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Chapter 3
AGRICULTURE FROM 2000 TO 2050—THE BUSINESS AS USUAL SCENARIO

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INTRODUCTION

Global food demand is expected to double by 2050. The question is whether there will be enough food to meet this demand. If sufficient food is not available, the question then becomes what that does to global food security. More importantly, if there is insufficient food, who will get it? At the individual level, will there be a rise in infant mortality and malnutrition, an increased number of children who do not achieve the mental capacity they would have had with adequate nutrition, and an increase in the incidence and severity of disease because of the compromise of people's immune systems? At the level of societies more broadly, will development be held hostage to food shortages; will further social equity gains be held hostage by efforts of a few to maintain their consumption levels; and will social conflict, famines and food refugees increase?

The challenge of feeding more than nine billion people is daunting. If global consumption doubles as many predict, the challenge is even greater. From an environmental perspective, what may or may not have been sustainable land use and farming practices with six billion people will certainly not be sustainable with more than nine billion. At the level of farming, the challenge is just as daunting. Today, half of the world's billion farmers cannot feed themselves. The remainder produces enough surplus' to feed 10. By 2050, as many as three quarters of farmers could well not feed themselves, but the remainder will need to feed 20, each consuming more than twice the levels at this time.

However, if current trends continue, by 2050 there will not be enough food to meet the expected needs of the combined demand posed by anticipated population and consumption increases. If this happens, either population or consumption will not increase as anticipated, or the number of people who are malnourished will increase. Moreover, if insufficient food is produced or if it is not distributed equitably, then the environment will suffer. The deterioration of key environmental parameters will reduce, in turn, the ability to produce food in the future. The chronic erosion of the resource base required to produce food creates a vicious cycle. The question is how do we prevent this from occurring?

This chapter is organized around the concept of "business as usual." The key trends related to the agriculture and food production systems that we need to achieve food security by 2050 and still have a livable planet are identified and discussed. However, the overriding question is, "What will happen if we do nothing between now and 2050 that changes the basic trajectory of food production?" We know that humans will adapt. So in that spirit some innovative approaches are identified and discussed, but without concerted effort it is unlikely that those innovations will permeate to the extent and in the time frame necessary to make any real difference in overall global performance by 2050.

1. The Problem

Most experts expect global population to peak at about 9.1 billion by 2050 (UNPF 2005). This represents an additional 2-3 billion or so people on the planet than in 2000. In addition, by 2050 global per capita income is expected to increase by 2.9 times the 2005 level with income in developed countries increasing by 1.6 percent per year and in developing countries by 5.2 percent per year (World Bank). Gross development product (GDP) is expected to increase faster on average in the period 2000-2050 than it did from 1930 to 2000 (Angus Madison, University of Groningen for the historical data and Jeff Malcolm, personal communication, for projecting the growth rates until 2050).

What is disturbing about this picture is that several studies have shown that during periods of rapid economic growth, not all segments of the population benefit equally. Indeed, some of the poorest populations may actually be worse off. Clay (1979), for example, found that during the United States Civil War the global price of cotton increased several fold. This stimulated massive shifts in planting to accommodate this market in Brazil, Egypt and India among other places. In Brazil, increased cotton prices led to the severe reduction of food crop production and the elimination of tenant and sharecrop relationships in favor of wages. Unfortunately, while wages increased faster than ever before, they could not keep pace with increases in food prices. As a consequence malnutrition, overall death rates and infant mortality rates soared for the bottom quarter of the population. This phenomenon was repeated in the 1960's when the US shifted its sugar purchases from Cuba to Brazil, triggering another shift away from subsistence and food crops to cash crops. Similar trends were noted during the rapid expansion of biofuels in 2006-08. In short, increased economic growth, per se, especially when it is based on global averages rather than improvement for the bottom quartile of the population, is not always an accurate measure of economic development.

While wealth will certainly not be distributed evenly, globalization may well lessen some of the largest global inequities.

Overall global food consumption is expected to double by 2050, driven largely by the increase in per capita income over the same period. However, consumption increases will not be distributed evenly.

By 2050, the wealthiest 2 billion will be able to afford just about anything they want to eat, but in general will not consume more calories than they do today. The poorest 2 billion people, by contrast, will be concerned (as are the poorest billion today) primarily with obtaining sufficient food each day to maintain themselves and their family. These consumers are the poorest on the planet, and meeting their daily caloric needs will continue to be a challenge that they largely are unable to accomplish. Evidence to date suggests that this challenge could be intensified if the poorest people on the planet continue to spend proportionally more of their income on alcohol and tobacco than other income groups.

However, the real issue with regard to food security is what the 5 billion people in the middle do. History suggests that as poor people make more money they tend to invest it initially at least in better food rather than houses, cars or other consumer goods.

For this middle group of consumers, the issue is no longer one of enough food as with the poorest people but rather the focus is on the types of calories they consume. The middle group will consume more animal protein and more oils, vegetables and fruits. Because of the other food calories (e.g. to produce animal protein) or land that it takes to grow these products, basic food calories will most likely become more expensive for all, but will be felt disproportionately by the poorest consumers.

At this time, hunger and malnutrition are in fact the number one risk to health worldwide, not disease. And, the number of undernourished is increasing. Today about half of the undernourished are small-scale subsistence farmers who are not only unable to feed themselves; they are also unable to generate surpluses to feed others. About a quarter are rural landless and a quarter live in cities (UN Millennium Project 2005). However, this is already changing. The number of small farmers globally, for example, has been declining since 2000.

By 2050, most of the world's poor will be living in cities not rural areas, so key issues about food security will also revolve around infrastructure and availability, unemployment rates and wage levels. To put this another way—between increased income and demand, the poorest two billion of the global population could represent three times as much demand for food they do not produce for themselves as they did in 2000.

For the five billion consumers that fall in the middle of global income, the primary issue between now and 2050 will be to improve the quality of the food they eat. In the past this has been defined as eating up the food chain—eating more meat and animal protein, vegetables and fruits as well as more ready to eat and processed food. Given the opportunity, these five billion people will probably diversify their diets more than the middle income earners did in the last fifty years as health and wellness awareness will probably drive this segment of the population to consume increased quantities of fruits and vegetables. In addition, if global trends continue, these five billion people will consume what is produced further from where they live than today. By 2050, the “middle” five billion consumers will represent the most significant increase in global consumption both of total calories and also of animal protein.

2. Food—The Legacy of the Past 50 Years

To understand the business as usual scenario for food production and food security over the next 40 years, it is important to understand the current trends and baseline. The number of undernourished people in the world is increasing, even while the production of agricultural commodities is at an all time high. The United Nations Food and Agricultural Organization (UN FAO) documented 1.02 billion people – roughly 1 out of every 6 people in the world – as undernourished and hungry by June 2009 (UN FAO 2009).

