

# 10

## **FOOD SECURITY**

### **I. Sustainable Food Supply and the End of Hunger**

One of the most complicated unsolved problems of sustainable development is how the world will feed itself. This problem is an ancient one. Yet many people thought it had been solved with great breakthroughs in food productivity based on scientific advances. Especially after the Green Revolution of high-yield crop varieties that took off in the 1960s, it seemed very likely that food production would inevitably stay ahead of the growing world population. Now we have some serious doubts. Not only

are we coming to realize that a large portion of humanity is poorly fed, but we are also realizing the seriousness of the threats to global food security that lie ahead.

We cannot say we have not been warned. The warnings have been with us for more than two centuries, starting in 1798 with Thomas Robert Malthus who, in *An Essay on the Principle of Population*, posed the basic challenge of food security for a growing population. Malthus's basic point was that any temporary boost in food production capable of relieving food insecurity would cause a rise in the population to the point that humanity was once again reduced to a condition of food insecurity. Malthus would look at our current overall global food surplus and warn, "Yes, that's all fine and good, but what will happen when the population surges from 7.2 billion people today to more than 10 billion people by the end of the century?" He would also note that many people even today live in chronic

hunger.

When Malthus posed the challenge of feeding the world population, there were around 900 million people on the planet. Since then, the population has increased by a factor of eight. With 7.2 billion people on the planet and with the global population continuing to grow by around 75 million people per year, the challenge of feeding the planet is with us again. The problem is even more complicated than Malthus could have imagined, for four main reasons:

1. A significant share of the world population today is malnourished.
2. The global population continues to grow.
3. Climate change and other environmental changes threaten future food production.
4. The food system itself is a major contributor to climate change and other environmental harms.

Let us look first at the issue of malnutrition (SDSN 2013c). Malnutrition is a pervasive problem: around 40 percent of the world's population is malnourished in one way or another. One major component of malnutrition is *chronic hunger*, or undernourishment. The Food and Agriculture Organization (FAO) defines chronic hunger as the insufficient intake of energy (calories) and proteins. Hundreds of millions of people are afflicted by chronic hunger and have only the energy for mere survival. The FAO estimated the number at 870 million people for the years 2010–2012.

There is another kind of less visible malnourishment that is sometimes called *hidden hunger*, or micronutrient insufficiency. The calories and proteins may be sufficient, but micronutrients like vitamins or particular fatty acids are not adequately present in the diet. Such micronutrient deficiencies result in various kinds of ill health and

vulnerability to infection and other diseases. Key micronutrient deficiencies prevalent in many low-income countries include vitamin A, vitamin B<sub>12</sub>, zinc, iron, folate, omega-3 fatty acids, and iodine.

The third kind of malnutrition, which is now at epidemic proportions in many parts of the world, especially the richest countries, is the excessive intake of calories leading to *obesity*, meaning weight is far too high for height. Technically, obesity is often defined as a body mass index (BMI) greater than 30, where BMI equals the weight in kilograms divided by the height measured in meters. Overweight is defined as a BMI greater than 25. It is estimated that roughly one-third of all adults in the world are overweight, and around 10–15 percent are obese.

Adding it all up, the numbers are staggering. Around 900 million people are chronically hungry. Perhaps another 1 billion more have enough macronutrients (calories and proteins) but suffer from one or more

micronutrient deficiencies. Roughly 1 billion more are obese. In total, around 3 billion people are malnourished out of a world population of 7.2 billion people, meaning that a staggering 40 percent of the world is malnourished.

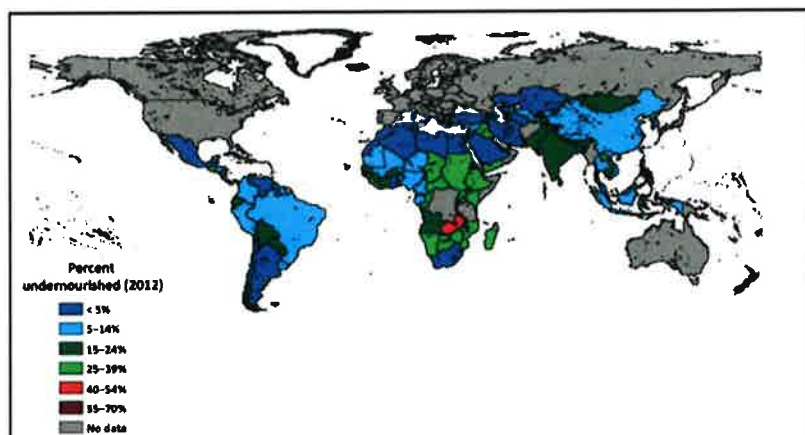
This is not exactly where we would want the world to be more than 200 years after Malthus warned us about the chronic crisis of food insecurity. We do indeed have a crisis of food insecurity. Sometimes it is hunger; sometimes micronutrient deficiency; and sometimes excessive caloric intake with unhealthy diets, such as diets too heavy in sugars and carbohydrates. Any serious focus on a sustainable and secure food supply for the world must view the nutrition crisis in all its dimensions, from those who lack the basic caloric intake to those who suffer from obesity and the ill effects that come from that condition.

Figure 10.1 shows where these problems are distributed. Chronic hunger is heavily concentrated in

tropical Africa and in South Asia. More than one-third of the population in tropical Africa, especially central and southern Africa, is undernourished. In South Asia, between 20 and 33 percent of the population is chronically undernourished. When young children are undernourished, their physical development may be irreparably damaged, leading to adverse health consequences that last throughout their lives. Such consequences can include impaired brain development and vulnerability to various kinds of non-communicable diseases (such as cardiovascular disease or metabolic disorders) as adults.

Chronic undernourishment of young children is measured according to various indicators of severity. The first is *stunting*. Stunting means that a child has a very low height for his or her age. Specifically, children are assessed relative to a standard population distribution of height for age. Children who are more than two standard

deviations below the norm are considered stunted. Stunting reflects the inadequacy of dietary intake but can result both from a poor diet and from chronic infections, such as worm infections. As figure 10.1 shows, the most severe stunting is found in tropical Africa, and the highest stunting rates in the world are in South Asia, especially India. We noted earlier, in our discussion about poverty in South Asia, that stunting typically reflects a combination of factors: inadequate diets, chronic infections (such as worms), and lack of access to safe water and sanitation, making children vulnerable to new infections.

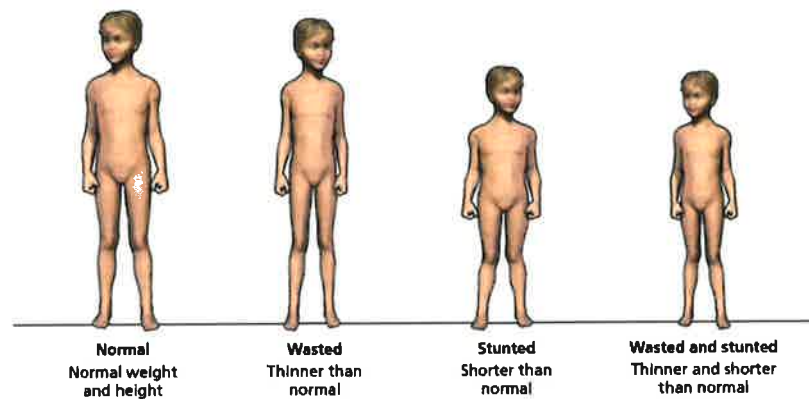


## 10.1 Undernourishment around the world

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*Source: World Bank. 2014. "World Development Indicators."*

The second condition is even more urgent, and that is *wasting*. While stunting is a chronic condition in which the child does not grow, wasting is a low weight for height. [Figure 10.2](#) illustrates the physical differences between the conditions. Wasting is often a sign of acute, life-threatening undernutrition, of the kind one often sees in a famine. In those cases, children may require an urgent rescue through therapeutic foods (high-intensity nutritional foods designed to combat acute undernutrition) and emergency procedures to help keep the children alive.



## 10.2 Illustration of stunting and wasting

*London School of Hygiene & Tropical Medicine.*

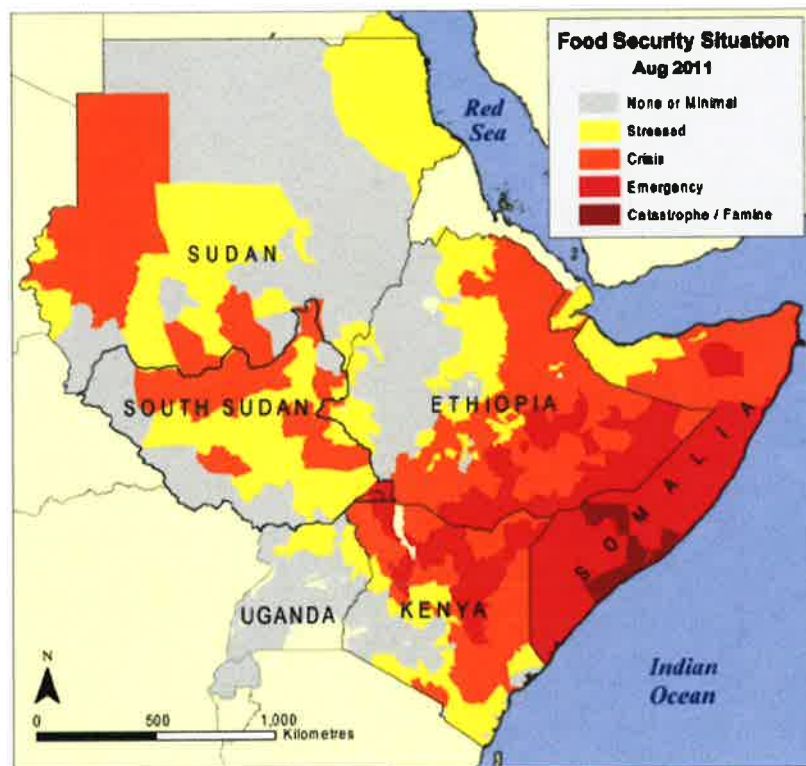
There is a key distinction between chronic undernutrition (chronic insufficiency of calories and proteins) and acute undernutrition that may arise from wars, disasters, droughts, and displacement of populations. When those acute episodes occur, there is not only massive suffering but also the risk of a massive loss of life from starvation and disease.

