Chapter 2
Climate Effects on Food Security: An Overview

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Abstract There are roughly 1 billion food insecure people in the world today, each having this status because food is unavailable to them, because it is unaffordable, or because they are too unhealthy to make use of it – or some combination of the three. Assessing the potential effects of climate change on food security requires understanding the underlying determinants of these three aspects of food security – availability, access, and utilization – and how climate change might affect each. This chapter explores these aspects and determinants of food security, summarizing the basic mechanisms by which climate change might impact the lives of the global food insecure.

2.1 Introduction

Roughly a billion people around the world live their lives in chronic hunger, and humanity's inability to offer them sustained livelihood improvements has been one of its most obdurate shortcomings. Although rapid improvements in agricultural productivity and economic growth over the second half of the twentieth century brought food security to broad swaths of the developing world, other regions did not share in that success and remain no better off today – and in some cases worse off – than they were decades ago.

Progress in understanding *why* some of these countries emerged from poverty and food insecurity, and why others did not, has been similarly limited. Such questions are central to the economics discipline and have been an active area of research for centuries, but they have generated remarkably little consensus on how to effect the transition from poverty to wealth.

Much of the controversy arises because food security (and related measures of well-being) have multiple, complex determinants, with varying agreement on which causes are more or less important. But confronting this complexity is central to any understanding of the potential impacts of climate change on food security. For

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instance, knowledge of the impacts of climate on crop yields alone is not enough to understand food security impacts, because food security is a product of complex natural and social systems in which yields play only one (albeit important) part. Instead, understanding climate change's full impact will require knowledge of its potential effects on both the proximate causes of food insecurity (e.g., low agricultural yields, low rural incomes) as well as on the more fundamental causes of poor economic progress (e.g., poorly-functioning institutions and markets, low education levels, high disease burden). Our goal in this chapter is not to assign priority among possible factors, but to outline how each might be affected by climate change and what in turn this could mean for progress towards achieving global food security.

2.2 Food Security: Definition, Measurement, and Recent Progress

Although an earlier study counted at least 30 definitions of the term "food security" (Maxwell and Smith 1992), the benchmark understanding of the term is roughly that of FAO (FAO 2001):

> Food security is a situation that exists when all people at all times have physical, social, and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.

Under this definition, food security consists of having, on an individual level, the food one needs and wants. This definition is then conventionally subdivided into three main components: *food availability, food access*, and *food utilization. Availability* refers to the physical presence of food; *access* refers to having the means to acquire food through production or purchase; and *utilization* refers to the appropriate nutritional content of the food and the ability of the body to use it effectively. We explore each of these aspects of food security in the context of climate change below.

2.2.1 Measuring Food Security

Proper measurement of food security is of clear policy and humanitarian concern, primarily because such measures are used to both assess progress in a given region and to target assistance where needed. However, given the multiple interacting components of food security listed above, measurement of food security is both difficult and controversial.

The most cited country- and global-level statistics on food security are those of FAO, who use a measure of "undernourishment" as a proxy for food security. This measure relies primarily on national level data on food supply to estimate the percentage of a given country's population that does not have access to sufficient dietary energy. FAO's estimation procedure, shown graphically in Fig. 2.1, is roughly as follows (Naiken 2002):

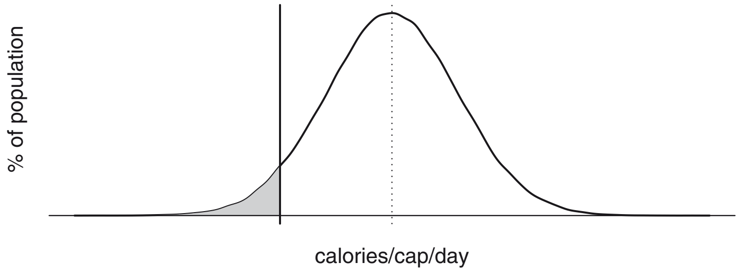

Fig. 2.1 Schematic of FAO undernourishment calculation. *Dotted line* = average per capita calorie availability; *curve* = population distribution around that average; and *vertical black line* = calorie undernourishment threshold. *Grey shading* represents proportion of population that is undernourished (after Naiken 2002)

1. For a given country, sum up the total number of calories available for human consumption in a given year, which will be a combination of locally produced food and imported food, minus exports.
2. Divide by the country's population to determine average per capita consumption.
3. Determine the shape of the distribution around this mean, either from household income or expenditure surveys where available, or from imputation from other sources where not.
4. Use country-level data on average height and weight to estimate the minimum amount of energy needed to maintain light activity, and apply the distribution from (3) to determine what percentage of the population falls below this threshold.

This undernourishment measure is attractive because it is both computationally simple and based on relatively available national-level data on the production and trade of agricultural products. But many criticize the measure for effectively focusing on food availability at the expense of issues of household food access and utilization – the status of which might correlate poorly with the national-level estimates of food supply on which the FAO measure is based. Others complain that the FAO statistics reveal nothing about the sub-national location or severity of food insecurity, and thus that they are of little use to practical policy planning (Smith et al. 2006).