Poor and hungry populations can spend up to 60 percent or more of their incomes on food and still go hungry (Clay 2004). Therefore, small increases in food prices can have disproportionately large impacts on the number of people that are unable to afford food. The latest estimate of hunger is a 100 million person increase over just a year ago and nearly 200 million more than 1995-1997 estimates of 825 million undernourished. If this trend continues until 2050, between 1.5 and 2 billion people on the planet then will have insufficient food—and the majority will live in cities. However, if climate change has a significant impact on food production, then the figure could be much higher. Today most people on the planet are dependent on domestically produced food—more than 90 percent of all food is consumed is the country in which it is produced. Variability could affect domestic food supplies. It is not clear that there are either sufficient global surpluses to offset these changes or global infrastructure and distribution systems effective enough to relieve the problems.

By 2010, as many as 10 million people (more than 25,000 per day) die from hunger or hunger-related causes each year. By 2050, if nothing is done, 14 million people (more than 35,000 per day) will die from hunger or hunger-related causes each year. Hunger and the lack of adequate daily caloric intake hit children the hardest. Fully 17 percent of those considered hungry are children less than six years of age who will bear the long-term consequences of early childhood malnutrition and developmental issues even if they escape their hunger later in life.

3. Productivity Projections to 2050—Business as Usual on the Farm

Total global cereal production increased 84 percent in the 30-year period between 1967 and 1997. This translated to a 10 percent increase in per capita cereal production, however, as global population also increased rapidly during the same period. Simultaneously, more cereal grains have been used to produce animal protein during this period than ever before in human history. This has reduced the available food per capita for direct consumption. In the latter half of that same period, real world prices of rice and maize declined by roughly 30 percent, and the number of undernourished people in developing countries declined from 920 million in 1980 to 825 million in 2001.

China was one of the key reasons that both the price of rice and maize and the number of undernourished both declined during this period. Productivity of cereals in China improved dramatically, and nearly all the global gains in hunger reduction were achieved in China. Thus, when China is removed from the global data, undernourished populations in the rest of the developing world actually increased from 1980 thru 2001.

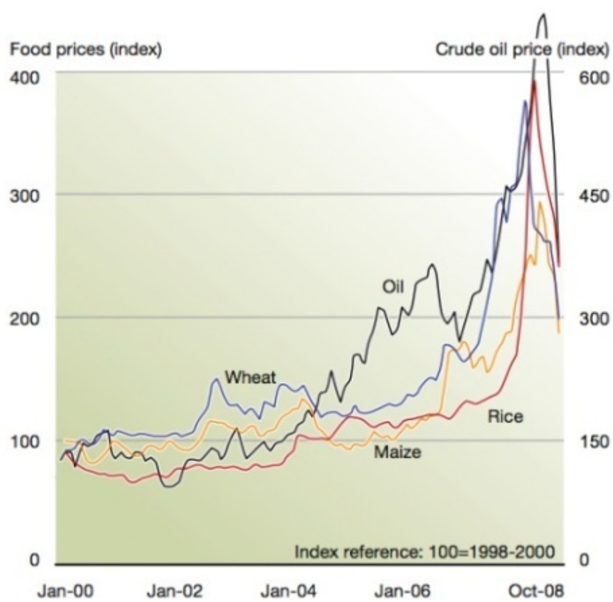

Figure 3: Changes in commodity prices in relation to oil prices. (Source: FAO, 2008; IMF, 2008).

Most recently, the real prices of food and the number of undernourished people have risen dramatically before settling at levels that were still considerably higher than just a few years ago. Most analysts attribute these changes to China as well. Increased economic growth in

China, beginning in the 1990's and accentuated in the 2000's, translated to increased consumption of food in general in China and increased consumption of animal protein in particular. After August 2008, many agricultural commodity prices began to fall. Prices are not expected to fall significantly or for long, however. Lower prices triggered increased purchases in China. For example, in the first quarter of 2009, China imported 30 percent more soy (three quarters into a global recession) than it did in the first quarter of 2008. Similarly, in 2009 China took advantage of a downturn in palm oil prices to stockpile palm oil and this tended to buoy prices, at least compared to what they might have been. The issue, both analysts and buyers say, is not the price of raw materials but whether they are available at all. Most retailers, manufacturers and brands acknowledge that they will have to pay more for raw materials on a finite planet with more people and increased consumption. Prices are bound to increase. The issue is will the private sector have access to the raw materials they need to make their products at any price.

Total calories—Which are the most important?

The top five crops that provide most daily caloric intake are wheat, rice, maize, sugar and soy. These five crops provide approximately 67 percent of the global calories consumed directly, accounting both for calories consumed directly and those fed to livestock and destined for human consumption. However, maize, soy, wheat and rice comprise about 75 percent of the caloric content of food production worldwide (EAERE 2009). By comparison, the next five crops (potatoes, palm oil, barley, sorghum and sunflowers) provide just 9 percent of daily calories. Maize and soybeans are the dominant sources of indirect caloric intake, followed by wheat and barley.

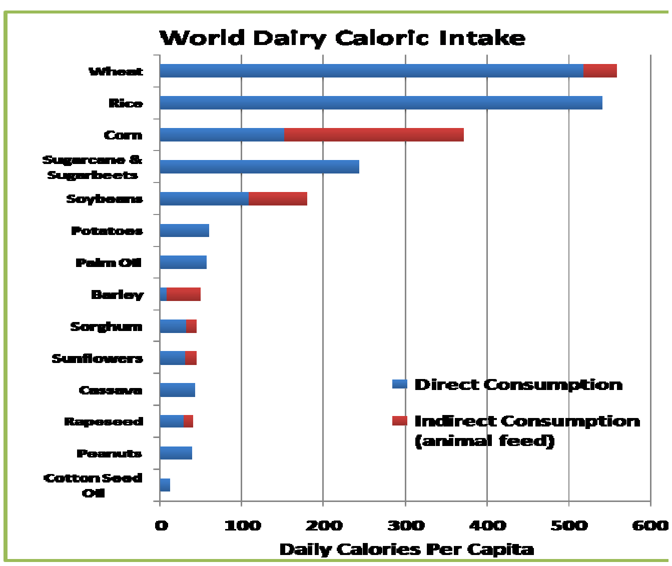

Figure 7: Top global crops based on cropland use (Source: FAOSTAT)

Calories vs. nutrition

Leaving nutrition aside for a moment, simply counting calories of food production and projecting caloric requirements into the future may underestimate the total demand for food by 2050. As noted previously, diets historically have changed as incomes improve, one change being increases in animal protein consumption. Smil (2000) has argued that when societies consume 10 percent or less of their total calories from animal protein, that protein can be produced with agricultural and food wastes. However, as the consumption of animal protein reaches 20 percent, then globally twice as much land needs to be devoted to the production of cereal grains and other sources of animal feed.

Calories are probably the best baseline for global food demand, particularly if the focus is on poor, at risk populations. Globally, for the one billion people who cannot afford sufficient food at this time, the issue is more one of calories than nutrition. For this group, simply meeting their caloric requirements is a challenge. Add to that the fact that this group tends to be more involved in manual labor and other forms of energy intensive employment than other segments of the population, the need for basic calories is accentuated.

