculture. Up to 2030 the greatest impacts could come from increased frequency and intensity of extreme events. Climate variability is currently the dominant cause of short-term fluctuation in rainfed agricultural production of sub-Saharan Africa and South Asia, and substantial areas of other developing regions. The most serious form is drought, when rainfall drops substantially below the long-term mean or fails at critical points in crop development. In semi-arid and subhumid areas, these rainfall deficits can dramatically reduce crop yields and livestock numbers and productivity. Such fluctuations can be countered by investment in irrigation or by food imports, but these options are not always open to low-income countries or remote regions. Indeed, the availability of water for irrigation may be reduced by the increased frequency and intensity of droughts together with long-term changes in surface water runoff or evapotranspiration, and this may reduce irrigated food production.

Although semi-arid and subhumid areas are generally the ones given the most attention in climate impact studies, humid areas are also vulnerable to climate variability. They can suffer from changes in the length of the growing season (Wilkie *et al.*, 1999) and from extreme events, notably tropical cyclones causing damage from high winds and floods. Such disasters are shorter-lived and more localized than those associated with droughts and other forms of climate variability and so fewer people may be affected. However, the consequences for their food security can be equally severe. Not only do they lose current crops and livestock, but in cases where perennial trees are lost or spawning grounds seriously damaged, they also lose future crops and fish catches. They may lose their stored food, homes and possessions, including irrigation infrastructure, livestock and tools, so that the negative consequences on food security may be felt for several years after the event. On the other hand, since these extreme events are relatively localized, other crop-producing areas within the same country can often provide the food needed in affected areas.

Recent research has suggested that some impacts of climate change are occurring more rapidly than previously anticipated (IPCC, 2001c). The impacts will stem primarily from:

- regional temperature rises at high northern latitudes and in the centre of some continents;
- increased heat stress to crops and livestock, e.g. higher night-time temperatures, which could adversely affect grain formation and other aspects of crop development;
- possible decline in precipitation in some food-insecure areas, such as southern Africa and the northern region of Latin America, although the main impacts will occur after 2030;
- increased evapotranspiration rates caused by higher temperatures, with lowering of 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 – a trend that is already apparent (Easterling *et al.*, 2000);
- changes in seasonal distribution of rainfall, with less falling in the main crop growing season;
- sea level rise, aggravated by subsidence in parts of some densely populated flood-prone countries;
- food production and supply disruption through more frequent and severe extreme events.

These impacts fall into three main groups, i.e. direct and indirect impacts of climate change *per se*, and impacts from enhanced climate variation (extreme events), though with a degree of overlap.

13.3.3 Direct impacts – changes in temperature and precipitation

Crops. Changes in temperature and precipitation will bring changes in land suitability and in crop growth. The projected net effect will be an increase in the area of land in higher latitudes suitable for crop production, because of milder and shorter winters, but a decrease in land suitability in arid and semi-arid areas. The changes will be qualitative as well as quantitative. In the East African highlands, higher temperatures may result in land becoming unsuitable for wheat but more suitable for other grains. The effects on potential yields will follow the same pattern as land suitability, with yield gains in middle to higher latitudes and losses in the lower latitudes. There may be some gains in tropical highlands where at present there are cold temperature constraints.

The overall effects of climate-induced changes in land and crop suitability and yields are small compared with those stemming from economic and technological growth. By 2020 world cereal production might be only about 0.5 percent less than what it would have been in the absence of climate change (IPCC, 2001c; Parry *et al.*, 1999), although this decline might be much greater by 2050 or later. The largest regional reduction would be in Africa where cereal production is projected to decline by 2-3 percent. This potential fall could be compensated by a relatively small increase in yields or imports. But this regional picture hides important subregional differences. Parts of central and northern Africa may experience small increases in cereal yields.

The rise in atmospheric concentrations of carbon dioxide not only drives global warming but can also be a positive factor in tree and crop growth and biomass production. It stimulates photosynthesis (the so-called CO_2 fertilizer effect) and improves water-use efficiency (Bazzaz and Sombroek, 1996). Up to 2030 this effect could compensate for much or all of the yield reduction coming from temperature and rainfall changes. Recent work for the United States suggests that the benefits from CO_2-induced gains in water-use efficiency could continue until 2095 (Rosenberg *et al.*, 2001).