Recent work by Smith et al. (2006) seeks to address these concerns by using nationally representative household survey data to construct detailed measures of food security. This approach tallies up the amount of food each household reports purchasing or producing, and based on these totals calculates how many households fall below given calorie and diet quality thresholds. Although more difficult and time-consuming to construct, and more limited in their spatial and temporal coverage given the absence of household surveys for many developing countries and many years, such measures can provide much more detail on both the nature and location of food insecurity in a given country. Furthermore, as discussed below, this approach often yields different conclusions about the severity of food insecurity than the benchmark FAO measures.

2.2.2 Where and How Numerous Are the Food Insecure?

Progress in reducing the number of food insecure over the last half century is at once both promising and discomforting. As Fig. 2.2 shows, since 1970 there has been a general decline in both the number of global food insecure and their percentage of the total population, as calculated using the FAO undernourishment measure described above. These reductions were driven primarily by large gains in East and Southeast Asia, where decades of strong economic growth liberated hundreds of millions from poverty and food insecurity. In both of these regions, the prevalence of undernourishment fell from 40% to 45% in 1970 to near 10% in 2004.

These remarkable gains stand in contrast to two more worrying trends. First, progress in reducing global food insecurity seems to have slowed and even reversed in the last few years, with the number of global food insecure actually rising slightly for the last two years for which there are data. Second, Sub-Saharan Africa stands out as a region for which progress has been particularly discouraging. While South Asia continues to have the highest total number of food insecure (around 300 million by the undernourishment measure), SSA is gaining rapidly and has the highest prevalence of food insecurity at around 35% of the population – a rate that has shown little deviation over the last 4 decades.

Moreover, household survey-based estimates of food insecurity suggest that FAO statistics might underestimate the prevalence of food insecurity in the region. Using estimates of food insecurity based directly on household survey data for 12 African countries, Smith et al. (2006) calculate rates of food insecurity on average 20% higher than FAO estimates, rising up to as much as 40% in some countries (Table 2.1), and attribute much of the difference to significantly lower estimates of mean food consumption when using household survey data directly. Household data also suggest differences in the relative rates of hunger across the same sample

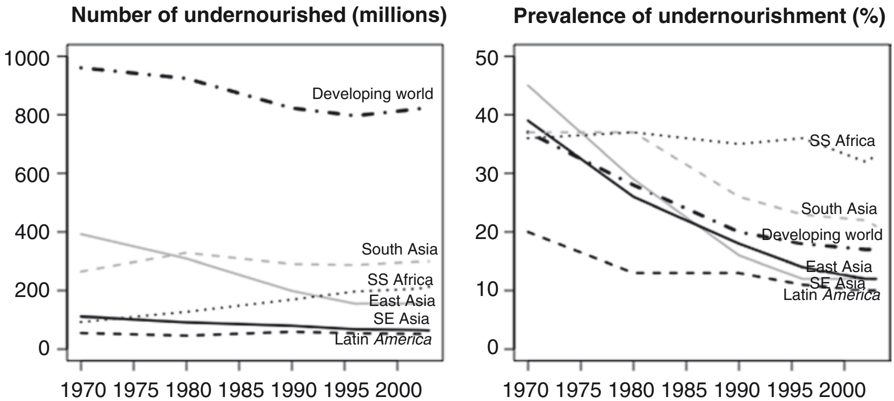

Fig. 2.2 Regional trends in undernourishment, 1970–2004. *Left panel*: number of undernourished in millions. *Right panel*: percent of undernourished in population (FAO 2009)

Table 2.1 Comparison of FAO and household survey-derived estimates of the prevalence of food energy deficiency for 12 African countries (from Smith et al. 2006)

Country	FAO estimate	Household survey estimate	FAO rank	Household survey rank
Ethiopia	44	76	4	1
Burundi	66	75	1	2
Malawi	32	73	8	3
Zambia	45	71	3	4
Rwanda	41	65	7	5
Mozambique	63	60	2	6
Senegal	24	60	10	7
Ghana	15	51	12	8
Guinea	31	45	9	9
Kenya	43	44	5	10
Tanzania	43	44	6	11
Uganda	21	37	11	12
Mean	*39*	*59*		

Table 2.2 Prevalence of rural and urban food energy deficiency in selected African countries (from Smith et al. 2006)

Country	Rural prevalence	Urban prevalence	Percent of food energy deficient who are rural	Rural population as % of total population
Burundi	76	41	95	90
Ethiopia	74	90	82	85
Ghana	50	53	53	55
Guinea	40	54	59	66
Kenya	46	30	71	62
Malawi	73	76	84	84
Mozambique	63	51	70	65
Rwanda	67	55	86	83
Senegal	54	69	45	51
Tanzania	42	53	60	66
Uganda	36	41	86	88
Zambia	71	71	65	65

countries, which is potentially of relevance to policy-makers trying to target assistance priorities across countries (right columns of Table 2.1). For instance, Ethiopia ranks as the fourth most food insecure country in the sample using FAO data, but the most food insecure country using household data.