That said, global increases in demand for all sources of animal proteins and diets that are diversified to include adequate levels of both macronutrients and micronutrients will have an impact on the availability and price of cereal grains and foods that can be fed to animals. As a consequence, shifts toward animal proteins (meat, poultry, fish, dairy, eggs, etc.) will have a disproportionate impact on the demand for cereal grains and oilseed commodities. It takes several calories of cereal grains or foods used to feed animals to produce the animal proteins that are consumed increasingly in the global diet. In the US nearly 28 percent of the average American diet comes from animal protein compared to a global average of about 17 percent (EDF 2007).

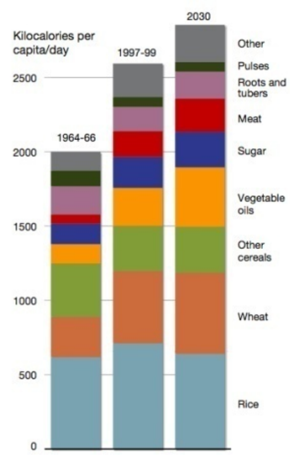

Figure 4: Changes in historic and projected composition of human diet and the nutritional value. (Source: FAO, 2008; FAOSTAT, 2009).

Increased income also drives increased demand for diversified sources of micronutrients from foods such as fresh fruit and vegetables. Traditionally, staple crops such as rice, wheat, or cassava have been thought likely to continue to increase in demand, albeit at more modest rates than those specifically suited to supply the nutritional requirements of an ever more affluent global population. As food security becomes an issue of increasing importance, the conflict between using calories to feed the poor versus using them to produce animal protein for wealthier consumers will become not only more transparent, but a more public and political issue as well. In a resource constrained world, starches, cereals and grains are "poor people's" foods. This is likely to continue or even increase as the norm rather than the exception.

Genetics and productivity

Humans have been improving production through genetic selection since agriculture began. For 99 percent of history this process was rather hit or miss and based on farmers saving seeds and saving animals. Only with the discoveries of the Augustinian Monk Gregor Mendel 150 years ago and with subsequent breeding programs, did we begin to understand how genetic traits were passed along. That work led to more targeted genetic gains and increased productivity through the selection of traits and selective breeding. During the first half of the Twentieth Century, improved breeding techniques and new varieties, including hybrids, were developed. These techniques were applied to the world's three most important cereal grains—wheat, rice and maize. By 2000, hybrids still did not dominate global production, but they were the norm in developed countries (e.g. in the US where hybrid maize produces four times as much as previous varieties) and increasingly important even in developing countries. For example, today more than 50 percent of China's rice crop comes from hybrids, which produce about 20 percent more than their counterparts.

Genetic engineering and modification: By the 1990's, advances in technology allowed more sophisticated genetic changes, including engineering and modification. Genetic engineering technology allows for the isolation and selection of traits within any genome. Genetic modification technology allows for the insertion of selected traits from one species into another. While genetic engineering can be focused entirely on a single species, genetic modification is the deliberate insertion of traits from one species into another (thus resulting in genetically modified organisms or GMO's). To date, less emphasis has been placed on selecting for traits within a species, although the ability to map individual genomes and to identify traits that can be turned on or off has the potential to be one of the most significant contributors to the overall increase in the production of food by 2050. And this technology, when more widely applied, will change agriculture forever.

We now have the ability to identify traits within a genome to increase productivity, increase drought resistance, and increase pest resistance. Scientific advances will also allow us to identify and improve other traits (increased efficiency of input uptake or even producing inputs within the plant, the production or enhancement of beneficial nutrients or oils, etc.) that will increase value to producers and consumers alike. These programs could improve overall product quality, flavor profiles, nutritional benefits, shelf life, and carbon sequestration while reducing input demands, water content, embedded carbon and water, and losses from waste throughout the value chain.

To date, most recent genetic work has focused on agrochemical tolerance and disease and drought resistance. These traits have tended to improve production, reduce input use, reduce environmental impacts, and increase farmer income. The crops that have benefited most from this technology to date are maize, soy, and canola. Two of these crops are in the top ten global calorie producers. All three are in the top 15. In short, genetic engineering work to date has focused on 20 percent of the world's most important crops with regard to total calorie production. The work on rice is ongoing, but it has lagged behind and met stiff consumer resistance in some countries. Business as usual with regard to genetics will not produce sufficient gains at the rate of current efforts to double current production to meet the caloric demand expected by 2050.

Leaving genetic engineering and modification aside, recent productivity gains from plant breeding alone suggests that it only will increase caloric production by 50 percent by 2050. In fact, recent production gains in wheat and rice (which account for about half of global calories each year) would increase yields by less than 70 percent by 2050, less than we need to meet most estimates of increased consumption needs. Of the top 15 caloric crops, only the current gains in sugar beet productivity would double production by 2050, and sugar beets are not important calorie crops globally. In particular, sugar beets are not produced in the areas where the greatest consumption is expected.

Opportunities for production gains: Still, global averages may be less important than the range of production and performance around the world or even within a single country. The highest productivity levels for most crops exist in countries where food security is generally a less important issue. For example, maize yields in Brazil, India, Mexico, and China would have to increase considerably if they were to achieve the average production of the Unites States. In many crops, however, the countries that are lagging behind the leaders are getting further behind, not catching up. Business as usual will not allow them to produce the food that is necessary even though producers in such countries could easily double their production using currently available technologies and inputs. Increasing global production of calories will most likely be as much about disseminating current technologies as it will be about developing new ones. In the face of this observation, however, the most significant global trends today are to reduce agricultural extension services in both developed and developing countries.

Globally, production gains can be made from a wide range of different breeding programs from the oldest and most traditional technologies on the one hand to the most advanced and high tech on the other. Each will likely be significant in different parts of the world and for different crops. Traditional plant breeding programs, land races, and hybrids are all important if we are to produce sufficient food to benefit all by 2050. In addition, through genetic engineering we also have the ability to identify and select specific traits within a species by leapfrogging some of the more traditional breeding techniques.

Most plant genetics research is conducted by the private sector, not governments. As a result, companies focus on the crops that offer the biggest, short-term commercial returns. This usually involves those planted on the largest areas and with the largest number of farmers who are able to purchase the technology. Consequently, most research is now being undertaken on temperate, annual crops in developed countries. For the past couple of decades, companies have attempted to adapt crops that now dominate in temperate zones (e.g. maize and soy) so that they can be produced in the tropics. There has been some success with soy, although this effort was sponsored by the Brazilian government rather than the private sector. That breeding program allowed soy to tolerate the aluminum rich soils in Brazil's Cerrado and Amazon regions.