Forestry. As with crop production, CO_2 fertilization effects will combine with those of climate change. This will make it difficult to determine net impacts on forestry, but these effects are likely to be small before 2030. The developed countries seem likely to be the major beneficiaries. Given the higher temperatures at high latitudes and the CO_2 fertilization effect, boreal and north temperate forests in North America, northern Asia and Europe and parts of China are likely to grow more rapidly before 2030. Tropical forests may decline in area and productivity, because of decreased rainfall and higher temperatures, with some loss of biodiversity. However, dieback of tropical forests, i.e. progressive death from environmental or pest causes, could be a concern in parts of northern South America and central southern Africa (Hadley Centre, 1999).

Livestock. Some grasslands in developing countries are projected to deteriorate progressively as a result of increased temperature and reduced rainfall but this is unlikely to occur until after 2030 (DETR, 1997). Much of this grassland is of moderate or low productivity and is in any case projected to decline in importance with the continued shift to intensive livestock production systems in more humid areas (see Chapter 5). Of more significance to livestock production is the rise in temperature over the period to 2030, and the CO_2 fertilization effect. These will favour more temperate areas (i.e. primarily the developed countries but also Argentina and China) through reduced need for winter housing and for feed concentrates (because of higher pasture growth). Many developing countries, by contrast, are likely to suffer production losses through greater heat stress to livestock. Fodder and forage yields may be lower because of reduced precipitation but this may be compensated by the CO_2 fertilization effect.

Fisheries. Some of the earliest negative impacts may be on fisheries rather than on crops. There are three impacts of concern: higher sea temperatures, changes in ocean currents and sea level rise (discussed below). Most of the effects will occur after 2030 or even 2050, but may intensify greatly thereafter (IPCC, 2001c).

Average sea temperatures in northern latitudes are already rising rapidly (in particular in the North Sea). Sea temperature rise can disrupt ocean currents and fish breeding patterns. It can reduce surface plankton growth or change its distribution, thereby lowering the food supply for fish, and cause the migration of mid-latitude species to northern waters (Reid *et al.*, 2000).

The net effect may not be serious at the global level but could severely disrupt national and regional fishing industries and food supplies. It is already a serious issue in Europe, where climate-change-induced impacts on cod populations could compound the effect of current overfishing in the North Sea, causing permanent damage to fish stocks if no action is taken (O'Brien *et al.*, 2000). In middle and southern latitudes coral bleaching and destruction through higher water temperatures could damage important fish breeding grounds.

13.3.4 Direct impacts – sea level rise

Sea level rise induced by global warming could lead to loss of land through flooding and saltwater intrusion, and damage to mangrove swamps and spawning grounds. Sea levels are rising at about half a centimetre p.a., and are likely to continue at this rate for several decades even if there is rapid implementation of international agreements to limit climate change. Thus sea levels could be 15-20 cm higher by 2030 and 50 cm by 2100 (IPCC, 2001b), increasing the flood risk in large parts of South and East Asia and placing populations and agriculture at risk (Gommes *et al.*, 1998). Three valuable production systems will be most affected: vegetable production that tends to be irrigated and heavily concentrated around urban areas threatened by saltwater intrusions; aquaculture systems sited in areas at or below sea level; and coastal fisheries dependent on spawning grounds in mangrove swamps and other coastal wetlands threatened by sea level rise, although some adjustment might take place through sediment deposition and the accumulation of organic matter.

Because tropical cyclones will increase in frequency and intensity, there will be more extreme high-water events and more severe storm surges penetrating further inland (IPCC, 2001a; Nicholls, Hoozemans and Marchand, 1999). Although most impact assessments have been on gradual sea level rise, these sea surges may pose the greatest risk to food security. Nicholls, Hoozemans and Marchand (1999) conclude that by 2080 the number of people vulnerable to flooding from sea surges in a typical year will be five times greater than those vulnerable to sea level rise. Earlier work suggests that 90 percent of these vulnerable people would experience flooding on an annual basis (Baarse, 1995). Migration to coastal zones because of the better employment opportunities associated with urbanization and industrialization and the overextraction of groundwater in urban areas will compound the problem. In Bangkok, for example, these trends have led to marked subsidence (up to several metres in the last century).

Even without climate change, population growth and urbanization will increase the number of people at risk from coastal flooding, possibly from about 200 million in 1990 to nearly 500 million by 2030 (Nicholls, Hoozemans and Marchand, 1999). Sea level rise alone will not raise this number substantially by 2030, but other expected developments, involving serious interactions between river flooding and sea level rise, could do so. These include greater river runoff because of increased precipitation inland, reduction of river width through siltation and urban and industrial development, and an increase in storm surges penetrating further inland (Arnell, 1999).

13.3.5 Indirect impacts

Indirect impacts operate primarily through effects on resource availability, notably water resources, and on ecosystems as they respond to shifts in temperature and precipitation; and through the loss of biodiversity, although the latter will have little impact by 2030.