Household data also allow further insight into the location of poverty within countries. While gripping images of urban slums are often the public face of food insecurity, household data typically reveal that the majority of the food insecure reside in rural areas. Table 2.2 shows that while the prevalence of food insecurity can be as high or higher in urban areas, a much greater percent of the total number of food insecure in a given country live in rural areas, largely reflecting the much higher percentage of the total population still residing in rural regions. And although the developing world is urbanizing, broader analyses of survey data suggest that the majority of the world's poor and food insecure will remain in rural areas for years to come (Ravallion et al. 2007).

This basic picture of the state of global food security – strong recent progress in some regions, little progress in other regions, many of which remain desperately poor, and the dominant role of rural populations in the total number of food insecure – provide the baseline for our exploration of the effects of climate change on the three aspects of food security, which we now take up in turn.

2.3 Food Availability and Climate Change

The *food availability* dimension of food security encompasses issues of global and regional food supply, and asks the basic question: can we physically produce enough food to feed our population? There is a vast literature on past trends and future trajectories in the world's ability to feed itself which cannot be adequately summarized in the current chapter (Conway and Serageldin 1997; Dyson 1999), Nevertheless, any discussion of the effect of climate change on the global food supply must take into account current realities and trends in global and regional supplies of food. We therefore highlight three particularly important characteristics of the global food supply.

The first is that on an average per capita basis, the world today produces more than enough food to meet caloric requirements, and that this success has been based mostly on yield gains over the last half century. Perhaps first popularized by Thomas Malthus in the early 1800s, the question of whether the world can produce enough food to feed a growing population has been a perennial concern. Thus far, technology has mostly precluded Malthusian doomsday predictions of population-driven food shortages. Through the first half of the last century, the need for increased food production was met by expansion of cropped area. But beginning in about the 1950s, when population and income growth were adding increasing pressure to global food markets, large-scale sustained investment in crop productivity greatly increased yields of crops throughout the developing world. This so-called Green Revolution allows the world today to produce 170% more cereals on just 8% more cropped area than 50 years ago (Panel (a), Fig. 2.3) – certainly an incredible achievement. Furthermore, on a global level this productivity growth has more than kept pace with the large observed increases in population, and global per capita cereal production currently stands at almost exactly 1 kg/person/day – or more than enough, on average, to feed everyone on the planet.

These global averages, however, hide large regional discrepancies, and the second important characteristic of the global food supply is that there are stark regional differences in the magnitude and source of agricultural productivity growth – differences that provide important insights into the challenge a changing climate might pose. Panels (a–c) in Fig. 2.3 show area, yield, and per-capita production trends by region

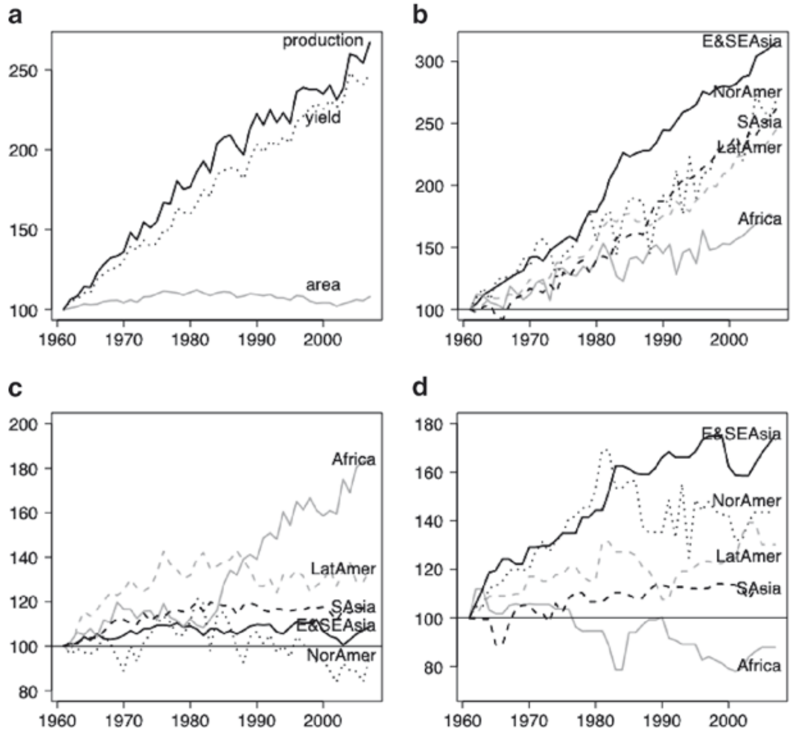

Fig. 2.3 (**a**) change in yield, area, and production of global cereals, 1961–2007. (**b**) Regional yield trends and (**c**) area trends over the same period. (**d**) Changes in per capita production. All values are indexed (1961 = 100) (FAO 2009)

over the last half-century. While most regions in the developed and developing world enjoyed somewhere between a doubling and tripling of yield since 1960, allowing them to increase their per-capita production of cereals with only minimal expansion in cropped area, Africa stands out as the continent on which progress has been most difficult. African cereal yields have grown at less the half the Asian rate, and despite an 80% increase in the amount of cropped area on the continent, total cereal production has not kept pace with population growth. As a result, the African continent is the only region where per capita production of cereals has declined over the last half century.