However, the biggest genetic gains in the future will probably come from working on tropical crops that have largely been ignored to date. For these so called "orphan crops," genome mapping technology and research could allow far bigger gains than in lesser known crops. Genetic engineering technology also lends itself to far more significant productivity gains in perennials, particularly tree crops, than have ever been achieved through conventional, hit-or-miss plant breeding programs. Mars, IBM, US Department of Agriculture (USDA) and other international entities are paving the way for this strategy with cacao. Their initial findings suggest that they will be able to identify traits within the genome that increase production four-fold, e.g. why 20 percent of the trees in cocoa plantations produce 80 percent of the crop. Work on drought tolerance also suggests that production could be doubled by identifying drought tolerant traits within the species and either enhancing them genetically or by providing water during the dry season as a management practice. In the case of cocoa, by 2050 it could be possible to produce 320 percent as much cocoa on only 40 percent of the land it takes today. If this strategy becomes more common for other crops by 2050, it will be a game changer for global food production. As it is, however, this cocoa work is the exception not the norm.

A related issue, however, is time. Even if genome mapping programs began today for the world's "orphan" crops, it would take a minimum of 2-3 years with today's technology to simply map each of the genomes. It would then take at least 15-20 years more to identify the most important traits, undertake the plant breeding and field trials needed to develop the new varieties, and meet all the government approvals to take the crops to market. This scenario is based on the assumption that these outcomes were based on plant breeding and genetic engineering within the specific plant genome. If, however, material from other organisms is brought into the process, i.e. if they are genetically modified organisms, then the timeframe would probably be even longer due to the field trial and regulatory complications.

Most of the increased consumption in the future will be in the tropics. That suggests that it would be a good idea to focus more plant breeding programs on tropical crops that are already adapted to those regions. Annual crops that have been relatively or absolutely neglected to date that provide most calories in tropical countries include rice, potatoes, yams, sorghum, millet, cassava, peanuts, sugarcane and sunflower. The specific crops vary considerably between the humid and the dry tropics, but all could benefit from dedicated research and development.

However, new genetic engineering technologies would also allow work to be done on perennials in a much shorter time frame than ever before. This would include important perennials and tree crops—sugarcane, cocoa, coffee, palm oil, oranges, bananas, plantains, fruits, nuts, etc. The work could focus not only on increased production but also disease and drought resistance or tolerance, dwarf traits so that tree crops could be harvested with less labor and for longer, and more marketable traits. This is the area of work that could have the biggest impact on caloric productivity; first, because these crops are grown in areas of need, and second, because these perennials would allow agriculture to support biodiversity and ecosystem functions. In particular, these crops could produce (e.g. sequester) carbon and reduce greenhouse gases (GHG's) associated with the production of annual crops in the tropics.

Animal breeding and genetics: Finally, another area of work that could result in a net increase in available calories is animal breeding and genetics. Most work to date has focused on reducing anti-nutritionals in feed and increasing the palatability of feed and feed conversion ratios (FCR's) of feed rather than in changing the animals themselves. In aquaculture, there are efforts to increase the Omega 3's in soy so that it can substitute for fish meal and fish oil. However, this is complicated because soy reportedly has nearly 70 anti-nutrients for fish.

Unfortunately, what is an anti-nutrient for one species is not necessarily so for another. And, the issue is not just about nutrition. There also is considerable work being undertaken at this time to reduce the amount of methane produced by livestock in order to reduce their GHG emissions.

As the productivity focus incorporates FCR's, carbon, nutrition and a variety of other efficiency measures, it is likely that aquaculture will receive more attention. Some animal protein market experts predict that poultry and tilapia will be head to head fighting for market share by 2050. After that, lower trophic level fish like tilapia, pangaseus or catfish are expected to win the "white meat" battle. In China, carp production already equals that of poultry, and aquaculture production is twice that of poultry.

Recent Yield Growth Rates: Annual yield growth rates over the past decade for the most significant global caloric crops vary significantly (see table). Of the edible crops, only sugar beets and palm oil are above two percent yield increases annually. If current global trends continue until 2050, these crops would likely double production per hectare by 2050. However, these crops combined do not represent even 10 percent of global calories per capita consumed each day. None of the other major food crops at current yield trends would double production by 2050. Maize and cassava (two food staple crops for the poor, particularly in Africa) could increase yields by more than 70 percent by 2050, however, if current production trends hold. Other staples for many of the world's poor such as wheat, rice, soy, sorghum, potatoes, sunflowers and barley are each below one percent productivity gains annually. These figures represent global average increases. While gains may vary greatly based on the production location for each crop, it is the global averages that produce the food that will ultimately feed the world.

Figure 12: Annual yield growth rates over the past decade (1998-2007) among major calorie crops.

Daily Calorie Ranking	Crop	Recent Growth Rates
1	Wheat	0.78%
2	Rice	0.93%
3	Maize	1.85%
4	Sugarcane	0.69%
5	Sugarbeets	2.79%

6	Soybeans	0.94%
7	Potatoes	0.36%
8	Palm Oil	2.02%
9	Barley	0.69%
10	Sorghum	0.11%
11	Sunflowers	0.34%
12	Cassava	1.80%
13	Rapeseed	1.81%
14	Peanuts	1.21%
15*	Cotton	2.73%

(Source: FAOSTAT)

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Production gains by yield vs. cropland expansion

While genetics has played a considerable role in increased food availability globally, another way production increases have been achieved is by expanding the amount of land devoted to food production. Over the past 40 years, for example, gains in the yields of rice, wheat, maize, soy and cotton have averaged from 1.5 percent to 1.95 percent. Growth of demand for these same crops has ranged from 1.9 percent (cotton) to 4.5 percent (soybeans). To bridge the gap in demand not obtained through yield increases, the area planted to each crop has expanded. The area planted to soy and oil palm have increased dramatically with well over half the increase in annual production coming from an expansion in the area planted during this period rather than increases in productivity.

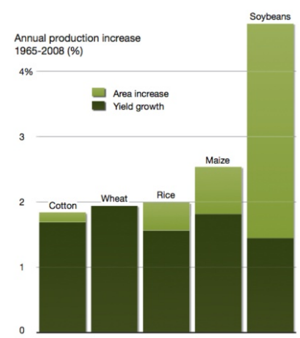


Figure 13: Production increase in yield and area (1965–2008) of several key crops. Yield increases have generally exceeded real increases. (Source: World Bank, 2009).

Nor are these issues limited to plant production systems. Brazil is the leading exporter of beef globally. However, average increases in production have resulted from the number of animals produced rather than intensification. The intensity of production has not increased over the last several decades. Thus, increased production has come almost entirely from the expansion of the area in pasture through the conversion of natural forest habitat in the Cerrado and Amazon regions.

Under a business as usual scenario, the intensity of production will not increase sufficiently to produce all the food that is needed on the land used today. Thus, the conversion of natural habitat for food production is expected to continue. The FAO estimates an additional 121 million hectares will be converted to crop production in order to meet demand for agricultural commodities by 2030. The most likely areas are Brazil, Indonesia, various countries in Sub-Saharan Africa, and Southeast Asia. Conversion of natural habitat comes at a cost to biodiversity and ecosystem functions. WWF (2008) has reported land use conversion to cropland may be responsible for 15-20 percent of GHG emissions.