Large changes are predicted in the availability of water resources because of reductions in runoff and groundwater recharge. Substantial decreases are projected for Australia, India, southern Africa, the Near East/North Africa, much of Latin America and parts of Europe (Hadley Centre, 1999). The main decrease will be after 2030 but there could be negative effects on irrigation in the shorter term. Moreover, the greater frequency of summer droughts in the interior of mid-latitude continents could raise the incidence of wildfires.

There will be changes in the distribution and dynamics of major pests. Although only small average temperature changes are projected to 2030, they are nonetheless large enough to bring about substantial shifts. In addition, fewer cold waves and frost days could extend the range of some pests and disease vectors, and favour the more rapid buildup of their populations to damaging levels.

Much of central and northern Europe could become more vulnerable to important pests and diseases such as Colorado beetle of potatoes and Karnal bunt of wheat (Baker *et al.*, 1999) as they expand their range north. Although control measures are known for these diseases there will still be some yield loss and associated production input and environmental costs. However, this is not just an issue for temperate areas. In subtropical Australia temperature rises up to 2 °C could favour the spread of the Queensland fruit fly and force production to shift substantially southwards (Sutherst, Collyer and Yonow, 1999).

The important changes in pest dynamics are increases in pest carryover (particularly overwintering in temperate regions) and population dynamics, since the life cycles of some major pests are extremely dependent upon temperature (Gommes and Fresco, 1998). Higher temperatures may foster larger pest populations, and may extend the reach of insect carriers of plant viruses, as in the case of aphids carrying cereal viruses, which are currently held in check by low winter or night temperatures. No attempt has been made to quantify these losses but they could be appreciable in terms of lower yields and higher production costs.

Finally, greater temperature extremes seem likely to give rise to higher wind speeds, and there may be increases in the occurrence of hurricanes. This will result in greater mechanical damage to soil, plants and animals; impacts on plant growth from greater wind erosion and sandblast damage; and drowning of livestock. Natural resource management decisions, both on the farm and at national level, could reduce or intensify the impacts of these factors on food security. For example, concerted efforts to promote IPM could lessen the impact of pest and disease outbreaks. Conversely, poor land management practices and inadequate protection for the diversity and stability of ecosystems could aggravate soil erosion and other damage.[1]

13.4 Implications of climate change for food security

13.4.1 Introduction

Up to 2030 the impact of climate change on global food production may be small, within the range

---

[1] In the case of hurricane Mitch in Honduras in 1998, where over 50 percent of agricultural infrastructure and production was reportedly severely affected or completely destroyed, human factors such as large-scale deforestation, the cultivation of marginal lands without soil conservation practices and a lack of adequate watershed management were largely blamed for severely compounding the effects of the hurricane. The Lempira Sur region, utilizing a diverse agroforestry farming system, suffered less damage than the rest of Honduras and was able to provide food aid for other parts of the country.

that normal carryover stocks, food aid and international trade can accommodate. During the 1992/93 drought in southern Africa, for example, crop production in some countries was reduced by as much as 50 percent. Yet there was no famine (Chen and Kates, 1996), and the negative food security impacts were relatively short-lived, although serious for some communities. National and international action was able to limit the increase in the numbers of undernourished. Nonetheless, Parry *et al.* (1999) consider that the 2-3 percent reduction in African cereal production they project for 2020 is sufficient to raise the numbers at risk from hunger by some 10 million people.

However, food security depends more on socio-economic conditions than on agroclimatic ones, and on access to food rather than the production or physical availability of food (FAO, 2001c; Smith, El Obeid and Jensen, 2000). Therefore, the implications of climate change for food security are more complex than the relations used by most of the current impact assessments. Future food security will be determined largely by the interplay of a number of factors such as political and socio-economic stability, technological progress, agricultural policies, growth of per capita and national incomes, poverty reduction, women's education, drinking-water quality (Smith and Haddad, 2001), and increased climate variation.

It is important to be clear about the respective roles and relative contributions to food security of these factors, and how they interact. For example, poverty is a major factor in food insecurity (FAO, 2001a), and urbanization can play an important role in improving physical access to food during serious droughts, although there are a number of positive and negative factors involved (FAO, 2000d). Urban wages are generally above rural wages, but urban food and housing costs can be higher, so actual food purchasing power in urban areas might in some cases be lower. Up to 2030 or even 2050, projected growth in incomes, urbanization and crop production for developing countries are likely to have a much greater impact on food security than the effect of climate change in reducing average cereal yields or the area suitable for grain production (Fischer *et al.*, 2001).