Violence and conflict often break out in hungry regions. [Figure 10.3](#) depicts food insecurity in August 2011. In West Africa there was drought and food crisis in the Sahel, covering Mali, Chad, and

Niger; in East Africa, there was drought and food crisis in the Horn of Africa, covering Ethiopia, Somalia, northern Uganda, northeast Kenya, and Djibouti. In both cases, the drought and resulting famines led to large population movements and resurgent violence as migrants clashed with local populations. In Mali, regional conflicts and local conflicts combined to produce a massive and devastating civil war.

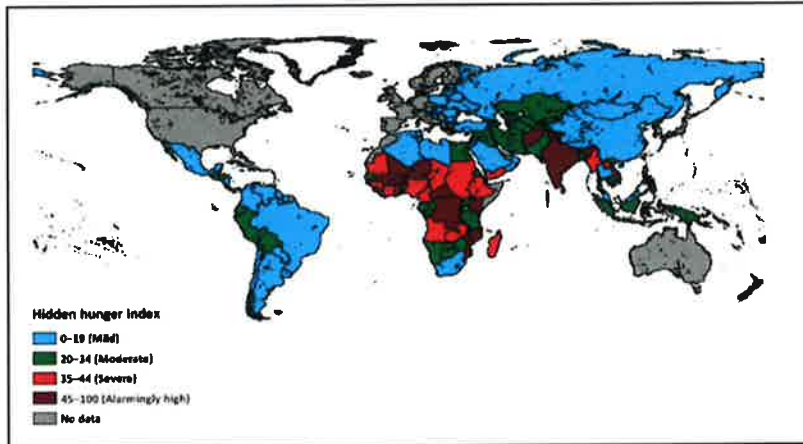
Hidden hunger afflicts not only those with chronic undernutrition but also another billion or so people who have an adequate caloric intake but an inadequate variety of nutrients in the diet. [Figure 10.4](#) shows estimates of three particular micronutrient deficiencies (iron, vitamin A, and zinc; Muthayya et al. 2013). We note the especially high rates of micronutrient deficiencies in South Asia, West and central Asia, much of tropical Africa, and the Andean region. Unfortunately, the data on hidden hunger are themselves hidden. There are no

precise estimates of micronutrient deficiencies around the world.



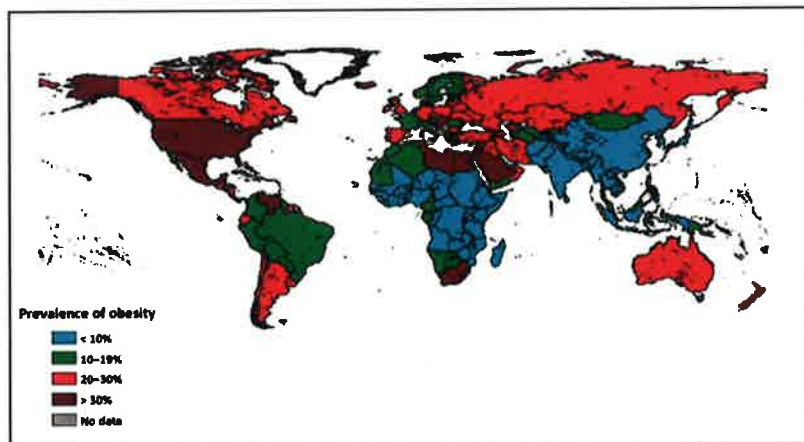
### 10.3 Acute food insecurity (August 2011)

*FEWS NET (2012).*



#### 10.4 Hidden hunger index (zinc, iron, and vitamin A deficiencies)

Source: Muthayya, Sumithra, Jee Hyun Rah, Jonathan D. Sugimoto, Franz F. Roos, Klaus Kraemer, and Robert E. Black. 2013. "The Global Hidden Hunger Indices and Maps: An Advocacy Tool for Action." PLoS One 8(6): e67860. doi:10.1371/journal.pone.0067860.



#### 10.5 Global prevalence of obesity

(2008)

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Source: GHO data repository, World Health Organization.

Obesity marks the other end of the malnourishment spectrum and also causes a tremendous amount of disease and premature mortality. As we see in [figure 10.5](#), the United States, Mexico, Venezuela, and several countries in the Middle East and North Africa (Libya, Egypt, Saudi Arabia), South Africa, and a few others, have an obesity rate above 30 percent. Several more countries, notably in Europe and the former Soviet Union, have an obesity rate between 20 and 30 percent. Why are we facing this obesity epidemic?

The fundamental causes of the obesity epidemic are still not fully clear. Part of the cause is total caloric intake and part is the result of relative inactivity in the urban environment. The high caloric intake may also result from the *kinds of highly processed foods* that people are eating, notably foods with a

high “glycemic index.” The glycemic index measures the rate at which a food raises the level of blood sugar. Foods with high glycemic indexes include soft drinks, potatoes, rice, and many baked goods. Foods with low glycemic indexes include whole grains, fruits, and vegetables. It is hypothesized that high-glycemic index foods give rise to a sharp rise in blood sugar followed by a sharp rise in insulin, which in turn lowers the blood sugar and raises the appetite. Satiety is therefore reduced, and overeating may result.

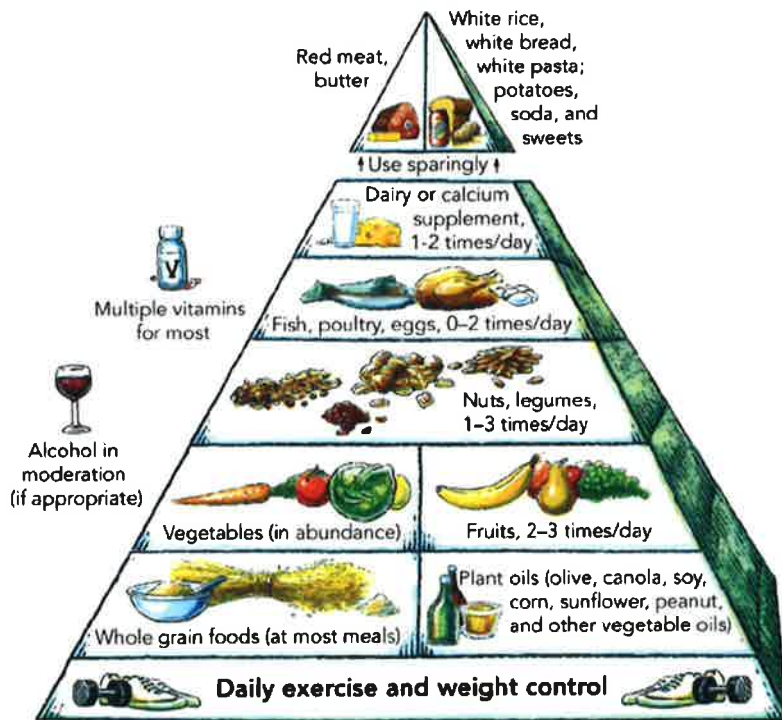
In short, the obesity epidemic most likely results from a combination of too many calories, the wrong kinds of calories, and the extreme physical inactivity of urban life. There is no doubt, as the map in [figure 10.5](#) indicates, that a global epidemic is underway. It is already spreading from high-income countries to middle-income countries, and poses a rising threat to health and wellbeing.

To counteract this epidemic, dietary

changes combined with more physical activity will be key. Breakthroughs in nutritional science are giving us guidance on improved diets. One of the leaders of modern nutrition is Walter Willett, chair of Harvard University's Department of Nutrition. He proposed a "healthy eating pyramid" (figure 10.6) that depicts the kinds of foods, and the relative frequency and amounts that should be eaten, in a healthy and well-balanced diet. A healthy diet includes whole grains (with low glycemic indexes), vegetables, fruits, and plant oils. Meats and foods with a high glycemic index (e.g., potatoes and rice) should be eaten sparingly. At the base of the pyramid is daily exercise. Unfortunately, actual diets in the United States and other countries with obesity epidemics are quite different, with very high intakes of processed grains, rice, potatoes, soft drinks, red meat, and unhealthy fats (trans fats) used in baked goods and fast foods.

Global food insecurity is already bad

enough, but it is likely to get worse before it gets better. Not only is around 40 percent of the world malnourished, but the global food supply is also becoming destabilized by climate shocks and other environmental ills (e.g., freshwater depletion threatening irrigation of crops), even as the world population continues to increase. Moreover, the global demand for grains is rising even faster than population. Countries with rising incomes like China are also shifting to diets with more meat products. Since each kilogram of beef requires 10–15 kilograms of feed grain to raise the cattle, there is a multiplier effect of higher incomes on the global demand for grains. The combination of unstable food production (due to climate change) and rising food demand (due to rising population and meat consumption) is resulting in upward pressure on global food prices.