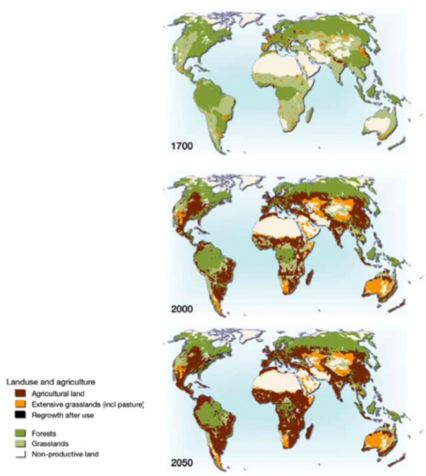


Figure 14: Projected land use changes, 1700–2050. (Source: IMAGE).

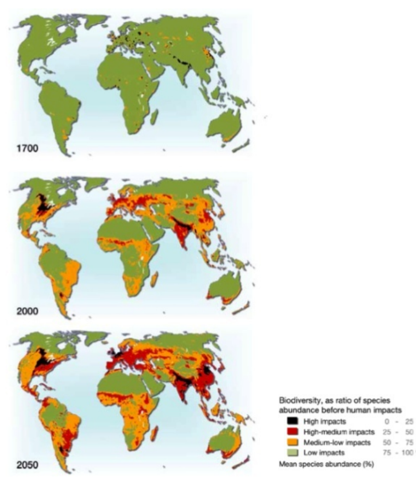


Figure 15: Loss of biodiversity with continued agricultural expansion, pollution, climate change and infrastructure development. (Source: GLOBIO; Alkemade et al., 2009).

Input availability and use efficiency

Regarding the overall factors of agricultural production—land, labor and capital, it is clear that we have an abundance or relative abundance of both labor and capital. What is also clear is that land and other natural resources are more finite in nature or even diminishing. We are reaching the limits of how much land and water we can use to produce food. Future gains need to come from increased efficiency (e.g. production per unit of input) rather than expansion.

There has been considerable discussion about peak oil. The idea is that we have passed the point where we have known reserves that are larger than our current use rates. There is some evidence to suggest that agricultural production (e.g. plant breeding potential as well as key inputs) may have peaked as well. Peak phosphorous is a good example of the scarcity of a key input. However, many are now asking whether we may have already reached "peaks" for agricultural production of such crops such as wheat. The focus of this discussion is the sense that we may have reached a production plateau—not the theory of genetic potential but the actual practice of production. There is some evidence, for example, that for certain crops production is actually declining and that this is based not on reaching the genetic optimum for each species but rather the lack of key inputs—water, nitrogen, potassium, phosphate, etc. For example, China's wheat harvest has declined from 123 M MT in 1997 to below 100 M MT in recent years (Brown and Halweil 1998, Brown 2002). Similarly, total grain production in China peaked in 1998 at 392 M MT but fell below 350 M MT in 2000, 2001, and 2002 and continued to fall after that. Today, China is one of the world's largest importers of grain.

Likewise, global climate change suggests that there are limits to how much GHG is acceptable for producing food. We have not mapped the overall availability of nitrogen, phosphorous and potash (N, P, K) or other trace elements that are essential for food production. Are we approaching, have we reached, or have we surpassed peak phosphate, peak nitrogen or peak potash? Which crops will be the most affected (e.g. annuals, perennials, or animals) in which regions (tropical or temperate) over what time frame (5, 20, 50, or 100 years)? Inputs are key variables that will affect our ability to increase global caloric production by 2050.

Land: From a business as usual perspective, it is important to understand the current parameters of how land is used for global food production. In this respect, two questions stand out—how much land is used to produce each of the most significant sources of food and how many calories are produced per hectare on average for each of the main calorie crops?
Most land used for food production is used for pasture. Pasture represents three times more land than all crops combined. Cattle (especially beef and to a far smaller extent dairy) are the most significant sources of food produced from pasture at this time.

Global Land Use for Agriculture, Pasture and Forests—2007

Permanent crops	142,571,400	Ha
Permanent meadows and pastures	3,378,173,200	Ha

Forest area	3,937,326,300	Ha
Arable land	1,411,117,400	Ha
Agricultural area	4,931,862,000	Ha

Citation: FAO Stat, Land Use Database (2007).

In terms of crops, wheat uses by far the largest amount of land in the world with approximately 217 million hectares annually. Rice and maize each occupy over 150 million hectares, and soy is planted on 94 million hectares, although the planted area of soy is rising due to long-term increases in demand for animal protein and soy-based feeds. These four crops occupy approximately half of all cropland worldwide. The next five largest crops (barley, sorghum, millet, rapeseed, dry beans) occupy another 15 percent of cropland. Upwards of 180 different crops are grown on the remaining 1/3 of global croplands.

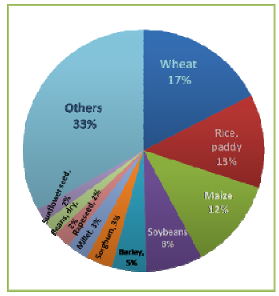


Figure 8: Top global crops based on cropland use (Source: FAOSTAT)

Metric options: The issue of how many calories are produced on average per hectare of production for food crops is more difficult to calculate because the type of information needed is generally not collected. Even so, we need to get the metrics right. If we are talking about food, food security and feeding the planet, then calories per hectare is a far more meaningful measure than kilos, bushels, or tons.

Calories per hectare is an efficiency measure. Other measures that are also important are calories per liter of water and calories per other important inputs (e.g. N, P, K, pesticides, etc.). The importance of these measures, however, depends on how limiting the input factor is. Calories per liter of water in an area with plenty of rainfall is not terribly important whereas calories per liter of water in a desert or dry climate is very important.

As the markets for carbon mature, carbon sequestered per 1,000 calories produced will likely be another useful metric. And, as biomass becomes important for making biofuels or other products, biomass will also be an important performance metric. The issue here is that the relative productivity between crops is likely to become important as resource scarcity impairs production. Which sources of vegetable oil are “better”? Which cereals are better? What are the key parameters? How will they vary depending on location and growing conditions? Going forward, the goal will most likely not be to maximize any single performance indicator (e.g. calories per unit of land, water or N), but rather to optimize a range of indicators. In this sense, it is likely that an index of several key performance areas may be the most useful way to think about which crops are "better" and which production systems are most efficient.

Metrics by crop: In 1995 FAO and CGIAR reported that four crops provided 73 percent of the calories consumed by humans directly—rice, wheat, maize and cassava (*The Washington Post*). Potatoes, sorghum, bananas, and sweet potatoes provided another 17 percent. In short, just 8 crops provided 90 percent of the calories. The increase in demand for these eight crops from 1974-1994 increased by an average of 72 percent while the average amount of land under cultivation increased by an average of 39 percent. In short, increases in the productivity of these crops from 1974-1994 were all accomplished by unacceptably large expansion in the total area of production.