The potential for reversing this decline and for further boosting productivity elsewhere in world is at once promising and troubling. The promise for Africa and other low productivity regions lies in the large gulf between observed yields and potential yields – the so-called "yield gap" – much of which is explained by low adoption of modern agricultural technology and inputs. In theory, developing appropriate agricultural technology for these regions and providing the proper incentives to use it could rapidly close these substantial yield gaps and quickly raise productivity. But elsewhere in the world, particularly in the high-input systems in much of North America, Europe, and parts of Asia, yield gaps are much smaller, and achieving the sustained increases in yield observed over the past 4 decades will likely be very difficult without further increases in yield potential ceilings (Cassman 1999).

Furthermore, expanding cropped area, which is the alternative to increasing yield, is either difficult or unappealing throughout much of the world, either because of urban encroachment on agricultural land or because of the environmental costs of bringing new land into production. The FAO, which periodically assesses trends in crop demand and supply, envisages a significant expansion of cropland area in Africa and Latin America but little growth elsewhere, mainly because so little land in Asia remains uncultivated (Bruinsma 2003). Overall, most global assessments project that (1) crop demand will grow considerably over the next few decades, given the additive pressures of population growth (estimated to peak at 9.1 billion mid-century), higher incomes resulting in shifting food preferences, and potential development of large-scale biofuel production and the additional crop demand it represents; (2) the rate of demand growth, however, will be slower than observed in the past few decades, as population begins to stabilize; (3) and based on existing land, water, and fertilizer resources, crop production should be able to keep pace with the decelerating demand growth, but only with a formidable and sustained investment in yield improving technologies, cropland expansion, and input use.

The third important feature of the global supply situation is that food is now a truly global commodity, and the movement of food across borders plays an increasingly important role in meeting regional food demand. As Fig. 2.4 shows, about 10% of world cereal production is traded internationally, with some regions (Oceania, North America) exporting substantial amounts of what they produce, and other regions (notably Africa) importing up to a third of what they consume. Such food trade can either buffer or exacerbate the effects of a local food supply shock. A country experiencing drought, for instance, might make up for production shortfalls through imports, but cereal

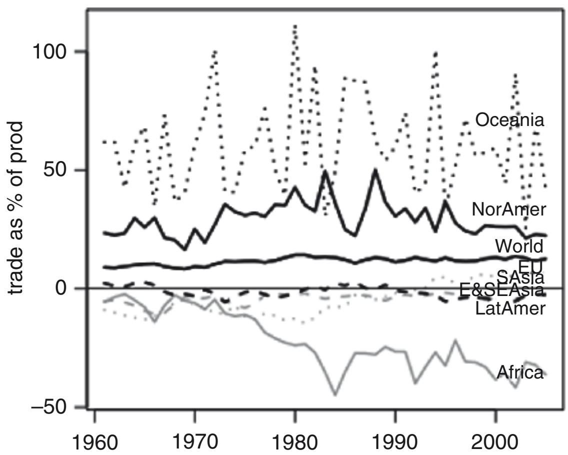

Fig. 2.4 Trade in cereals as a percent of production, 1961–2005. Regional values are exports or imports as a percent of production, with negative values indicating net importers. Global values reflect total trade as a percentage of production (FAO 2009)

importing nations would pay higher food prices on the world market when large exporting countries suffer similar shortfalls. In the event that such shocks happen simultaneously, poor importing nations would need to import when prices are very high, greatly increasing their difficulties in bolstering local food supplies.

So how might climate change affect global and regional food supply? As the rest of this book will show, climate change will have potentially large effects on both agricultural yields and potential cropped area, with global trade acting as a potential buffer when countries trade and when climate shocks are not uniform across space. But agricultural production and food availability are just one part of the food security story, and we now turn to the less frequently discussed potential effects of climate change on access and utilization.

2.4 Food Access and Climate Change

If Thomas Malthus is the customary jumping-off point for discussions of food availability, economist Amartya Sen dominates introductory paragraphs in discussions of food access. Recalling the definition above, food access refers to the ability of an individual to acquire food, either through its production or its purchase. Sen referred to these means of food acquisition as "entitlements", and he won the Nobel Prize in part for showing how famines were a result of households or entire regions periodically lacking entitlements. His basic insights hold today: for a farmer, entitlements are the means of food production available to her (e.g., land and labor), and her access to food is secure if she can command sufficient amounts of these factors to produce enough food. For those who don't farm, access to food is a function of incomes and prices – how much money one has to spend on food, and how much the food costs. Food access then can deteriorate when non-farm incomes fall, when food prices rise, or when the productivity of farm households suffers.