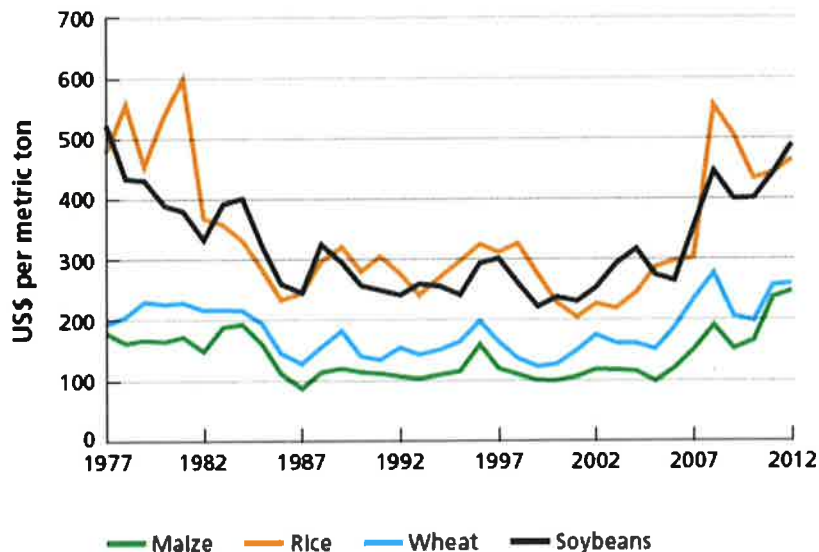


## 10.6 The healthy eating pyramid

*The Healthy Eating Pyramid, Department of Nutrition, Harvard School of Public Health. From Eat, Drink, and Be Healthy by Walter C. Willett, M.D., and Patrick J. Skerrett (2005). Harvard University.*

Figure 10.7 shows food prices since the late 1970s (Rosegrant et al. 2012, 90). From 1970 to the early 2000s, real food prices were falling: the rise of food production was outpacing the growth of food demand. Yet since the early 2000s, food prices have been soaring in real

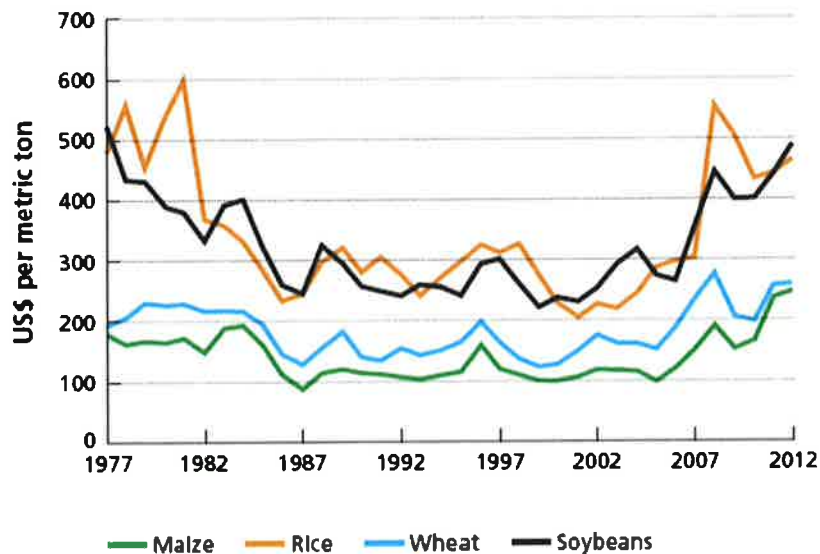
terms (i.e., food prices have increased much faster than average inflation). Indeed, the rise of food prices during the period since 2000 marks a major reversal of an even longer trend of falling real food prices throughout the twentieth century.



## 10.7 World prices for key commodities (1977–2012, \$2005)

Source: Rosegrant, Mark W., Simla Tokgoz, Prapti Bhandary, and Siwa Msangi. 2012. "Scenarios for the Future of Food." In 2012 Global Food Policy Report, 89–101. Washington, DC: International Food Policy Research Institute.

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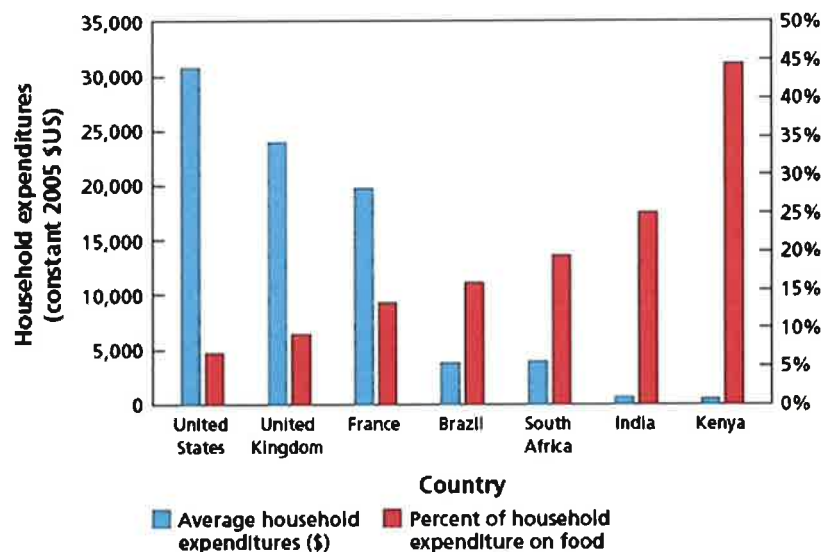


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Source: Rosegrant, Mark W., Simla Tokgoz, Prapti Bhandary, and Siwa Msangi. 2012. "Scenarios for the Future of Food." In 2012 Global Food Policy Report, 89–101. Washington, DC: International Food Policy Research Institute.

For wealthy people, the rise in food prices is an inconvenience. As we see in [figure 10.8](#), only around 6 percent of U.S. household consumption is for foodstuffs. Yet for poor people, diets consume a large percentage of the family income, as much as 45 percent of the household budget in the case of Kenya, as shown in the figure. This inverse relationship of total consumption per person and the share spent on food is known as Engel's Law, and it is one of the most robust patterns in the economy. Because of Engel's Law, the recent rise in global grain prices is more than just an annoyance or a hindrance for the poor, especially the urban poor. It is often a profound threat to their wellbeing, one that pushes many people into abject poverty, hunger, and desperation. Of course, for farmers who are net sellers of grain on the market, the rise in food prices can be a blessing, not a curse, as it may raise the farmers' incomes by more than it raises their households' cost of food consumption.

In summary, we have around 40 percent of the world still not properly nourished, a food supply already under stress, rising food prices, and increasing demand for food production. What can be done? We now turn to the supply side: how food is grown, where it is grown, and what might be the prospects for sustainable and nutritious food production in the future, especially in the era of climate change and water scarcity.



## 10.8 Engel's Law: Proportion of income spent on food falls as income rises

Source: World Bank. 2009. USDA.

## II. Farm Systems, Ecology, and Food Security

One of the challenges of addressing global food security is the remarkable variation in farm systems around the world. There is no “one size fits all” when it comes to farming or to methods to increase farm yields. This enormous diversity should not be surprising. Farmers differ incredibly in what they grow; how they grow it; and the challenges of climate, soil, water, topography, pests, biodiversity, and transport costs they face. These variations in turn have an enormous effect on farm systems and strategies. As a result there is no single or simple answer as to how farmers can become more productive and more resilient to environmental risks. Part of the proper diagnostics and solutions for a global sustainable food supply depends on thoroughly understanding how farm

systems differ around the world.

There are about 130 million square kilometers of land on Earth and of that, a remarkably large proportion is already taken for human needs (United Nations Environment Programme 2014). Agriculture constitutes around 50 million square kilometers, roughly 40 percent of the world's total land area. Roughly 14 million square kilometers are arable land (land that can be used for agricultural crops), and roughly 34 million square kilometers are meadows and pasturelands. Farmland itself accounts for a little over 10 percent of the world's land area. Pastures are much bigger, around a quarter of the total land area. Another 39 million square kilometers are forests, covering about 30 percent of the Earth's land area. A modest proportion of the forests, perhaps around 15–20 percent of the total, are managed for pulp, paper, timber, logging, and other products. The remainder of the Earth's land is about 41 million square kilometers, roughly 30

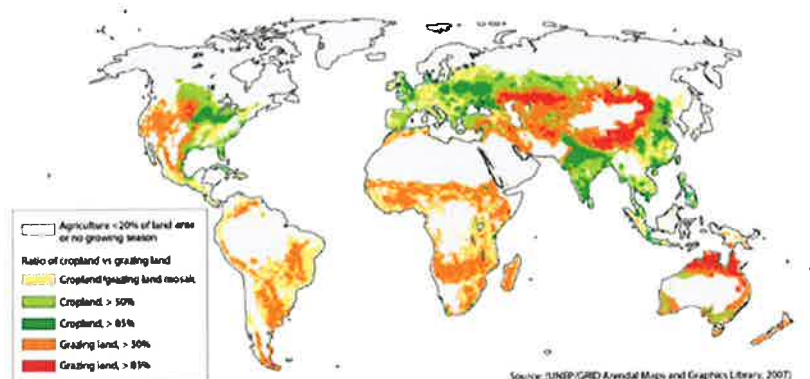
percent of the total, much of which is uninhabitable land such as deserts and high mountains. Only a few percent of the world's land areas is in cities, where half the world's population lives. Recent estimates put the urban landscape at around 3 percent of the total, and rural households and businesses at another 3 percent.

Figure 10.9 maps where the agricultural land is, both for cropland and grazing land. The green shaded areas, where cropland is greater than 50 percent of the total, include the U.S. Midwest; parts of western, central, and eastern Europe; Russia; and much of China and India. In Africa and South America, the grazing land and cropland are mixed. The drier areas tend to be places where food crops cannot be grown with high productivity, and so are used more for animal grazing. In semi-arid environments, one finds nomadic populations that move herds of livestock across large areas in pursuit of the grasslands watered by the seasonal

rains. In Africa, these pastoralist environments are found in the semidesert regions of the Sahel in West Africa, the Horn of Africa, and the deserts (like the Kalahari of Botswana) in Southern Africa.

There are two major forest areas to study in the map of the world's forests in [figure 10.10](#). First are the rain forests around the equatorial belt. The Earth receives the highest solar radiation per square meter at the equator. The intense solar radiation warms the equatorial land and causes the humid equatorial air to rise and cool. The water vapor condenses and gives rise to massive precipitation at the equator (and a descending dry area at around 25 degrees north and south latitude, giving rise to deserts north and south of the equator). The equatorial rainfall and warm year-round temperatures produce the three great equatorial rain forests of the planet: the Amazon in South America, the Congo Basin in Africa, and the great rain forests of the Indonesian

archipelago in Southeast Asia. This rain forest band circles the planet at the equator. The other major forest regions are in the high latitudes, like the boreal forest across the vast Eurasian land mass and Canada. Unlike the forests that once stood at midlatitudes in North America, India, China, and Europe, but have since been cut down, the boreal forests remain standing today in large part because the land under the forests cannot be used profitably for farming, as the temperatures are too low and the potential growing seasons are too short. Otherwise, human settlers would likely have deforested the high-latitude regions just as humans long ago deforested the temperate midlatitude regions.