Using 2008 FAO data (see table below), it is possible to begin to compare the total amount of human edible crop produced per hectare, the calories that can be derived from it per hectare, and the amount of water that is required to produce one kilogram of the product. This is the type of information that will be necessary to compare (all else being equal) the relative advantage of producing one crop or another in any given place. These are global averages, however, and we know that many crops cannot be substituted for each other because of their temperature, water or soil requirements. Adding other key inputs like energy, N, P, K, and labor would also be helpful in any attempt to determine which foods are the most efficient producers of calories.

Yield, Calories and Water Requirements for Selective Crops

Commodity	Yield (kg/ha)	Calorie Conversion	Average Water to produce 1 kg of commodity
Wheat	3,086.1	6.62918×10^{19}	1300 liters
Rice	4,309.4	9.25692×10^{19}	3400 liters
Maize	5,109.4	1.09754×10^{20}	900 liters
Sugarcane	71,510.2	1.54×10^{21}	1500 liters
Soy	2,384.1	5.12123×10^{19}	
Potatoes	17,267.6	3.70921×10^{20}	900 liters
Oil palm	14,079.5	3.02438×10^{20}	
Barley	2,776.6	5.96435×10^{19}	1300 liters
Sorghum	1,459.1	3.13426×10^{19}	2800 liters
Sunflowers	1,424.3	3.05951×10^{19}	
Cassava	12,460.4	2.67659×10^{20}	
Rapeseed	1,908.8	4.10025×10^{19}	
Nuts	1,357.5	2.91601×10^{19}	

Bananas	18,828.2	4.04444×10^{20}
Sweet potatoes	13,466.6	2.89273×10^{20}
Yams	10,497.2	2.25488×10^{20}
Plantains	6,370.8	1.3685×10^{20}

Source: FAO, 2008, http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor
Source for water comparison: http://www.waterfootprint.org/

Anecdotal information suggests that temperate agriculture thinking about food, calories and production has dominated our global food focus. For example, commercial banana producers in Central America claim that the five percent of bananas that are rejected by exporters from their harvests each year represent more calories per hectare than the most productive maize farms in Iowa. In short, bananas produce 20 times more calories per hectare than maize (Dave McLaughlin, personal communication, 2005).

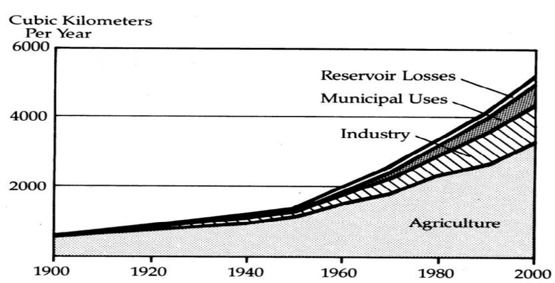
Similarly, one of the first domesticated food crops in the Americas was the peach palm [*Bactris gasipaes*, Palmae; pupunha (Portuguese) or pejibaye (Spanish)] which was found near Amerindian villages from Honduras and Costa Rica in the north all the way to Bolivia and Brazil in the south. At the time of European colonization, peach palm had spread from the Amazon (its origin) into Central America where it was displacing maize production as the local food staple. In the Sixteenth Century, Spanish colonists cut 50,000 peach palm trees in southern Costa Rica in order to starve the Indians. The trees produced so much food the local Indian populations could not otherwise be enticed to work for them. Recent research shows that peach palm produces 6-10 MT per hectare on poor soils, with non-selected genetic material, without fertilization, and with three months dry season. This is 6-10 times more than average maize production under the same conditions. Other studies have shown that production under improved conditions can reach 24-25 MT per hectare, and with better soils or improved genetic matter, production of 50 MT per hectare is possible (Clement 1993).

The calculations of calories per hectare can be complicated. Some areas can produce more than one crop per year, so the calculation of calories per unit of land should reflect that. Similarly some crops need to be grown in rotation with lower calorie crops or non-food crops, and the calculations should also take that into account as well. Getting the metrics right will be important. However, the 2050 business as usual scenario suggests that we will most likely continue to focus on total production (e.g. MT/ha) rather than caloric production (kilocalories/ha). Thus, we are managing the wrong outcome.

Water: Environmental aspects of water in agriculture will be discussed later in this chapter. For now, water will be addressed as a critical input that underpins our global food system. Food production and food processing companies are attempting to predict where water will be more abundant or scarce in the future to guide their investments in production, infrastructure and processing. And of course, climate change will make the availability of freshwater even more variable from year to year and harder to predict. From a production perspective, the issue will be what crops or mix of crops will be best for variable and changing climate conditions.

Water use in agriculture: Unfortunately, as with land use changes associated with agriculture that were outlined previously, all water use projections are headed in the wrong direction. In 1900, agriculture accounted for some 90 percent of all water used by humans. By 2000, the percentage of all water used for agriculture had fallen to 69 percent (see graph below); however, total water use had increased by more than five times. By 2025, total water use by humans for agriculture is expected to increase by an additional 13 percent. Without increased irrigation efficiency, experts suggest that by 2050 we could require 50 percent more water to meet global food needs. As it will be impossible to increase the total amount of water used for irrigation in absolute terms, it will be imperative that we find more efficient ways to irrigate crops. Fortunately, we already know a lot about achieving this goal. There are several forms of irrigation including (from least to most efficient): flood, furrow, alternate furrow, center pivot, modified center pivot, drip, and underground drip. Each of these forms of irrigation provides an efficiency of 25-50 percent improvement over the method mentioned immediately previous to it. The difference between the least and the most efficient irrigation may be as much as 10-100 times depending on how the systems are implemented.

Agricultural Water is 69% of Global Water Use



Undervalued input: However, while we know how to improve irrigation efficiency, the technology required to do so is usually more expensive than water since water is notoriously undervalued throughout the world. The following table shows how much water it takes to produce ingredients in common consumer goods. The data suggest that we have a problem.

None of the farmers in the illustration receives enough money when they sell the raw materials needed to produce a particular final good to pay any "real" price for water. In other words, if we ever bring water into the pricing of products rather than leaving it as an externality, the costs of goods such as those in this chart will increase significantly. In short, water is subsidized—by nature as well as many governments. This is true of environmental impacts of producing raw materials. The price paid to farmer at this time does not cover the cost of water, the cost of pollution, loss of soil, loss of biodiversity, etc.