Determining the effects of climate change on food access for a given household therefore requires addressing the role of climate change in relation to four basic questions: how households earn their income, the nature of their exposure to food prices, how well integrated their local food markets are with global markets, and their broader longer-run prospects for livelihood improvement.

The first question concerns *the extent to which a given household is dependent on agriculture for its income*. If agriculture will be one of the sectors most affected by climate change, then the greater a household's livelihood depends on agriculture, the more that household is sensitive to the impacts of climate. While good systematic data on sources of household income in the developing world are hard to come by, there have been multiple recent efforts to try to systematize the available survey data on household income and to discern basic patterns across the developing world.[1]

[1] See, for example, the RIGA project (Davis et al. 2007, Ivanic and Martin 2008), IFPRI's HarvesChoice Project, Stanford's ALP Project, and Banerjee and Duflo (2007).

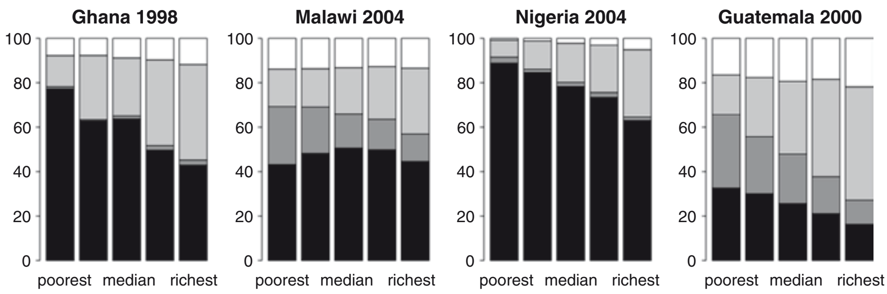

Fig. 2.5 Percentage of rural household income derived from agricultural sources, by income quintile for selected countries (Davis et al. 2007). *Black* = on-farm income; *dark grey* = agricultural wage income; *light grey* = off-farm income; *white* = transfer income/other. For instance, the poorest 20% of rural Ghanian households derive about 80% of their income from farm activities

Recall from the Smith data that most of the food insecure live in rural areas. Figure 2.5, adapted from data in Davis et al. (2007), shows the percentage of rural household income derived from agriculture in a set of poor countries for which good income data were available. The general trend from these data is clear: rural households in many developing countries depend to a significant extent on agriculture for their livelihoods, and this dependence tends to rise the poorer the household is. For the poorest of these households, two-thirds or more of income is earned on average through agriculture – a total that includes income from sales of crop and livestock goods in the marketplace, as well as the value of such goods produced by the household for home consumption. Such an agricultural dependence suggests that the income effects of a decline in agricultural productivity (all else equal) could be significant.

Importantly, however, few households even in rural areas are fully dependent on agriculture. The inherent seasonality and year-to-year variability of agriculture encourages diversification of income sources, and in the dry season or in particularly bad years many rural households seek additional income in non-agricultural wage labor or self-employment. As Fig. 2.5 shows, these sources of income can be important, and introduce a second main aspect of climate change and food access, *the nature of a household's exposure to food prices*.

All households are consumers of food, and as consumers benefit when food prices are low. But rural households are often producers of food as well, selling surplus in local markets. As a result, such households benefit as consumers but are hurt as producers when food prices fall. So if climate change induces changes in the supply of food that in turn affect food prices, the net impact of these price changes on food access in a given household will depend on the particular net consumption position in that household – that is, whether they spend more on food purchases than they earn from selling what they produce.

Estimating net consumption position again requires the use of household surveys, in this case surveys that have detailed information on both agricultural production and consumption behavior. As with income, there have been some recent efforts to characterize household net position for staple grains across a subset of developing countries (Fig. 2.6). These data show, unsurprisingly, that urban households are largely net consumers of food, purchasing nearly all of what they consume. More surprising perhaps is that the majority of rural households in many poor countries are also net consumers of food, with even farm households using non-farm income to purchase what they are unable to produce. These net-consuming households will likely be helped if prices fall, or hurt if climate change makes food more expensive.[2]

Finally, the extent to which these net consuming households are affected by changes in food prices depends on how much of their income they spend on food, and on what types of food they buy. For instance, most households in wealthy countries are substantial net consumers of food, but because they spend such a small percentage of their total income on food, they are little affected if the price of food changes. This is not the case in poorer households, who can spend half or more of their income on food (Fig. 2.7), and for whom changes in food prices can have serious effects on the quantity and quality of food consumed. Because climate change might also affect the relative prices of different staples (for instance if warming hurts one cereal more than another), the particular diet composition of