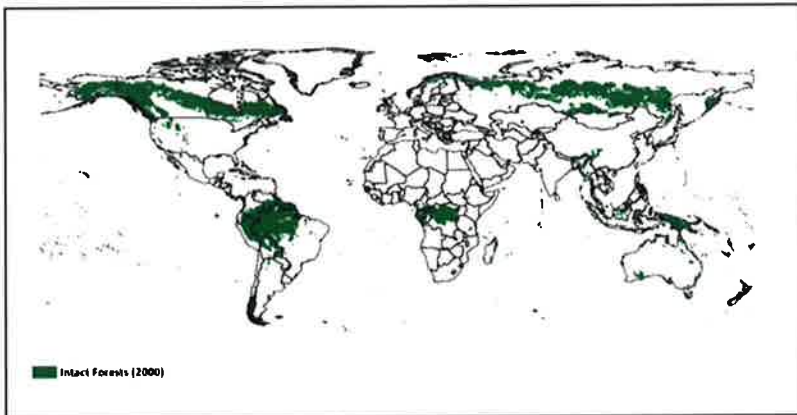


## 10.9 Global distribution of pastureland and cropland (2007)

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Source: Ahlenius, Hugo. 2006. UNEP/GRID-Arendal.

[http://www.grida.no/graphicslib/detail/agriculture-land-use-distribution-croplands-and-pasture-land\\_a0ab](http://www.grida.no/graphicslib/detail/agriculture-land-use-distribution-croplands-and-pasture-land_a0ab).



## 10.10 The world's forests (2000)

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Source: Potapov P., A. Yaroshenko, S.

Turubanova, M. Dubinin, L. Laestadius, C.

Thies, D. Aksenov, A. Egorov, Y. Yesipova, I.

Glushkov, M. Karpachevskiy, A. Kostikova, A.

Manisha, E. Tsybikova, I. Zhuravleva. 2008.

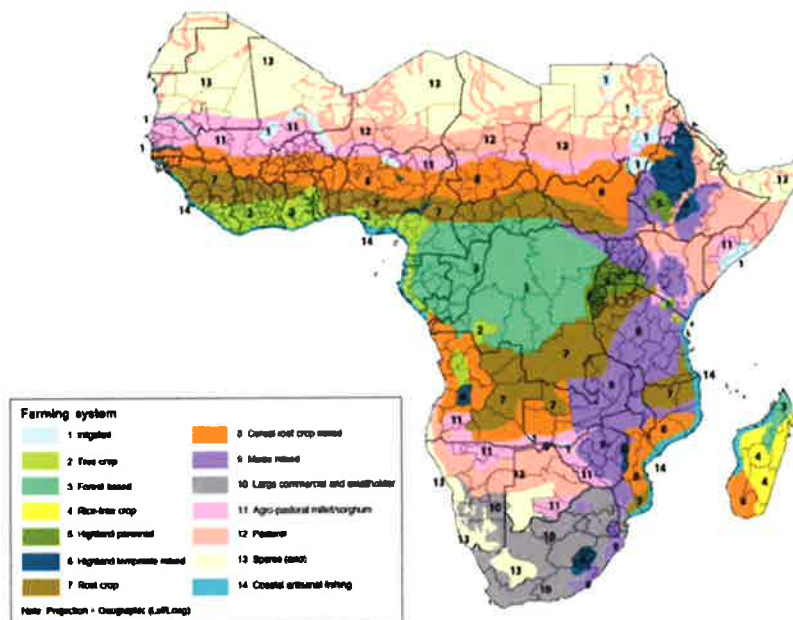
"Mapping the World's Intact Forest Landscapes by Remote Sensing." *Ecology and Society*, 13(2): 51.

<http://www.ecologyandsociety.org/vol13/iss2/art51/>.

We see therefore that the locations of cropland and forests are deeply rooted in the ecological conditions, including temperature, rainfall, topography (e.g., if the land is too steeply sloped it may be impossible to farm), whether irrigation is feasible, and more. All of these patterns shape the farm systems and shape the location of human populations. Population densities are nearly zero in the deserts and tundra and low in the near-desert areas and areas in high latitudes just lower than the tundra. Population densities and farmlands are prevalent in temperate midlatitude zones that are well watered, with good soils, moderate temperatures, and therefore good growing conditions for crops. These areas were heavily forested in prehistory, but humanity began deforesting them long ago to make way for croplands and pasturelands.

Many of the forests today are being threatened with deforestation, especially the equatorial rain forests.

Populations are encroaching on these areas for a variety of reasons, including to make way for pastureland and cropland or to get fuel wood and other goods and services. The pace of deforestation is currently unsustainable in all of the great equatorial rain forests. Some of the forests are overlogged for tropical hardwoods, which are highly valued but used in an unsustainable manner around the world. Rain forests are also being cut down and replaced by massive tree plantations; for example, to grow high-demand products like palm oil, a problem that is particularly intense in Indonesia, Malaysia, and Papua New Guinea.



## 10.11 Major farm systems in sub-Saharan Africa

Source: Dixon, John et al. 2001. Farming Systems and Poverty. Food and Agriculture Organization of the United Nations.

[http://www.fao.org/farmingsystems/staticssa\\_en.htm](http://www.fao.org/farmingsystems/staticssa_en.htm). Reproduced with permission.

It is worthwhile to take a deeper look at one part of the world to illustrate how the geography shapes the farm systems and the society. In Africa, there are distinctive characteristics of climate that cause distinctive farm systems and distinctive economic results as well.

Figure 10.11 maps the various farm systems in Africa—the fourteen major agroecological zones, each with a specific kind of farm system adapted to the particular ecology.

Start at the equator. There the year-round high temperatures and high rainfall give rise to a rain forest ecology. The Congo Basin rain forest (shown as the bright green area 3) is not especially productive for annual crops (the soil nutrients are rapidly washed away by the intense rainfall), so the forest is mainly used for tropical forest products (tropical logs and tree crops such as rubber, palm oil, and cocoa). A similar situation applies in the tree-crop ecology of the coast of the Gulf of Guinea (green area 2) in West Africa, stretching from Liberia in the west to Cameroon next to the Congo Basin. This area too is given over to massive tree-crop plantations.

As one moves poleward (meaning toward the North Pole in the Northern Hemisphere and toward the South Pole

in the Southern Hemisphere), the rainfall diminishes and becomes more seasonal. In general the rainfall is greatest in the summer months (e.g., in May–September in the Northern Hemisphere, examples being Nigeria and Kenya, and September–March in the Southern Hemisphere, examples being Malawi and Tanzania). Instead of growing tree crops, these regions grow annual crops. Maize growing is especially prevalent in East Africa (in purple zone 9). Root crops like cassava are grown in the brown zone 7. As one continues poleward in both hemispheres, the rainy season becomes shorter still. Only short-season crops that are well adapted to temporary dry spells, such as sorghum and millet, can safely be grown. These dryland crops are found in purple zone 11 in both hemispheres. Continue the poleward journey and one arrives at the arid regions, where the rainfall is too low to grow crops but just enough to water pasturelands for nomadic livestock.

Thus ecological zone 12 in both hemispheres is home to the pastoralists of Africa, such as the Tuareg and Fulani of West Africa and the Khoikhoi of southern Africa. Finally, take one more step poleward, and we are in the deserts of the northern Sahara and the southern Kalahari.

Countries naturally straddle several of these zones. A country like Ghana has tree crops in the humid south near the Gulf of Guinea and maize and dryland crops in the north. Mali has irrigated rice in the south and pastoralism in the north. Kenya is a mosaic of farm systems, as is Ethiopia, with deserts, pastoralism, lowland and highland crops (crops are graded by elevation as well as by latitude). These distinct ecologies also are home to distinct ethnic, racial, and religious groups, leading to remarkable social and cultural diversity, as well as the potential for clashes, such as the age-old tensions that can arise between sedentary farm communities and

migratory nomadic livestock herders.

People living in food-secure, well-watered (and often irrigated) croplands of the temperate regions often have little feel for the complexity of food production and the potential for food insecurity in seasonal tropical environments, especially those of low average rainfall and high vulnerability to drought. When the rains fail in dryland regions, populations may face hunger and may be forced to migrate in desperation, often bringing them into contact with other ethnic groups competing for scarce land and water. The result can be an explosion of violence, as in Darfur, Ethiopia, and northern Mali. (Ecological tensions are generally one factor among several that give rise to such violence, so complex phenomena such as interethnic violence typically have many drivers, not one factor alone.)

The world has especially failed to grasp the deep crises of the hyperarid regions, such as the Horn of Africa

(including parts of Ethiopia, Kenya, Somalia, and other neighbors) and the Sahel (including parts of Senegal, Mali, Niger, Chad, and others). These are agropastoralist regions or in some cases solely pastoralist regions. They tend to be very poor, utterly dependent on rainfall, and suffering under the burdens of climate change, instability of rainfall, rising populations, falling trends in total precipitation, increasing hunger, and resulting instability and violence. However, the long-term drivers of crisis—including climate change and rising populations—have been too slow-moving to be recognized by most policy makers in Washington, London, and other rich-country capitals. When violence breaks out in these impoverished and vulnerable places, the rich countries have tended to respond with military approaches (e.g., to fight terrorist groups in the Sahel and coastal pirates in Somali) rather than to address the underlying problems of poverty, climate change, and unsustainable

population increases (e.g., for lack of access to family planning). The military strategists in Washington or NATO fail to see the human and ecological dimensions of the crises.

### III. How Environmental Change Threatens the Food System

Yet the problems are even deeper. Not only are massive numbers of people currently food insecure; farm systems almost everywhere are under tremendous stress, unable to ensure healthy diets and nutrition in economical and sustainable ways to meet the needs of the populations locally and globally.

There are some enormous challenges ahead that will make these problems even tougher than they are now. The most direct of these challenges is the fact that the world's population continues to grow relatively

rapidly, even in absolute terms. Every year, another 75 million or so people are added to the world population. By 2025, the world will reach 8 billion people. The current medium-fertility variant of the UN Population Division puts the world's population at 10.9 billion people by 2100, although the number could be even larger than that (UN Department of Economic and Social Affairs Population Division 2013). (With a faster fertility decline than in the UN medium-fertility variant, the world population would stabilize at perhaps 8–9 billion.)