Selected Products, Water Use and Farmer Income

	Raw material input	**Water to produce input**	**Farm gate price**
1 cotton T-shirt	4 oz ginned cotton	500 to 2,000 liters of water	US$0.20 (Aust.)
1 liter of soda	6 T sugar	175-250 liters of water	US$0.006 (Brazil)
1-oz slice of cheese	6 oz milk	40 liters of water	US$0.03 (US)
1 double quarter pounder	8 oz of hamburger	3,000 to 15,000 liters of water	US$0.25 (US)

Range of efficiencies: Rice is the largest user of freshwater withdrawals globally. In fact, rice production accounts for 21 percent of all water used for irrigation in agriculture and 14 percent of all freshwater withdrawals by people for any use. Wheat, maize and soybeans are the next food crops that use the most water from irrigation. One way to consider water use is in terms of the amount of water needed to produce a metric ton of output or a kilocalorie (a thousand calories). Among those that require the most water per ton of output, only cocoa, coffee and natural rubber also require high rates of water withdrawals annually.

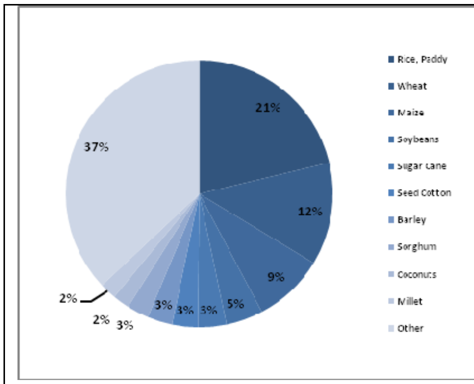


Figure 9: Top global crops based on total, annual withdrawn or "blue" water use (m^3/year) (Source: Water Footprint Network)

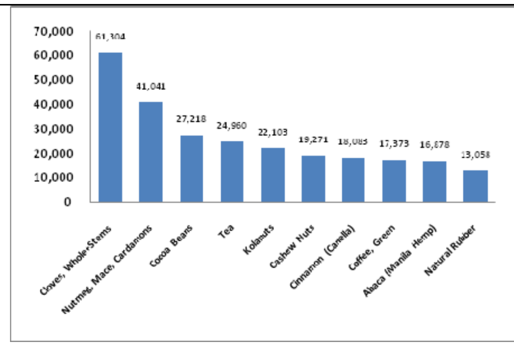


Figure 10: Top global crops based on withdrawn or "blue" water use per ton of output (m^3/ton/year) (Source: Water Footprint Network)

The impacts of different producers' practices can vary widely for water, as well as for a number of other key impacts and inputs. Even when producers use the same technology or practice, they may achieve very different results. The impacts of some are many times greater than those of others. In fact, if we could simply shift the global norm to equal that of the average performance of the top 50 percent of producers, we could have a huge positive impact on overall global efficiency. Nowhere is this any clearer than with water. The following table shows which countries on average use the least and the most water to produce seed cotton, cotton lint and finished textiles. In those instances where the difference between the worst and the best countries of production are closest, the average is still 4 times better for the most water efficient producing countries than their poorer performing counterparts. In some cases where only irrigated production is being compared, the difference is as much as 120 times.

Global Water Use in Cotton Production

	Global Average	**Lowest**	**Highest**
Seed Cotton	3,544 l/kg (I & R) 1,818 l/kg (I only)	2,018 l/kg (China) 46 l/kg (Brazil)	8,663 l/kg (India) 5,602 l/kg (Turkmenistan)
Cotton Lint	8,506 l/kg (I & R) 4,242 (I only)	4,710 l/kg (China) 107 l/kg (Brazil)	20,217 l/kg (India) 13,077 l/kg (Turkmenistan)

Final Textile	9,359 l/kg (I & R) 4,917 l/kg (I only)	5,404 l/kg (China) 608 l/kg (Brazil)	21,563 l/kg (India) 14,122 l/kg (Turkmenistan)

I & R = Irrigated and Rainfed; I = Irrigated only

UNESCO-IHE 2005, from Tables 3.4 and 3.5.

Improving efficiencies: Some farmers are beginning to understand how to achieve higher production with the same or even less water. One way to do this is to water only one side of a plant. This sends signals to the plant that there is too little water and that it should flower and set fruits in order to produce seeds for the next year. In effect, by watering only one side of a row of plants, the farmer can trick the plant into thinking that it needs reproduce seeds to produce plants in the future. This cannot only reduce water use by 40 percent, it can also increase production by 25-50 percent.

In addition to improving irrigation efficiency, there are other ways to increase the efficiency of water use in agriculture. Perhaps the most important is to increase organic matter (or soil carbon) both in and on the soil. Studies have shown that increased soil carbon can reduce water needs by as much as 50 percent where soil carbon acts as a sponge, soaking up the water and making it available over time, while surface carbon acts as a mulch reducing evapo-transpiration.

Technological gains

Technology can increase total food production outright as well as net food production (e.g. the net of animal protein less the amount of grain it takes to produce it). It also can reduce the financial and environmental costs of food production. As with genetics and better management practices, technology can improve the efficiency of food production, processing, storage, distribution and utilization—throughout the value chain.

Technology opportunities and barriers: In addition to genetics, the key areas of technology development and dissemination that relate directly to production involve planting, tillage and cultivation, application of agrochemicals and water. and harvesting. No-till, conservation tillage, ridge tillage and reduced tillage are all methods to reduce the costs and impacts of planting, tillage and cultivation. They do not work equally in different climates, with different crops or in different soils. They are also difficult to apply to smaller plots due to the cost (and often the scale) of machinery. Still, there is considerable room for improvement regarding technology, particularly with the development of technology for different scales of production.

Similarly, technology is available to make the application of agrochemicals and water far more targeted and efficient. But again, the issue is often the initial investment costs for the equipment or the fact that what is available is inappropriate for the scale of many farmers around the world who produce food on small areas. In the case of water, most farmers belong to larger group of irrigation organizations. This means that even if one farmer is interested in or willing to make changes, it may be difficult if not impossible for that to happen within the existing organization, where it is simply easier to set water distribution systems up to irrigate on a regular basis rather than when the crops actually need additional water.

Planting efficiency and input use: As with other issues, efficiency of planting practices and input use may be directly related. No-till planting requires no previous tillage and no subsequent tillage for weed control. This reduces labor time, machinery use, agrochemicals (both soil amendments and pesticides) and fossil fuels for machinery. Similarly, mechanical or aerial planting of rice can reduce overall water use by 50 percent and methane production as well. Machinery and other forms of technology can save inputs, increase profits and reduce waste. In the near term increased efficiency means increased net profits. However, as we begin to address global climate change and GHG emissions, farmers are likely to find that carbon and overall GHG emissions are issues that they will have to address—either because they will be charged for emissions or because they can make money through carbon sequestration and avoided GHG emissions.

Underperforming land

Globally there is considerable land that is "underperforming." However, there is no consistent definition of this land so the actual amount is subject to debate. One extreme that is easy to agree upon is land that truly is abandoned and no longer used for farming or ranching. However, even these lands may still be used periodically for shifting cultivation or pasture. Along the continuum toward increased productivity are lands that are severely degraded but continue to be used for pasture, albeit with very low carrying capacity and productivity. Finally, there are the lands that continue to be used for agriculture but are poorer performing than the average for the area where they are located. Depending on how underperforming lands are defined and who is doing the defining, they could represent anywhere from 200 million to 1.5 billion hectares. However, underperforming lands are not a static classification—they are being created every year. In a business as usual scenario, the creation of degraded lands will continue through 2050.