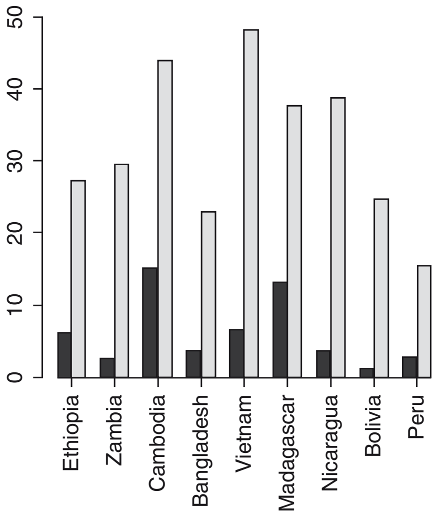

Fig. 2.6 Percent of households who are net sellers of staple crops, selected countries (Ivanic and Martin 2008). *Dark grey* = urban households; *light grey* = rural households

[2] There are cases where the longer-run effects of high prices might actually benefit net consumers, for instance if in response to the incentives of higher prices they are able to expand their own production and become net sellers of food, or if higher food prices induce expansion of production on other farms and raise the total demand for agricultural wage labor. For a more complete treatment of these longer-run dynamics, please see Singh et al. (1986).

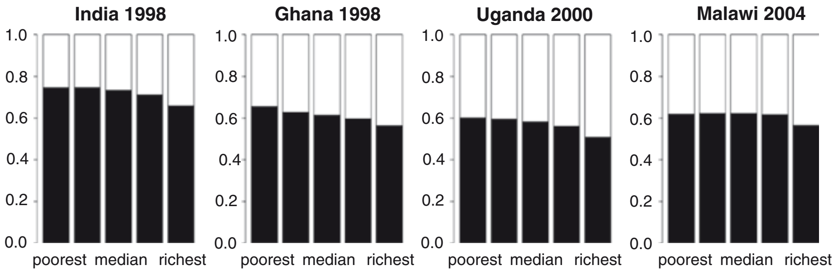

Fig. 2.7 Food expenditure as a percent of total household expenditure, by expenditure quintile. India data are for Bihar and Uttar Pradesh. Data from Stanford's ALP project (Karen Wang, pers. comm.)

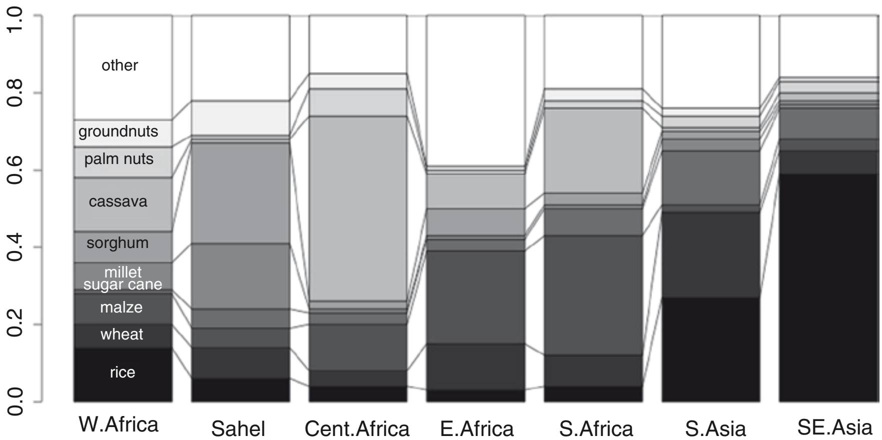

Fig. 2.8 Average percent of dietary calories derived from different crops for selected regions. Data are from FAO (2009), as calculated in Lobell et al. (2008)

poor households can also be important. As Fig. 2.8 shows, this composition can vary greatly from region to region, with the three primary cereals (rice, wheat, and corn) accounting for over 75% of calories consumed in parts of Asia, to less than 20% throughout much of Africa.

The third important determinant of climate change's effects on food access concerns *how well integrated local food markets are with global markets.* As discussed in later chapters, the effects of climate change on agricultural productivity will likely vary by region, and so it is important whether in a given area local food prices and availability are driven primarily by local shifts in production, or whether that area is well integrated with regional or global food markets such that local prices track global price movements. This degree of integration could play a large role in the welfare effects of climate in a given region. For instance, a region that suffers large productivity losses under climate change but whose food markets are well integrated with global markets could see little change in the price of food if it is able to import food to cover losses. Conversely, a country well integrated with global markets could see food prices rise even if it doesn't experience local climate effects.

The final determinant of the effects of climate change on food access concerns *the degree to which longer-run prospects for growth in income and food security are climate sensitive*. This question is undoubtedly the most contentious of the four, because there is remarkably little agreement on the underlying causes of economic development, and thus little understanding of the relative importance of climate in determining why some countries become rich and others remain poor over the long run.