At the same time that the world will be grappling with the challenge of feeding more people, the current food supply, already under so much stress, is going to be even further stressed by another couple of features (SDSN 2013c). One that I noted earlier is the tendency of countries with rising incomes to add more meat to the diet, amplifying the demand for feed grains. The second major challenge is the environmental threats that will make it

harder to grow food in many places in the world. These environmental threats and changes come in many shapes and forms. Climate change is the biggest of all. As the climate changes in complex ways under the force of human emissions of greenhouse gases (GHGs), for many parts of the world these changes will be highly adverse for food production.

Higher temperatures in general are going to be harmful for food production in today's warm environments. (The very high latitudes of the world, such as in Canada and Russia, could experience a rise in food productivity as very cold places become a bit less cold.) Especially in the poorest, tropical parts of the world, crops are likely to face temperature-related stresses. At high temperatures, crops may not develop at all, seeds may become infertile, and plant respiration may mean a net reduction of yields of farm crops. Higher temperatures mean faster evaporation of water in the soils and more

transpiration of water through the stomata of the leaves of plants (the combination of evaporation and transpiration is called evapotranspiration). Climate change threatens the soil moistures, which in turn threatens the productivity of crops.

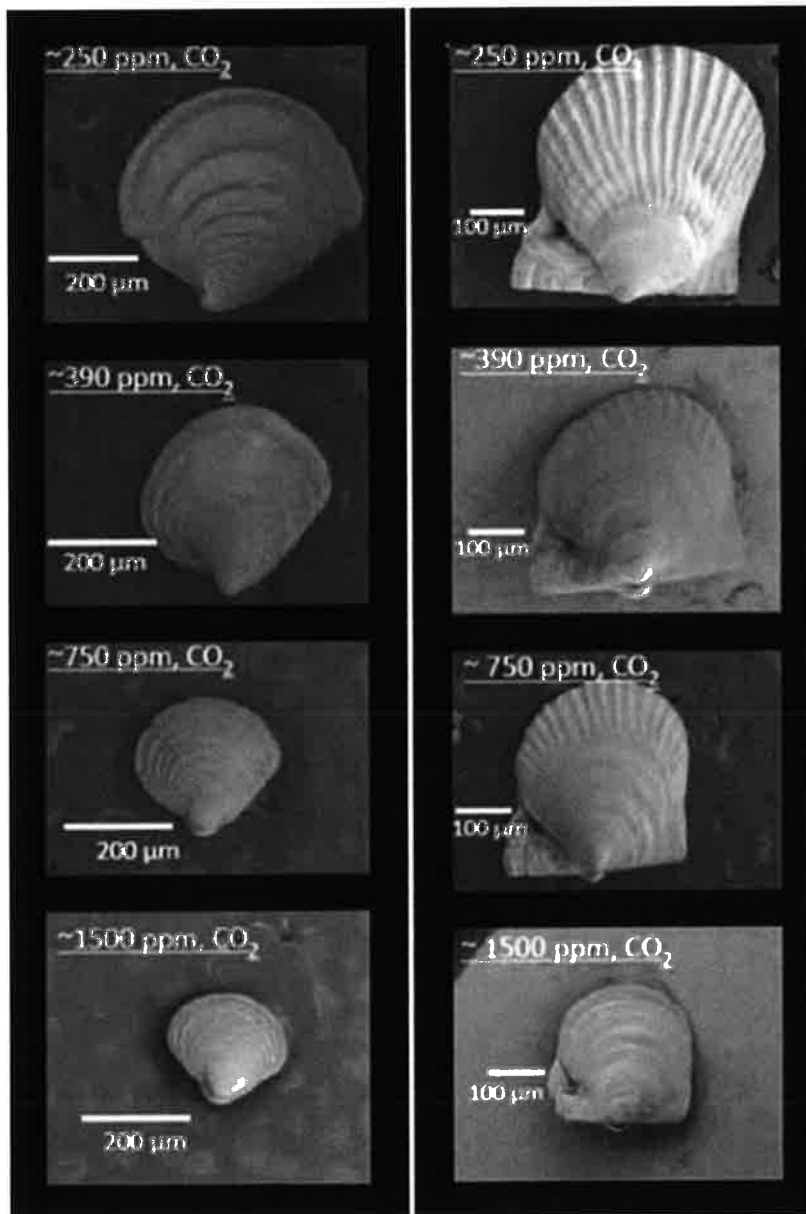
Warming also will be accompanied by changes in regional and global precipitation patterns. Many parts of the world will become drier, and many dry parts of the world will find it extraordinarily difficult, perhaps impossible, to continue to grow crops. It is a general principle that today's dry places in the tropics and subtropics will tend to get drier, while today's wet places closer to the equator will tend to get wetter, with more intense episodes of precipitation. Dryland places that today are on the very edge of crop growing may find themselves in a new climate that is too dry for food production. Wet places may find a great increase of flooding and extreme tropical storms.

Climate change will also mean rising sea levels. Coastal lowlands that are farmed right now will be threatened. Places on the deltas of the great rivers, like Bangladesh, may be inundated by floods or even permanently submerged.

In addition to climate change, carbon dioxide (CO<sub>2</sub>) emissions are having a direct effect of acidifying the oceans. Ocean acidification has serious implications for another part of our food supply: marine life. [Figure 10.12](#) illustrates the effect on shellfish of increasing acidification (from the top pictures to the bottom pictures in each column). A higher concentration of atmospheric CO<sub>2</sub> will lead to greater ocean acidity, which in turn will lead to smaller and damaged shellfish, as the acidity impedes the formation of the calcium carbonate shells. Many highly aquatic environments for marine life will be undermined, with a consequent threat not only to biodiversity but to human nutrition as well.

In addition to climate change and

ocean acidification, many other environmental changes are already degrading farmlands and threatening agricultural productivity. Farmers use large amounts of pesticides and herbicides to grow crops, but these chemicals can poison the soils and the environment and take a major toll on biodiversity in farming regions. For example, pollinators like honeybees are vital for crop productivity, e.g., for growing fruits and other kinds of flowering crops. Yet the pollinator populations are plummeting. While the reasons are not clear, and perhaps include several factors, chemical pollutants are likely among the culprits.



## 10.12 Impact of CO<sub>2</sub> on shellfish

*Talmage, Stephanie C., and Christopher J. Gobler. "Effects of Past, Present, and Future Ocean Carbon Dioxide Concentrations on the Growth and Survival of Larval Shellfish." Proceedings of the National Academy of*

Sciences. *September 20, 2010.*  
*doi:10.1073/pnas.0913804107.*

Invasive species are another issue. This is when animal or plant species are deliberately or accidentally relocated from one environment to another environment, which can derange the entire ecology. A new species without any natural predators might be introduced in a new setting, and its population may run wild and overtake the native species. In this way there may be a rapid overgrowth of new superweeds, rodents, or other kinds of pests and pathogens that overtake the ecosystem where they have newly arrived.

Environmental stress also threatens the world's irrigated lands, which provide a disproportionate amount of the world's grain production. Crop production obviously depends on water availability, both rainfed and irrigated. Irrigation is the farm system of choice for farmers when they can afford it, because it offers the chance of a high

degree of water control and even multiple crops during the year (including during the dry season). The problem is that our current global irrigation depends on freshwater sources—rivers, glaciers, and groundwater—that are all under threat from overuse and human-induced climate change. Glaciers are retreating as they melt under the warming climate. This melting can give rise to a temporary increase of river flow and crop production based on that flow. Yet when the glaciers finally disappear, the meltwater flows will swing from excess to zero. The result of the loss of glacial meltwater could prove to be a devastating and dramatic loss of food production.

Many major rivers have been so overused at this point that they are not even flowing to the sea. This, added to the pressures of climate change, will mean less river flow overall. The Nile, which hundreds of millions of people depend on, will most likely have a significant decline of river flow due to

climate change. Those who depend on the vital Yellow River in northern China are experiencing the consequences of declining river flow and a river that no longer reaches the ocean. So too with the Rio Grande, shared by the United States and Mexico and now the cause of deep contention, as water supplies are facing grave stresses in the drought-prone regions of northern Mexico and the southwestern United States.

Groundwater pumping for irrigation, such as in the American Midwest, the Ganges plains, and the northern China plains, is now far faster than the natural recharge of those aquifers. The groundwater aquifers are therefore being depleted. The shocking reality is that hundreds of millions of people depend on irrigated crops where the underlying water sources—groundwater, rivers, glaciers—are already under tremendous stresses that are very likely to intensify in the future.

Rapid land degradation, soil loss, and depletion of soil nutrients are other

results of intensive agriculture, when farms have encroached upon land areas with topographies not really suitable for farms, such as the steep slopes on mountainsides. The consequences are very high. There is likely to be deforestation, the loss of habitat of other species, and a significant emission of CO<sub>2</sub> into the atmosphere as the forests are cut down and burned. There is also a habit of abandoning farm areas after the farm productivity quickly diminishes.

All of these environmental threats—climate change, ocean acidification, chemical pollutants, invasive species, retreating glaciers, excessive pumping of groundwater and river flows—emphasize the fact that farm systems, more than any other human activity, are dependent on the climate and environments we know and have had for the past centuries. Our food supplies are dependent on the known hydrologic patterns, ocean chemistry, and patterns of biodiversity, all of which are now

undergoing enormous and rapid human-driven change. The human pressures on the planet are creating a new world—the Anthropocene—and it will be a dangerous one from the point of view of food security.

Of course there are possibilities for adaptation and far more efficient resource use. But the current inertia in habits, and the instability, crises, and conflicts that result from the collision of nature and our current systems, need to be addressed. We must realize how big the challenge will be. It has been hard enough feeding the planet—a challenge we have not even met for our current population in today's environment. When we consider the rising populations and the growing environmental stresses, we realize the magnitude of the food challenges that lie ahead.

#### IV. How the Food System Threatens the Environment

The problem with the food supply is further complicated by the fact that while the food supply is threatened by environmental change, today's agricultural systems are also the single largest source of human-induced environmental change! In other words, the agricultural systems themselves are a source of the threat to future food production. The arrows of causation run in two directions. On the one side is environmental change that threatens food production. Yet at the same time, agriculture as it is currently practiced gravely threatens the natural environment.