However, there will be problems arising from increased climate variability. Climate change may affect, for example, the physical availability of food from production by shifts in temperature and rainfall; people's access to food by lowering their incomes from coastal fishing because of damage to fish spawning areas from sea level; 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.

In food-insecure countries, there is often a large seasonal as well as interannual variation in the ability of people to grow or purchase food. In parts of Africa, there is the so-called "hungry season" prior to the new harvest, when grain prices tend to rise substantially as stocks fall and lead to temporary food insecurity. Such features are lost in the annual or seasonal averages of most analyses of long-term food production and climate change impacts on agriculture, but they are important in determining people's ability to purchase food.

There is also the question of spatial variation of climate impacts, and the level of countries' ability or inability to exploit this to overcome local food production deficits. Inability generally stems from weaknesses in infrastructure or institutions, although it is reasonable to project improvements in these respects over the next 30 years. These features are not captured in climate impact assessment models, yet they are very important since quite large negative impacts on production from climate change will not necessarily result in diminished food security. Large countries such as India and China contain a range of agroclimatic situations, and droughts and floods in one area can be compensated by production from unaffected areas and carryover stocks. Thus, when parts of northeast and central China were seriously flooded in 1998, local food production losses were readily replaced by food from elsewhere. In countries in which agriculture is a small proportion of GDP, any food deficits from extreme events can normally be covered by imports, and by 2030 it is expected that more countries will be in a position to compensate for climate change impacts on domestic food production by imports from elsewhere.

13.4.2 Socio-economic developments and vulnerability to climate change

Given the above, it is necessary to examine food security in the context of the future agricultural and wider economic situation, which is likely to be quite different from today's in a number of respects. One only has to look back 30 years to see the need for this. For example, in the 1970s Bangladesh was being classified as incapable of functioning properly and with little hope of survival, and South Asia, particularly India, was considered to be the most food-insecure region, whereas sub-Saharan Africa was thought to have better food prospects (IFPRI, 1977). In reality, during the last decades sound agricultural policies, investment in irrigation, etc. have enabled Bangladesh and India to overcome their large food production deficits, whereas sub-Saharan Africa suffered from poor agricultural performance and prolonged food shortages for much of the same period.

Looking ahead 30 years, a number of today's food-insecure countries seem likely to have overcome their food production or food access problems, with much of the remaining food security problem concentrated in sub-Saharan Africa (see Chapter 2). Given the relatively high economic growth projected for most Latin American and Asian countries, they should be able to overcome any negative impacts of climate change on food production by increasing food imports. This demonstrates that it is not enough to assess the impacts of climate change on domestic production in food-insecure countries. One also needs to (i) assess climate change impacts on foreign exchange earnings; (ii) determine the ability of food-surplus countries to increase their commercial exports or food aid; and (iii) analyse how the incomes of the poor will be affected by climate change.

No matter how the climate changes, any impacts will be on a food security situation very different from the present. The structure of most developing economies will have shifted closer to that of today's developed countries. Food production will have changed in response to new technologies and changes in comparative advantage. Food consumption and food security will have changed because of shifts in consumer preferences and higher per capita incomes.

Economic growth in non-agricultural sectors and an increase in urbanization and non-agricultural employment will make people's incomes less dependent on agriculture. People may have easier and more reliable access to food during extreme events and thus become less vulnerable to climate change. The increasing role of home remittances in raising the food purchasing power of the rural poor has reduced seasonal and long-term food insecurity. This has been particularly the case in sub-Saharan Africa, where 20-50 percent of rural incomes now commonly come from off-farm sources, and increasing amounts of food are purchased rather than home produced (FAO, 1998d; Reardon, Matlon and Delgado, 1994; UNSO, 1994; Turner, 2000). This situation is likely to continue for the next 30 years. Provided government policies and infrastructural improvements allow food imports to flow readily to drought-affected and other natural disaster areas, their food security situation will become less dependent on local production. Fewer people will be vulnerable, as long as prices do not go up (although this is unlikely, as discussed in Section 13.4.5).

13.4.3 Climate change and crop production

Cereal yields play a key role in the food security of the poor. Recent estimates suggest that, relative to the no climate change situation, yields could change by -5 to +2.5 percent depending on the region (Table 13.2). In many but not all countries it may be possible to overcome this by expanding cultivated land, because there are still substantial suitable areas that could be brought into cultivation (Chapter 4). Furthermore, very small and quite feasible annual improvements in yields could compensate for a potential 5 percent yield reduction from climate change (Chapters 4 and 11), although in the regions facing the most negative potential impacts, yield increases were hard to realize in the past.