The economics literature offers perhaps three main explanations of why some countries have succeeded economically over time and others have not (Easterly and Levine 2003). The first explanation, argued prominently by Bloom and Sachs (1998) among others, suggests that *geography* is central to long-run economic success. Noting the high correlation between tropical location and underdevelopment, proponents of this explanation argue that a country's geographic location directly shapes various factors fundamental to long-run economic success – for instance the quality of the country's soils, the favorability of its climate for agriculture and habitation, the prevalence of various diseases, and the ease with which goods can be traded within and across its borders.

A second strain of thought places primary emphasis on the role of *institutions* in economic development. This explanation, promoted by Acemoglu et al. (2001) and Easterly and Levine (2003) among others, argues that economic progress has less to do with a country's soils and climate and much more to do with the quality of its institutions – in particular, factors such as limited corruption and institutional respect for private property and the rule of law.

A final explanation focuses on the role of particular *policies* in explaining long-run economic performance. Proponents in this camp (Williamson 1990) argue that even with favorable geography and well-functioning institutions, countries with bad economic policy are destined for poor economic growth. They point to instances in which poor economic management resulted in the collapse of otherwise prosperous countries as evidence of the primacy of good policy.

A casual observer might suspect that all three explanations – geography, institutions, and policies – play some role in shaping long run economic success. But if one explanation is relatively more important than another – a possibility that each camp adamantly claims is the case – then climate change could have a greater or lesser effect on longer run prospects for the alleviation of poverty and hunger. In particular, if the climate worsens, and it is in fact geography that constrains eventual economic success, the aggregate effects of climate change on food security could be great. If on the other hand institutional quality dominates long-run success, then climate change could have little effect on long-run progress.

Aside from these important questions about the long run determinants of economic progress, however, it should be clear that climate plays an important and direct role in the immediate food security of a large number of the world's poor. For households who eat much of what they produce, or who face food prices tightly linked to local agricultural production – and these households number in the hundreds of millions – the welfare effects of a negative supply shock can be large and lasting. Various studies demonstrate the persistent welfare effects of short-term adverse climate shocks for rural households, as for instance households in crisis sell productive assets to meet immediate consumption needs (Dercon and World Institute for Development Economics 2002; Hoddinott 2006). If climate change alters the likelihood of these shocks, we could expect large effects on rural household welfare in poor countries, even if the economy-wide consequences are minimal.

2.5 Food Utilization and Climate Change

Even if climate change were to have minimal impacts on the supply of food or on the ability of households to access it, it could still affect food security through its effects on the *utilization of food*. The utilization component of food security is perhaps its murkiest and least well-studied aspect, but generally relates to the nutritional aspects of food consumption. Supposing availability and access issues are taken care of, achieving proper food utilization requires satisfactory answers to three questions: does the food an individual eats contain all the energy, protein, and nutrients necessary for her to lead a healthy and productive life? Is the food itself safe and not likely to make her ill? And finally, is the individual healthy enough to take advantage of the food's nutritional qualities?

New evidence is indeed emerging about the potential effects of climate change on food utilization. Nevertheless, and as in the case of food access, climate will be only one component of a broader suite of issues that shapes an individual's ability to utilize food properly.

2.5.1 Food Utilization and Nutrition

Although a primary purpose of food is provision of dietary energy, and widely used undernourishment indicators such as FAO's lean heavily on estimates of calorie consumption to estimate food security trends, food is of course much more than just energy. Food also provides protein and various nutrients essential for bodily function, and there is increasing recognition of the important role insufficient intake of these nutrients plays in global illness and death from infectious disease (Black 2003). Importantly, prevalence of micronutrient deficiencies around the world is generally higher than estimates of caloric deficiencies, and alleviating these deficiencies has become a major public health priority.

Table 2.3 lists major micronutrient deficiencies, some of their health effects, and the most recent estimates of their global prevalence. It reveals that estimated prevalences for deficiencies in nutrients such as iodine and zinc are more than twice the FAO benchmark estimates for number of global undernourished. As a result, added together these micronutrient deficiencies account for one of the largest sources of global health loss (Lopez et al. 2006).

Table 2.3 Global prevalence of micronutrient deficiency (http://www.who.int/vmnis; (Ezzati 2004))

Micronutrient	Effects of deficiency	Number of global deficient (billion)	Percent of population deficient (%)
Iron	Child and maternal mortality, reduced cognitive development	1.6	25
Iodine	Reduced cognitive development, deformation, goiter	1.9	31
Vitamin A	Blindness, immune deficiency	0.6 (children <5 yrs)	20
		0.1 (women 15–44)	6
Zinc	Immune deficiency	1.9	31

Most poor households receive what micronutrients they do get through the consumption of plants, with vitamins sourced largely from fruits and leafy greens, and minerals from cereals. For instance, some estimates suggest that 80% of African and Southeast Asian intake of vitamin A comes through fruit and vegetable consumption (Ruel 2001). Meat and dairy products are a primary source of many nutrients in the developed world, but are often too expensive for poor households, and are thus a minor source of micronutrients throughout much of the developing world.