The damage agriculture does to the physical environment adds yet another dimension to the challenge of feeding the planet in a sustainable way. Our problem is not only about how to feed more people and how to feed the growing population more nutritiously than today. It is not only how to maintain farm yields in the face of environmental threats. It is also the

challenge of changing current agricultural practices in order to stop inflicting so much environmental damage from the agricultural sector itself. Yet because farm systems differ so much around the world, there will have to be distinctive, localized problem solving in order to make local farm systems compatible with conservation of ecosystem functions, the preservation of biodiversity, and the reduction of human impacts on the climate system and freshwater supplies.

The agricultural sector is in fact the most important sector from the point of view of human-induced environmental change. Many people imagine the automobile or perhaps coal-fired power plants to be the biggest source of human-made environmental damage. And they are indeed major causes of global environmental unsustainability. Yet it is food production that takes the dubious prize as the most important single driver of environmental harms

(SDSN 2013c).

What are the kinds of pressures generated by agriculture? The first is GHGs. The farm sector (including deforestation to make room for new farms and pasturelands) is a major emitter of all three of the major GHGs: CO<sub>2</sub>, methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O). This means that farm practices will need to be redesigned to help the world move to lower GHG emissions.

The second major impact is on the nitrogen cycle. Our atmosphere is 79 percent nitrogen in the form of dinitrogen (N<sub>2</sub>). That form of nitrogen is inert, odorless, without taste, and not very useful for us. However, nitrogen in the *reactive* forms of nitrates, nitrites, and ammonia is absolutely vital for living species, because nitrogen is the backbone of amino acids and proteins. Reactive nitrogen is absolutely core to our metabolism and to every aspect of our lives, including the ability to grow food. It is for that reason farmers put nitrogen on the soil in the form of

chemical-based fertilizers and green manures. The nitrogen is a critical macronutrient for the crops. Nevertheless, the heavy use of nitrogen fertilizers (both green and chemical-based) causes major damage to ecosystems by changing the intensity of nitrogen fluxes in the environment.

The third major way that the farm system impacts the planet is the destruction of habitats for other species. This is not entirely surprising considering that an estimated 40 percent of the total land area of the planet is agricultural land. Humanity has already grabbed a huge amount of the land area, but it is still grabbing more. It is especially grabbing more in the forest areas, and the rain forests at risk right now are places of incredible and irreplaceable biodiversity. One of the major reasons that the Earth is vulnerable to a sixth great extinction of species is this process of habitat destruction by human hands.

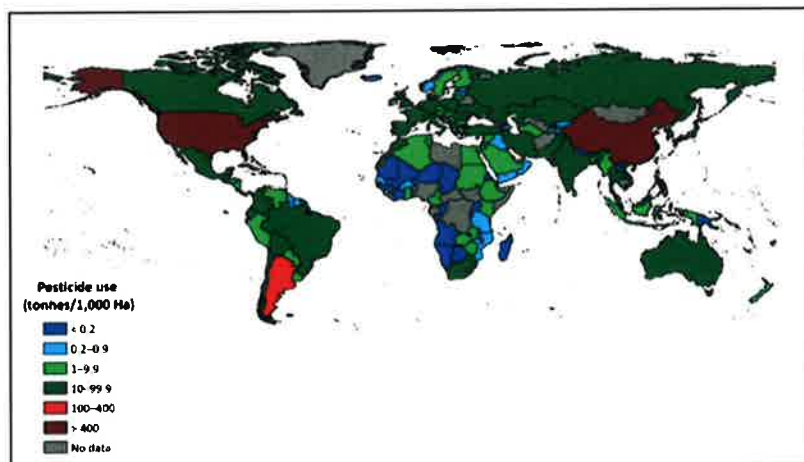
There are many other ways in which

the environment is damaged by farm activity. These include the pesticides (shown in [figure 10.13](#)), herbicides, and other chemicals that are used in farm production and that are a major threat to biodiversity. The overuse of freshwater for crop irrigation is another. Around 70 percent of the total human use of freshwater goes through agriculture, with only 10 percent going through household use and the remaining 20 percent or so for industrial processes. Agriculture is a voracious user of water, and that water itself is under threat.

For all of these reasons, the agriculture sector is a key driver of anthropogenic environmental loss. There is a strong need to change farm technologies and processes and patterns of land use to make the food system compatible with a sustainable planet.

The circle graph in [figure 10.14](#) shows us the estimated total amount of GHGs that are emitted, according to the

key sectors of the economy. Electricity and heat production, through the burning of coal, oil, and gas, is responsible for a massive amount of CO<sub>2</sub> emissions and for an estimated 25 percent of the total GHG emissions. The transport sector, with the internal combustion engine in automobiles, is responsible for an estimated 14 percent of total emissions. Industrial processes, such as steel production or petrochemical production, account for around 21 percent of total GHG emissions. In total, the direct and indirect use of fossil fuels accounts for around two-thirds of the GHG emissions.



### 10.13 Global pesticide use (1992–2011 average)

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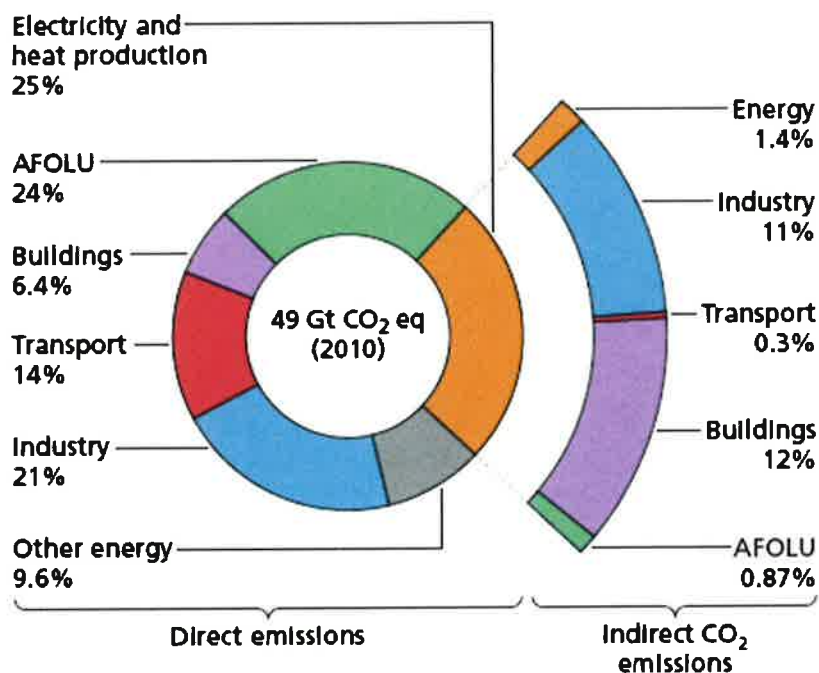
*Source: Food and Agriculture Organization of the United Nations. "Pesticide Use." Latest update: 7/18/2014.*

<http://faostat3.fao.org/faostat-gateway/go/to/download/R/RP/E>.

The non-energy sphere is therefore responsible for around one-third of the total GHG emissions. These include CO<sub>2</sub> emissions, CH<sub>4</sub>, N<sub>2</sub>O, and chemical pollutants from specific chemicals like hydrofluorocarbons. Within the broad category of non-energy GHG emissions, agriculture plays by far the predominant role, both in the direct impacts of farming and the indirect impacts of deforestation and land-use change to make way for farming and livestock management. Of course, agriculture also emits CO<sub>2</sub> through energy use, for the planting, harvesting, storage, and transport of agricultural products.

Agriculture is a major source of CO<sub>2</sub> emissions through land use, but also a

major source of the second- and third-ranking GHGs. Methane is emitted in the production of certain crops, notably paddy rice, and by livestock, through the natural processes of their digestion. Nitrous oxide is also emitted from agriculture, for example, through the chemical changes to nitrogen-based fertilizers. Instead of being taken up by the plants, the nitrogen in the fertilizer volatilizes (evaporates) and also goes into the water supply. Livestock and fertilizer use thereby emit  $N_2O$  in large amounts.



## 10.14 Sources of greenhouse gas emissions by economic sectors

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*Source: IPCC AR5 Summary for Policymakers. Total anthropogenic GHG emissions (GtCO<sub>2</sub>eq/yr) by economic sectors. Inner circle shows direct GHG emission shares (in % of total anthropogenic GHG emissions) of five economic sectors in 2010. Pull-out shows how indirect CO<sub>2</sub> emission shares (in % of total anthropogenic GHG emissions) from electricity and heat production are attributed to sectors of final energy use. "Other Energy" refers to all GHG emission sources in the energy sector. ... The emissions data from Agriculture, Forestry and Other Land Use (AFOLU) includes land-based CO<sub>2</sub> emissions from forest fires, peat fires, and peat decay that approximate to net CO<sub>2</sub> flux from the Forestry and Other Land Use (FOLU) sub-sector. ... Emissions are converted into CO<sub>2</sub>-equivalents based on GWP100 from the IPCC Second Assessment Report.*

Indeed, the natural nitrogen cycle has now been overtaken in quantity by humanity. In nature, the N<sub>2</sub> molecules in the atmosphere are converted into reactive nitrogen through various biological processes of nitrogen-fixing bacteria, as well as by lightning. Yet now

humanity is converting more  $N_2$  into reactive nitrogen than even nature itself. Humanity does it through industrial processes that convert atmospheric nitrogen into ammonia and other forms of reactive nitrogen. Back in the early years of the twentieth century, two great chemical engineers, Fritz Haber and Carl Bosch, developed a process that some consider to be the twentieth century's single most consequential industrial innovation. The Haber-Bosch process is a way to break that  $N_2$  triple bond through the application of high amounts of energy and the use of various identified catalysts, and create ammonia in a large-scale industrial process. This ammonia can then be used to provide the base stock for urea and other nitrogen-based fertilizers. This process, developed between 1908 and 1912, solved the scarcity problem of nitrogen nutrients needed to increase global food production. Up until the Haber-Bosch process, nitrogen deposited on soils came either from the