The regions and countries where food security is most at risk from sea level rise include South Asia, parts of West and East Africa, and the island states of the Caribbean and Indian and Pacific Oceans. They include deltaic areas that are difficult and costly to protect, yet play an important role in food production, e.g. in Bangladesh, Myanmar, Egypt, India, Thailand and Viet Nam. The concerns for food security are particularly great where farm sizes are already too small to provide adequate subsistence and where conversion of uplands to food production cannot compensate for the loss of coastal land. A number of the areas at

Table 13.2 Potential changes in cereal yields (percentage range, by region)

	2020	2050
Sub-Saharan Africa		
Sahel and southern Africa	-2.5 to 0	-5 to +5
Central and East Africa	0 to +2.5	-5 to +2.5
Latin America and the Caribbean		
Tropics and subtropics	-2.5 to 0	-5 to -2.5
Temperate	0 to +2.5	0 to +2.5
Near East/North Africa	-2.5 to +2.5	-5 to +2.5
South Asia	-2.5 to 0	0 to -5
East Asia	-2.5 to +2.5	-2.5 to +2.5
Canada and the United States	-5 to +2.5	-10 to 0

Source: Parry *et al.* (1999).

risk are in low-income countries that may not undergo appreciable economic development over the projection period, and so might find it difficult to undertake the necessary protective investments (Nicholls, Hoozemans and Marchand, 1999).

Three factors will affect food security: the loss of cropland and nursery areas for fisheries by inundation and coastal erosion; saltwater intrusion; and flood damage to crops and food stores. Each of these will eliminate livelihoods and lower agricultural production and incomes.

The loss of cropland could be substantial. India, for example, has more than 6 500 km^2 of low-lying coastal land, much of which is cultivated. Asthana (1993) estimated that a 1-metre sea level rise in India would result in the loss of some 5 500 km^2. Rises of this magnitude are not foreseen before 2100 according to the IPCC's latest estimates. Losses by 2030 could be from 1 000 to 2 000 km^2. Assuming an average farm size of 1.5 ha this could represent the loss of some 70 000 to 150 000 livelihoods. In the case of Bangladesh a similar rate of sea level rise by 2030 could result in the loss of 0.8-2.9 million tonnes of rice p.a., offsetting yield gains arising from changes in temperature, precipitation and atmospheric CO_2 concentration (Asian Development Bank, 1994).

The inland movement of saltwater into the aquifers used for irrigation, with negative impacts on crop yields, is already of significant proportions in some North African countries because of excessive extraction of groundwater, and it will be intensified by sea level rise. Yet over the next 30 years much could be done to overcome this problem, e.g. by the introduction of new GM varieties of wheat, rice, oilcrops and green vegetables that are tolerant to saline conditions (see Section 13.5). However, yield losses may also occur through physical-chemical damage to the soil by salinization, so other measures will be required. Nonetheless, the food security impacts of saltwater intrusions could be quite small if appropriate policy and technology changes are made.

Flood damage to crops and food stores could be important at the national, local and household level: at the national level, in cases where agriculture is the main source of export revenues to pay for the imports of the development goods essential for economic growth, and of food to cover shortfalls in domestic production; locally, if public or private food stores are destroyed, shortages and higher prices can be expected; and at the household level, where season-to-season storage of food is essential to insulate families from pre-harvest price rises.

13.4.4 Implications for livelihoods and incomes

Food insecurity is in most cases caused by poverty. Food purchasing power depends on a person's income level and on food prices. For farmers, incomes depend mainly on the quantity and quality of the natural resources they have to produce food. Consequently, any impact of climate change on land and water resources, on agricultural and non-agricultural livelihoods, and on the prices of food or of other agricultural commodities sold to purchase food could have an important impact on food security. With the possible exception of sub-Saharan Africa, it seems doubtful that climate change will have an appreciable impact on agricultural livelihoods and incomes over the period to 2030. The wide range of domestic and international factors governing national economic performance could swamp any small effects resulting from climate change.

However, climate change will have some adverse effects on incomes and income distribution. A number of groups are particularly vulnerable, namely: low-income groups in drought-prone areas with poor food distribution infrastructure; low- to medium-income groups in flood-prone areas who may lose stored food and possessions; farmers whose land is submerged or damaged by sea level rise or saltwater intrusions; fishers who suffer falling catches from shifts in ocean currents, or flooding of spawning areas or fish ponds; and food or export crop producers at risk from high winds.

On the other hand, some of the short- to medium-term negative impacts on food security may lead to positive outcomes in the longer term. For example, increasing aridity may accelerate the migration of low-wage agricultural workers to urban centres where wages are higher and there is more secure access to food markets.