Climate change could directly affect micronutrient consumption in three main ways: by changing the yields of important crop sources of micronutrients, by altering the nutritional content of a specific crop, or by influencing decisions to grow crops of different nutritional value.

There is little published evidence on the effects of climate change on micronutrient content of crops, and also much less evidence on the potential effects of climate change on fruits and vegetable yields compared to that available for cereals. Some studies show that higher CO_2 concentrations can lower protein content in various food crops, particularly in the context of low nitrogen inputs (Taub et al. 2008). While the estimated reductions could be relatively modest in magnitude – 10–15% decrease in grain protein content by around the end of century – such declines would be amplified by any yield losses, and would hit hardest in poor areas where nitrogen application rates are low and where crops constitute a primary source of dietary protein.

Beyond direct effects on yields, climate can also shape the decisions farmers make about what crops to grow (Rosenzweig and Binswanger 1993), and thus could potentially alter planting decisions in ways that alter micronutrient availability. For instance, in the poor soils and highly variable climates of much of central and western Africa, starchy tubers such as cassava and yam often dominate cropping systems, in no small part because of their ability to achieve at least some yield in the worst weather years. Unfortunately, such crops are also very poor sources of both protein and micronutrients, and to the extent that they are favored in future climate relative to cereals as a source of dietary energy, nutrient consumptions could decline.

2.5.2 Disease and Food Utilization

Food utilization also concerns the ability of individuals to make use of the nutrients available to them, and is thus closely linked to both the overall safety of the food and to the individual's health. While not all unhealthy people are necessarily food insecure, health status can be a primary contributing factor to food security. Of particular concern in poor countries are the strong feedbacks between malnutrition and disease, in which undernutrition leads to increased infection and a higher disease burden, which in turn leads to energy loss, reduced productivity, and further diminished access to food (Schaible and Kaufmann 2007). And while the underlying determinants of health and food safety are complex and clearly extend far beyond narrow climate issues, most possible manifestations of climate change (e.g., warming, drought, or floods) have the potential to negatively affect health in ways that compromise food utilization (Confalonieri et al. 2007).

Growing evidence indicates the significant role climate can play in the safety of food, as pathogens enjoy warmer climates. For instance, warming temperatures have been shown to increase the incidence of *Salmonella*-related food poisoning in Europe and Australia, and warming ocean temperatures have been shown to increase the incidence of human shellfish and reeffish poisoning (Kovats et al. 2004; McMichael et al. 2006).

Perhaps more importantly, climate change has the potential to affect health status directly, in ways that alter an individual's ability to utilize food. In areas with limited access to clean water and sanitation infrastructure, diarrheal disease is a leading killer, and contributes directly to child mortality and poor food utilization by limiting absorption of nutrients. Extreme rainfall events, drought events, and warming temperatures have all been shown to increase the incidence of diarrheal disease, often significantly (Checkley et al. 2000; McMichael et al. 2006; Confalonieri et al. 2007). Warming temperatures will likely also expand the range of important vector-borne diseases such as malaria and dengue (e.g., McMichael et al. 2006). Similarly, changes in rainfall patterns could also affect disease incidence, for instance with increasing drought heightening the risk of meningitis outbreak, or increased extreme rainfall events increasing the likelihood of cholera outbreaks (McMichael et al. 2006; Confalonieri et al. 2007).

Unfortunately, all available evidence suggests that the health effects of climate change will hit hardest where disease burdens and susceptibility to disease are already high, and where public health infrastructure is poorly developed – that is, in the poorest countries of the world. And since diseases such as malaria and diarrheal disease disproportionately affect younger ages, the health burden of climate change will be borne primarily by children in the developing world. The broader food security impacts of these climate-related health losses have not been well quantified, and are a topic in immediate need of attention by researchers.

2.6 Summary

There are clearly many pathways through which climate change will impact food availability, access, and utilization. Climate induced changes in agricultural productivity will likely affect the incomes earned and the food prices faced by poor households, with the net effect on food security a function of each household's particular set of livelihood strategies. In addition, health impacts associated with climate change could hamper the ability of individuals to utilize food effectively. These multiple potential impacts will occur in the midst of broader trends in global and regional food security, which include rapid recent progress throughout much of the developing world, but little improvement across most of the African continent, much of which remains desperately poor and food insecure.

The remainder of the book treats in detail some of the evidence surrounding specific aspects of climate impacts on food security, and in particular the methods used to understand them. Somewhat inescapably, however, the book focuses on topics where current knowledge and methods are most developed – which are issues primarily surrounding the food availability aspects of food security. But this subsequent focus should not distract from the broader message of this chapter, which is that food security is more than just food production, and that some of the most important effects of climate on food security could be through its effects on incomes, food prices, and the health of the poor.

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