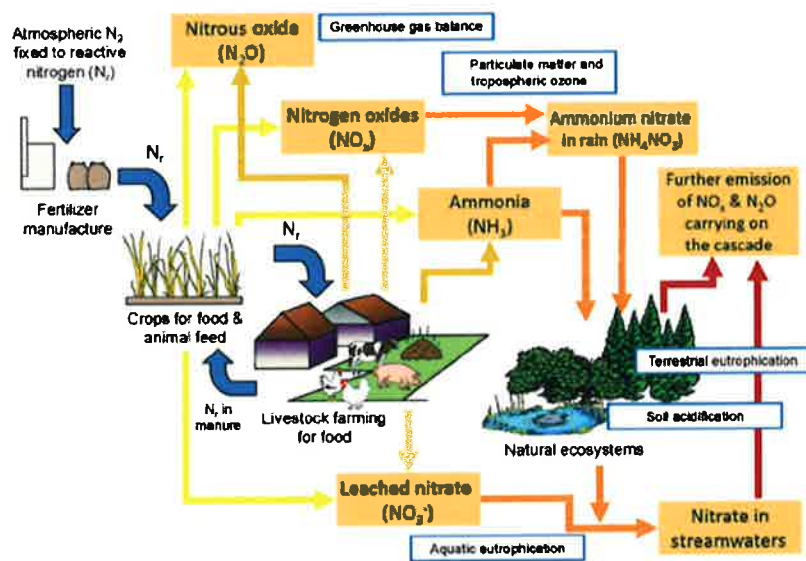
manures of farm animals or from the mining of bird and bat excrement (guano), largely off the coasts of Peru and Chile. But those guano deposits were being quickly depleted, and there was a nitrogen crisis developing at the end of the nineteenth century. Along came the Haber-Bosch industrial process, which spurred production of nitrogen-based fertilizer. What was then a world population of fewer than 2 billion people could thereby become a population of more than 7 billion people one century later.

It was the advent of nitrogen-based fertilizer, along with high-yield seed varieties of the Green Revolution and other agronomic advances, that made it possible to produce enough food to support 7.2 billion people (recognizing that a large number of those 7.2 billion are not well nourished!). Yet with all that nitrogen now being converted from  $N_2$  into reactive nitrogen, there is a huge problem, shown in the complicated flow chart in [figure 10.15](#). What happens to

all that chemical nitrogen when it is used in the farms? It runs off into the water supplies and volatilizes into the air, to be carried by the winds to land and water downwind. When reactive nitrogen enters the water supply as nitrates, it creates major dangers to the water supply and ecology. Some of the reactive nitrogen runs into the rivers and the sea, which leads to algal blooms and nitrification in downstream estuaries. Some of it enters the atmosphere, not as  $N_2$ , but as  $N_2O$ , a GHG. Some of it enters the atmosphere not as  $N_2O$ , but as  $NO_2$  (nitrogen dioxide), which causes smog and local pollution.

The graphic from a European Union study in [figure 10.16](#) shows the host of problems arising from the heavy use of fertilizers: more GHGs released; soil acidification; threats to water quality from nitrates and the nitrites in the water supply; eutrophication of the downstream estuaries; and fall in air quality as  $NO_2$ ,  $NO_3$ , and other nitrogen-

based molecules enter the urban atmosphere to create smog, tropospheric ozone, and massive health hazards in our cities (Sutton et al. 2011).

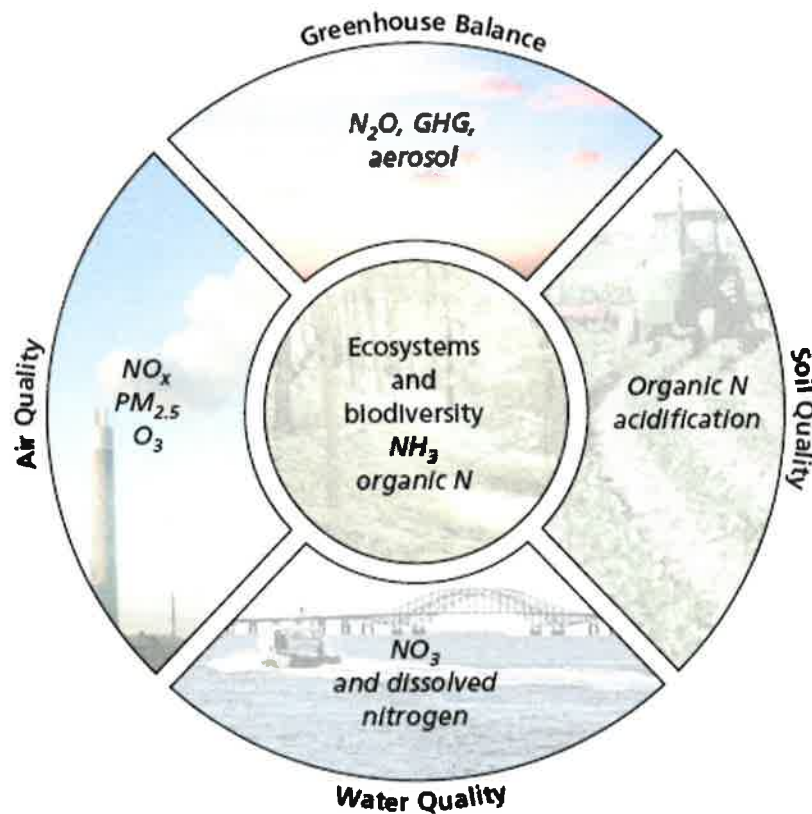


## 10.15 The nitrogen cascade

*Sutton et al. 2011. Reprinted with permission from Cambridge University Press.*

Here then is a major dilemma that is rarely discussed in our day-to-day life. We absolutely need the nitrogen, including the chemical fertilizers, for our global food production. Yet the multiple negative impacts of nitrogen on the

physical environment, from climate change to eutrophication to urban smog, are serious and growing. The map in [figure 10.17](#) comes from a study showing estuaries around the world suffering from eutrophication, particularly from nitrogen- and phosphorous-based fertilizers off the coasts of the economies with high rates of fertilizer use. The zones in red are “dead zones” in the coastal areas, where eutrophication (excess nutrient loading) has been followed by algal blooms and then by the bacterial decomposition of the algae leading to the depletion of oxygen in the water and a killing off of marine life. The problem is growing and is likely to get worse unless we address how to use the needed nitrogen in a more responsible way, for example, through far more precision in the use of chemical fertilizers to reduce the runoff and volatilization of the reactive nitrogen.

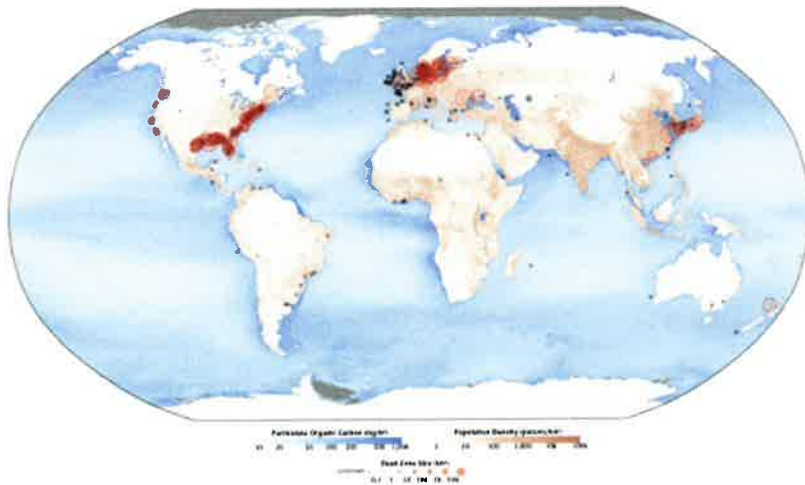


## 10.16 Key societal threats of excess reactive nitrogen

*Sutton et al. 2011. Reprinted with permission from Cambridge University Press.*

Another key area of heavy agricultural impact is on forests. Forest loss is occurring in all of the great rain forest regions, including the Amazon basin, the Congo Basin, and the Indonesian archipelago. In the Amazon, the clearing of the rain forest to make

way for new pastureland, farmland, and construction of infrastructure accounts for most of the deforestation. Fortunately, there has been some reduction of Amazon deforestation in recent years. In Southeast Asia, tropical hardwoods are in huge demand for the booming economies of Asia, especially China. Logging and clearing of the rain forests to grow tree-crop plantations also account for a major part of the destruction of original rain forest.



## 10.17 Marine dead zones (2008)

*NASA's Earth Observatory.*

In Africa, there is yet another driver: peasant smallholder agriculture. This is

not large-scale clearing for logging but the spread of smallholder farmers into the forest margin. Often there is significant deforestation from the use of the forest for fuel wood (e.g., to make charcoal). In the wealthier rain forest regions of the Amazon and Southeast Asia, the fuel wood problem is typically not as severe, because there are alternative energy sources. But in the Congo Basin and other forest areas of Africa where populations are very poor and alternative fuel sources are not available, charcoal is used in such large amounts that it is an important driver of the deforestation and habitat loss of other species.

In each of these areas, in order to preserve habitat, protect biodiversity, and reduce the GHG emission consequences of deforestation, actions that are responsive to the particular challenges in those areas and the particular needs of the local populations clearly need to be encouraged. This will not only play an enormously important

role in helping to reduce the rate of climate change but will also be absolutely vital if we are to succeed in heading off the massive loss of biodiversity.

## V. Toward a Sustainable Global Food Supply

Creating a sustainable farm system around the world is absolutely vital. The farm system must simultaneously feed a growing world population and reduce the tremendous pressures our current systems are placing on the Earth's key ecosystems. And the farm systems need to be made more resilient to climate change and other environmental changes that are already underway. We need to think about what will happen if we continue with business as usual (BAU), and contrast that with what we really need to do, which is reshape our own behavior with regard to food. We must reshape farm systems and create

an alternative trajectory of sustainable development.

What are the threats of the BAU path? The chart in [figure 10.18](#) attempts to summarize those risks and gives an expert assessment of how serious the particular risks are in particular regions of the world (SDSN 2013c, 10). The boxes that are shaded red are major alerts—these are places in the world where the challenges are of the first order of significance. The boxes that are yellow are like yellow warning signs—things could get bad in these areas with regard to these particular threats.

Business as usual will mean an increase in food insecurity in some parts of the world. The places under greatest threat are sub-Saharan Africa and South Asia, the two epicenters of undernutrition. But one should also note the growing threat to North Africa and the Middle East, because these are places where all of the climate evidence suggests there will be significant drying in the future, and therefore crop

production will be under even greater threat than it is today.