Increased frequency of extreme events could have substantial impacts on the economic performance of some countries and regions, and on transitory food insecurity. The Mozambique floods of 2000, for example, have been estimated by the World Bank to have reduced economic growth by 2 to 3 percentage points, and caused damage in excess of total export earnings. The 1998 floods in China caused over US$100 billion damage, and for the main provinces affected, the damage amounted to the equivalent of 3 to 4 percent of their GDP. Cambodia suffered similar economic losses from floods in 2000. In each case the number of people considered to be transitory food insecure increased ten to 100-fold or more. However, their recovery normally took place within months (FAO/GIEWS, 2000a) and the overall impact on national food production was quite small because of good harvests in other areas or seasons.

Finally, it is important to consider how policy responses to climate change could affect livelihoods and incomes. This aspect could become of increasing importance through the CDM and efforts to substitute fossil fuels by renewable ones, opening up new opportunities for job creation and income improvements. First, carbon sequestration and trading in carbon emission permits could improve the overall sustainability of agriculture (see Section 13.2). They could raise farm incomes and create new agricultural livelihoods. There could be growing competition for land and labour resources in some areas between biofuel production, carbon mitigation activities and food production, but such impacts are likely to be small over the next 20-30 years. Second, new non-fossil energy systems, particularly wind power, could provide marginal areas such as the slope lands of southwest India with new livelihoods and lower energy prices for rural electrification.

13.4.5 Implications for food prices

The analysis in Chapters 3 and 9 suggests that, independently of climate change, real world market agricultural prices will remain more or less constant or decline slightly over the projection period.

Climate change to 2030 may reduce the costs of crop and livestock production in some temperate areas, according to IPCC projections (IPCC, 2001b), for example, from milder winters, longer growing seasons and the reduced need for winter concentrate feeds for livestock. In contrast, some humid tropical and semi-arid areas of developing regions may face rising production costs, e.g. because of rice yield declines from higher night temperatures, higher irrigation costs and salinization induced by sea level rise.

The net effect of these regional differences could be downward price pressures in developed countries and upward pressures on prices in developing countries, but in both cases the movements in real prices would be relatively small to 2030. Parry *et al.* (1999) conclude that (other factors remaining equal) climate-induced cereal yield declines could push up global prices in 2020 by about 5 percent (and by implication much more in parts of Africa), with substantially greater rises by

2050-2080. Cereals tend to be more sensitive to climate change than other food crops, and many developing countries are growing net importers of cereals. Therefore they could become more vulnerable to climate-induced increases in grain prices.

However, most studies suggest that in the short term the net impact of climate change on current cereal areas is likely to be positive and in the longer term the area suitable for cereal production could expand considerably (IPCC, 2001c; Fischer *et al.*, 2001). Hence, even in the context of climate change, world market prices for cereals are likely to remain relatively stable. In addition, price developments may be partly offset through the implementation of present and future WTO Agreements on Agriculture. The gap between international and national prices should narrow, so that movements in national prices should follow movements in world market prices more closely. National and local prices, however, will still be perturbed by extreme events and more direct international to domestic price links will moderate these fluctuations but not eliminate them.

Technological change and infrastructural improvements allowing better flows of food from surplus to deficit areas could also offset some of the pressure on national and local prices. Given the slow progress of the last decades, however, there is great uncertainty whether all of the required national and regional infrastructural improvements will take place over the next 30 years. In south Mozambique, for example, maize prices in the spring of 2000 increased rapidly because of food shortages following the floods. At the same time, however, maize prices in north Mozambique were about half those in the south and declining. Yet the high transport costs from the north to the south made it cheaper to import maize from South Africa (FAO/GIEWS, 2000b).

Extreme events affect food prices in characteristic ways: price increases can be very rapid and large, particularly where both household and commercial stocks are lost, and transport is disrupted; price changes can be very localized, with appreciable differences between urban and rural areas with restricted access to outside supplies; and price increases can be short-lived, i.e. weeks rather than months. These points show how critical general economic development will be in reducing the vulnerability of countries to climate change and to increased frequency and intensity of extreme events.

It is important to bear in mind that changes in international commodity prices estimated by the models used for climate change impact studies do not necessarily relate closely to the food prices actually paid by consumers and hence to the ability of low-income groups to purchase their food needs. For example, bread is increasingly a purchased good rather than a home-baked food even for the rural poor, and the cost of the cereal may be less than 25 percent of the purchase price, with the rest coming from processing, distribution and marketing costs (Norse, 1976). Hence, even if climate change increases farmgate or international food prices over the next 30 years, this increase may have a much smaller impact on consumer prices, and limited effects on the food security of those low-income groups that purchase most of their food from the retail sector.

13.5 Technology and policy options

Many of the actions required to mitigate or to adapt to climate change can also be justified in terms of present needs. Many do not require large capital investments, and can be appropriate for poor smallholders as well as large farmers. They do not have to be justified on the basis of the uncertain economic benefits of lowering some climate change impacts. For example, improved water conservation would help to overcome current aridity as well as reduce the impact of any future deterioration in rainfall. Most of the actions would also contribute to the wider objective of alleviating poverty and improving access to food rather than just safeguarding the production of food.

13.5.1 Greenhouse gas reduction and abatement

The priority actions to lower agriculture's role as a driving force for climate change are clear from Section 12.3.1 in Chapter 12: reduction of methane and nitrous oxide emissions from mineral fertilizers, manure, livestock wastes and rice production. The wider benefits are also clear, e.g. lower production costs through greater fertilizer-use efficiency and better waste recycling, and reduced air and water pollution. The policy response options in the agrochemical sector include removing any subsidies on energy inputs and introducing carbon taxes to promote energy-use efficiency in fertilizer and pesticide production.

Other policy options include general actions to promote sustainability through conservation agriculture, together with specific measures such as environmental taxes on nitrogen fertilizers; promotion of precision placement and better timing of fertilizer and manure applications; development of rice cultivars emitting less methane; adoption of direct seeding and better water management for rice to reduce methane emissions; better feed quality for livestock; improved livestock waste management; promotion of biofuel crops to replace fossil fuels; and expansion of agroforestry.

13.5.2 Climate change impact mitigation and adaptation

Several actions need to be taken to mitigate and adapt to climate change. First, comprehensive support mechanisms must be formulated to help farmers adapt to climate change and to increase production under more variable conditions. Such mechanisms could include approaches to crop production which improve the resilience of farming systems.

Second, given the probability of higher incidence of drought, aridity, salinity and extreme events, greater priority will need to be given to the following measures:

- maintenance, both onsite and offsite, of a broad genetic base for crops and development and distribution of more drought-tolerant crop varieties and livestock breeds;
- breeding for greater tolerance of crops, livestock and fish to higher temperatures;
- development of salt-tolerant varieties of wheat, rice and oilcrops;
- improving the resilience of agricultural ecosystems by promoting NT/CA and practices such as agroforestry that utilize and maintain biological diversity;
- raising the efficiency of rainwater use and groundwater recharge by conservation agriculture, etc. and that of irrigation water by appropriate pricing policies, management systems and technologies;
- supporting pastoral and other livestock production systems, many of which are already food insecure. Activities should be centred on maintaining livestock mobility and providing location-specific investment in supplementary feed production, veterinary services and water supply (Sandford, 1995), and on improving the marketing of livestock during droughts and making it easier to restock after droughts or floods; and
- developing improved sea defence and flood management systems in sea level rise and storm surge situations, where these are economically viable.

All these actions have the benefit of helping to ameliorate the impact of current climate variation as well as countering future adverse effects of climate change.

13.5.3 Reducing or avoiding food security impacts

The IPCC now expresses high confidence in the projected increase in the frequency and intensity of relatively localized extreme events including those associated with El Niño, notably droughts, floods, tropical cyclones and hailstorms (IPCC, 2001b). The impacts of these increases will fall disproportionately on the poor (see Box 13.1).

All developing regions are considered by the IPCC to be vulnerable to increased droughts and floods. These extreme events could pose significant threats to food security, requiring policy action and investment both outside and within the agricultural sector.

For many countries the key to reducing food insecurity will be better disaster preparedness planning, although actions to lower the sensitivity of food and agricultural production to climate change will clearly be important to cope with the longer-term impacts of climate change. Many of the actions in response to drought and sea level rise should be conceived on the pattern of disaster management strategies being developed to reduce agricultural vulnerability to tropical storms (FAO, 2001g). The objectives of such strategies include avoiding or minimizing death, injury, lack of shelter and food shortages, loss of property or livelihoods of poor households, and preparing funding and procedures for large-scale relief and rehabilitation. Such strategies may be implemented through:

- the development of early warning and drought, flood- and storm-forecasting systems;
- preparedness plans for relief and rehabilitation;
- introducing more storm-resistant, drought-tolerant and salt-tolerant crops;
- land use systems that stabilize slopes and reduce the risk of soil erosion and mudslides;
- constructing livestock shelters and food stores above likely flood levels;
- equipping fishers with communication systems and safety devices so that they can benefit from early storm warnings, and credit systems so they can quickly replace any lost boats or equipment.