Certainly the BAU course also means considerable dangers for East Asia and Southeast Asia, because these regions will be places of tremendous water stress and places where higher temperatures will wreak havoc on the food supply. Malnutrition from deep undernourishment will continue to have its epicenter in sub-Saharan Africa and South Asia. On a BAU path, the other kind of malnutrition, obesity, is likely to worsen in North America and many parts of Latin America. It is already at epidemic proportions in Mexico. There are serious risks in Southeast Asia, East Asia, India, and other parts of South Asia as well.

	North America	Latin America and Caribbean	Europe	Middle East and North Africa	Sub-Saharan Africa	South and Central Asia	Southeast Asia and Pacific	East Asia
Food insecurity				H	H	H	M	M
Malnutrition					H	H	M	M
Obesity, health	H	H	H			M	M	M
Poverty				M	H	H	M	M
Poor rural infrastructure		M		M	H	H	M	M
Land use change		H			H	M	M	M
Soil degradation				M	H	M	M	H
Water shortage	M			H	H	H	M	M
Water and air pollution	M		M	M		H	H	H
Biodiversity loss	M	H	M	M	M	M	H	H

## 10.18 The risks of business as usual

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*Source: Rockström, Johan, Jeffrey D. Sachs, Marcus C. Öhman, and Guido Schmidt-Traub. 2013. "Sustainable Development and Planetary Boundaries." Background Paper for the High-Level Panel of Eminent Persons on the Post-2015 Development Agenda. New York: Sustainable Development Solutions Network.*

Land-use change will have huge costs, especially in the rain forest regions. That means costs in Latin America, sub-Saharan Africa, and parts of Southeast Asia. Soil degradation is already a major crisis in parts of sub-Saharan Africa and South and East Asia, where the land has already eroded. The soils often have been swept away due to farmers trying to grow crops on steep slopes or in places where the winds blow the topsoil away, as is occurring in many parts of China. Biodiversity loss is also a moderately or acutely high threat in every region of the world.

While there are a few regions that will escape some of these risks, there are no regions that will escape all of them.

Today's poor regions are in extreme peril, because they are already living on the edge. They already have people living in fragile environments, such as in tropical or dryland ecosystems. Part of their poverty has come from the fact that the natural environment is already fairly inhospitable. With environmental change, what is currently a difficult environment can quickly become an impossible environment for support of human life. When that happens, people will suffer, die, have conflict, and migrate. There will be environmental refugees created by the millions, possibly even hundreds of millions. In a world not often open to migration, poor newcomers forced to move can face a very hostile environment when they arrive. We are in for a lot of trouble if we maintain the BAU trajectory.

How do we move to a sustainable development (SD) trajectory? Because of the complexity of the food system; the interlinkage of land use, nitrogen use, and chemical pollutants; and the

vulnerability of crops to higher temperatures, the kinds of responses that are needed will have to be varied, holistic in nature, and carefully tailored to local contexts. This is among the toughest sustainable development challenges that we face, because the world is in crisis and the problems will tend to get worse. It is not easy to say that one region will bail out the others, because all regions will have stresses. There will be no magic key that will suddenly make it possible to solve this problem. Each region is going to have to identify its own pathways to sustainable agriculture.

What are some of the things that can be done? The first is to improve the ability to grow food. We should be more productive in terms of higher yields per unit of land area and more resilient in terms of the ability of food crops to withstand the shocks that we already know are coming. Just as Norman Borlaug and his colleagues M. S. Swaminathan and Chidambaram

Subramaniam made the Indian Green Revolution possible, we are going to need another Green Revolution of new crop varieties that will be especially propitious for the environmental challenges ahead.

For some regions this will mean a focus on drought-resistant varieties of crops, because the frequency of serious droughts is likely to become much higher. Certain plants in nature have a high level of drought tolerance. Plant scientists are now attempting to identify those genes and through various means, both conventional plant breeding or advanced genetic modification, to create new crop varieties that also share drought resistance. Natural breeding techniques have already helped to develop new seed varieties that are better able to withstand bouts of low rainfall during the growing season. The creation of genetically modified organisms (GMOs), or GMO crops, has taken the experimental pathway of identifying the

gene complexes in naturally occurring drought-tolerant plants and transplanting those gene complexes into crops.

Many people find this idea of genetic modification to be very threatening, risky to the environment and potentially to human health. Whatever is done in this research domain of cutting-edge genomics needs to be tightly monitored and regulated, but I would argue that we should certainly test these technologies to see what they have to offer. It seems very promising that by identifying genes for drought resistance or saline tolerance, we can get major advances in food security. We should therefore not dismiss a whole class of technology so quickly. While GMO technologies may pose certain risks, those risks are likely to be controllable and monitorable. The underlying technology itself may offer huge breakthroughs in food security in an age when we will need such breakthroughs.

The second step of what can be done

is to make crop varieties more nutritious. Crops should not only grow better in harsh conditions, but they also should be more nutritious. Of course part of an improved diet involves choosing the right crops in the first place, with a well-balanced diet with fruits, vegetables, whole grains, and plant oils. Part of the solution is to make a particular crop (e.g., rice) more nutritious. This is the idea of the so-called golden rice, a crop that has been developed by the International Rice Research Institute (IRRI) in Los Baños, Philippines. The IRRI helped bring about the Green Revolution in rice. Now its scientists are reengineering the rice genome to express beta-carotene, a precursor for vitamin A, so that children who eat the golden rice will have the vitamin A they need, which will help to combat one of the key kinds of hidden hunger.

The third direction is absolutely essential and is known as “precision farming” or “information-rich farming.”

Such precision farming is already in widespread use in high-income countries. The point of precision farming is to economize on the use of water, nitrogen, and other inputs into production, so that more food can be produced with less environmental impact. In the coming years with the declining costs of information technology, poor farmers will use these techniques too. Precision farming involves, for example, a more precise application of fertilizer, so that there is less volatilization and runoff of fertilizer not taken up by the crops themselves.

Precision agriculture depends on information technologies, on detailed mapping of soil types, and often on global positioning systems that can tell a farmer exactly where that farmer is in the field and what is happening in the soil in that part of the farm. This kind of precision farming is on its way to the middle-income and poor countries, and it continues to be developed at lower costs. It is very promising, because it

efficiently uses scarce resources and enables farmers to cut down significantly on the amount of fertilizer applied on the soil. Farmers can then economize, make a better income, not waste as many resources, and decrease their environmental impact.

More generally, better nutrient management can occur through better soil testing, soil mapping, and localized chemistry. Reading the qualities of the soil on handheld devices or from satellites makes it possible to get far more detailed resolutions of soil needs. This kind of soil nutrient management offers places with soil nutrient depletion a massive potential boost in yields. Africa is the first in line for this yield boost. It also offers places that use far too much fertilizer, such as China, a way to cut down very sharply on their fertilizer use.

Another breakthrough that lies ahead is improved water management. We need to apply less water to get more “crop per drop,” because we are already

depleting the scarce water we have and because the water challenges will get tougher in the future. That is not only because of water depletion but also because of the consequences of climate change. Solar-powered irrigation can play a very important role in microirrigation technologies, especially to help smallholder farmers.

Another major breakthrough that will offer us a tremendous opportunity will be better harvesting, storage, and transport of crops to avoid the very large losses of foodstuffs that now occur from farm to plate. Such food waste is often estimated to be around 30–40 percent of total food production. These large losses come from rodents and pests, food rotting, physical loss of the crops, exposure to rain, and so forth. Simple, low-cost means of more effective storage systems, better incentive systems for food handling, and the empowerment of local farmer cooperatives to invest in community-based storage facilities offer a

tremendous hope for reducing losses in the agriculture value chain in low-income, hungry settings. These improvements will not only lead to large gains in farm incomes and more food security, but also to fewer human pressures on the environment.

Better business models for poor smallholder farmers are vital, not only for ending extreme poverty but also for empowering smallholders to make investments in improved crop varieties, irrigation, water management, and storage, all to raise farm yields and incomes. There are gains to be achieved through the aggregation of smallholders into farmer cooperatives and farmer-based organizations. These new business models can improve value chains and incomes.

Finally, we have to take responsibility ourselves for our personal health and for the way we approach the issues of food as individuals. Massive epidemics of obesity show that something is seriously wrong with prevailing diets. A

lot of the problem comes from the fact that our governments have subsidized the wrong kinds of foods. Carbohydrates, trans fats, and other kinds of fast foods that are absolutely unhealthy are heavily subsidized and widely consumed. Our economic incentives have often been aligned against the very kinds of foods that are better for our health. We have subsidized, in effect, the feed grains that have led to massive overconsumption of beef in the United States and Europe, to the point where so much meat is eaten that it is detrimental to human health and is exceedingly damaging for the environment. Deploying 10 or 15 kilograms of feed grain for every kilogram of beef that is consumed tremendously multiplies the burdens on the land, on fertilizer use, and on water supplies, which aggravates all of the natural problems.

We have also been aggravating these problems more recently by diverting

invaluable food production into the gas tank! In the United States, through unjustified subsidies driven more by politics than by any common sense or ecological insight, the U.S. government has turned a significant part of the annual corn (maize) production into ethanol for automobiles. This is a miserable deal because of the amount of vital resources needed to produce that ethanol. The maize-to-ethanol strategy creates no savings for the natural environment and diverts a tremendous amount of food production away from the food chain. These subsidies thereby push up food prices and place extra pressures on the natural environment. All this is being done at the behest of a few powerful companies with powerful lobbies in Washington (and comparably in European capitals). This is an example of where behavior and policy have gone awry.

The conclusion is as we have noted time and again: the pathway to sustainable development involves

behavior change, public awareness, political and individual responsibility, and the mobilization of new systems and technologies that can dramatically reduce the pressures on the natural environment and help make our economy and way of life more resilient to the environmental changes already underway. Sustainable agriculture and food security remain a huge unsolved, yet solvable, problem. It is one of the areas that will require the most intensive problem solving at local levels all around the world. For these reasons, sustainable food systems and the fight against hunger have a major place in the Sustainable Development Goals that were recently adopted.