13.6 Conclusions

The projections of this study point to the likelihood of an appreciable increase in carbon sequestration by agricultural soils. Although the gains will eventually level off, they will extend the time available to introduce other measures with longer-term benefits. Thus, agriculture's role as a driving force for climate change could still increase, but its contribution to climate change mitigation will rise through greater carbon sequestration and increased resilience to climate variation.

The main impacts of climate change on global food production are not projected to occur until after 2030, but thereafter they could become increasingly serious. Up to 2030 the impact may be broadly neutral or even positive at the global level. Food production in higher latitudes will generally benefit from climate change, whereas it may suffer in large areas of the tropics. However, there could be large intraregional disparities in the medium term, e.g. western, central and eastern Africa could experience a reduction in cereal production and southern Africa an increase.

Up to 2030 these potential decreases in food production are relatively small and most countries should be able to compensate for climate change impacts by improving agricultural practices.

Box 13.1 Food-insecure regions and countries at risk

The IPCC and the other assessments considered in this chapter conclude that the main regions and countries at risk from climate change are the following:

Climate change

- Countries of arid, semi-arid and subtropical Asia, sub-Saharan Africa, Near East/North Africa and Latin America where temperatures are above the optimum for crop growth or even close to their maximum temperature tolerance, and already result in heat stress in livestock and fish.
- Water-scarce countries of arid, semi-arid and subtropical Asia, sub-Saharan Africa, Near East/North Africa and Latin America (northeast Brazil) where reduced stream flow and water recharge, higher transmission losses from irrigation systems and greater evapotranspiration from crops may lower irrigation and increase water stress in crops and livestock.

Sea level rise

- West Africa (Gulf of Guinea, Senegal and the Gambia), southern Mediterranean (Egypt), East Africa (Mozambique), South and Southeast Asia (Bay of Bengal), the Caribbean and island states of the Indian and Pacific Oceans.

Extreme events

- Droughts for much of semi-arid and subhumid Africa (particularly the Sahel, Horn of Africa and southern Africa), South Asia and northeast Brazil.
- Floods in deltas and their immediate hinterland during storm surges.
- Floods in river valleys and lake basins of all regions, including temperate ones, during abnormally long or intense rainfall events.
- High winds associated with tropical cyclones in Central America and the Caribbean, South and East Asia.

Priority should be given to raising the resilience of agricultural ecosystems, increasing the cropped area, and raising and diversifying yields through improved access to genetic resources and technologies. Moreover, with the exception of sub-Saharan Africa, the growing income of developing countries should make it possible for many of them to choose between greater food imports and greater mitigation and adaptation by their agricultural sector to overcome climate change impacts. The world's traditional cereal exporters should be able to meet any increase in demand, either because their production potential will be boosted by climate change, or because they will have the capacity to adapt to climate change and overcome any negative impacts.

Up to 2030, the most serious and widespread agricultural and food security problems related to climate change are likely to arise from the impact on climate variation, and not from progressive climate change, although the latter will be important where it compounds existing agroclimatic constraints. However, the more frequent extreme events will not necessarily increase food insecurity in all situations, given the other economic and social changes taking place. Given the likely structural change in the sectoral composition of the economy and of employment in developing countries, access to food will increasingly be determined by urbanization and non-agricultural incomes. As a result, food security in some countries will improve and they will become less vulnerable to climate change. Developed countries will also experience more frequent extreme events but it seems possible that these will not have a sustained impact on their food export potential.

Nonetheless, low-income groups in many countries will remain vulnerable to short- to medium-term supply constraints arising from climate change. The basic food security issue will remain that of poverty and the lack of food purchasing power.

Although the impacts of climate change on food production and food security up to 2030 may be relatively small and uncertain, those projected for the remainder of the century are larger and more widespread. By 2100 climate change could pose a serious threat to global and local food security. It is therefore vital that action be taken now to counter this threat. Actions should include measures to reduce agriculture's role as a driving force for climate change, through the reduction of GHG emissions, as well as measures to mitigate and adapt to climate change.

Institutional changes are going to be as important as or more important than technological ones. Institutional actions will be needed to raise national preparedness and reduce rural and urban poverty to enable vulnerable low-income groups to purchase all of their basic food requirements. Policies for agricultural development will need to emphasize the importance of improving not just the production capacity of agricultural ecosystems but also their diversity and resilience. It is vitally important to initiate the institutional and technological changes now, because of the long lead times for the development of new technologies and for the improvement of road and rail links between food-deficit and surplus areas, and between ports or railheads and isolated rural areas.