The opportunity: Degraded and underperforming lands are often those that have been used longer and with technologies that are often considered obsolete by today's standards. As a result, however, they may well be more accessible and nearer infrastructure and markets than the agricultural frontiers that are currently being opened as productivity declines and producers seek opportunities in new regions. Because of market access and the potential for application of new technologies, many of these areas are ripe for rehabilitation or the adoption of new technologies and better management practices. Farmers are beginning to rehabilitate degraded land, and as land becomes more scarce and food more expensive, this trend is likely to increase considerably by 2050.

In both Brazil and Indonesia, agricultural producers have found that it is more profitable to grow soy and oil palm, respectively, on degraded land than it is to clear natural habitat such as forests and peat land for planting (Clay 2004, Landers 2004, McLaughlin and Fairchild 2008). In these scenarios, the internal rate of return is quite high. In fact, farmers' net worth increases faster from the increased value of the land, at least in the first five to six years, than it does from growing crops. It is not unusual, for example, in Brazil for the value of degraded land to increase each year by the amount the farmer paid for it. By the end of five to six years, the land produces more than the neighbors' land, requires fewer inputs, and consequently is worth more per hectare.

What is clear globally is that most underperforming lands (regardless of one's definition) could be more productive than they are at present. New technologies, genetic improvements in seeds, different crops, infrastructure and new markets will all make it increasingly worthwhile to intensify production in underperforming areas and to rehabilitate, in some instances at least, degraded regions. It is likely that rehabilitation of degraded land will result in significant increases in calories produced globally, both per unit of land as well as per unit of other key inputs such as water, energy, soil amendments and other agrochemicals, at least over time. No one knows for sure how significant the gains may be or how such gains may contribute to food security by 2050 or beyond.

Property rights

When property rights do not exist or are not acknowledged or respected, it undermines agricultural production potential. This is true for small farmers as well as multi-national biotech companies. What farmer, regardless of his or her scale, is likely to plant perennial crops, invest in terracing, efficient irrigation systems or other technologies that would increase production and/or make it more sustainable, if their basic rights to the land are not guaranteed? In fact, many farmers are effectively forced to clear land in order to increase their claims to it. What producers will take marginal land out of annual crop production and use it for long term fallows and crop rotation to rehabilitate the soil if someone else can invade that land and take it over because it is "idle"?

Similarly, what companies will invest $1 billion dollars in research to identify and develop new commercially viable crops if their intellectual property (IP) is not protected or if their access to certain markets is blocked directly or blocked as a condition of foreign assistance to the local government? While much of the technology used for genetic engineering and genetic modification have been shared, some researchers suggest that the practice of "blocking patents" (where patents are taken out on large research areas rather than more narrow ones) has reduced productivity gains that could have been made by a more narrow interpretation of IP that would have allowed other researchers to begin to work on key traits.

In our efforts to meet global food demand by 2050, we simply cannot ignore property rights. The trend to recognize the property rights of farmers is generally on the increase, but it is still a complicated issue in most of Africa where states tend to own the land. Property rights are also complicated on many agricultural frontiers around the world, e.g. Brazil and Indonesia, where the rights of indigenous people and local communities are often ignored by immigrants and states alike. The issue of property rights, particularly for poor and economically marginal producers, will most likely remain pivotal through 2050, particularly as the awareness of land scarcity becomes more common and governments seek to appropriate "unoccupied," "idle" or "degraded" lands that can then be sold or leased to others.

Specific groups are most likely to be at risk in this scenario. The most at risk will tend to be tribal and indigenous peoples and ethnic groups who are distinct from those who govern. Women in general often have fewer rights, or their rights are less respected. This is especially true of widows and orphans and again, depending on the place, especially HIV/AIDs victims and their survivors.

The issue of recognizing the IP of biotech and other companies investing in technology to increase productivity is similarly being recognized increasingly and enforced, though biotechnology is still all too often an explicit or implicit condition of overall foreign assistance and development aid packages from some wealthier countries to many African countries for example. It is not clear what the business as usual case will be for either of these fundamentally different property rights issues.

Post-harvest losses and waste

Increased production is not the only way to meet global food demand. Reducing waste is important as well. Waste in agriculture occurs at harvest, through post-harvest handling, drying, storage and infrastructure, as well as in manufacturing and distribution, retail, and both with individual and institutional consumers (e.g. in restaurants and homes). Increased efficiency can reduce waste in each of these areas. Inefficiency equals waste which equals lost profits. Waste also reduces food availability and translates to higher food prices for all consumers. It is in everyone's interest to reduce waste, yet it is still unacceptably high. Reducing waste is a key component of any effective global strategy to meet food demand by 2050. Simply put, once so many resources have been used to produce food, it is criminal to waste it.

No one knows precisely how much food is wasted or where exactly waste occurs from harvest to the consumer. Total food waste has been estimated at 20-30 percent of production globally, while in the EU it is estimated at 30 percent and in the US at 40 percent. Efforts are under way to reduce this waste, and it should be possible to at least cut it in half. This would represent 10-15 percent of today's production, but the volume of waste (or the savings from reducing it) could increase considerably as overall production increases through 2050 to meet global demand.

Global food waste can be divided into two general areas. On the one hand, there is waste related to harvesting and post-harvest losses, which is more common in lower income countries. On the other hand there is consumer or institutional waste, which is more common in higher income countries. On the production side, waste most often results from the lack of infrastructure—the lack of adequate on-farm storage which results in losses from insects, rodents, mold and mildew. In addition, post-harvest losses result from inadequate local processing, the inability to dry grains and other food, and the inability to maintain fresh produce. Losses also result from inadequate or nonexistent markets, infrastructure or storage for dry goods, and/or refrigeration facilities for fresh fruit and vegetables and animal protein throughout the supply chain. Losses of fresh produce appear to be about equal, approximately 32 percent globally, when comparing developed and developing countries (Kader 2009). However, developing countries have double the rate of loss on farm, while developed countries have double the losses at the retail, foodservice and consumer level. The on-farm rates of loss in developing countries can be quite high. Insects, rodents, mold and mildew can destroy half or more of food in some places. It has been estimated, for example, that 80 percent of the mango production in India, the pineapple production in Ghana, and the cashew and acai fruit production in Brazil rots before it can be harvested because there is a lack of processing capacity locally.

According to a recent United Nations Environment Program (UNEP) report, as much as 30 percent of the calories that are produced by farmers, or approximately 1,400 kcal/capita/day are lost due to harvest and distribution losses and overall waste in food supply chains. Investments in infrastructure to improve market access, storage and transportation could substantially reduce these losses. As populations become more urban in the coming decades, the issue of infrastructure and post harvest losses will undoubtedly increase in importance.

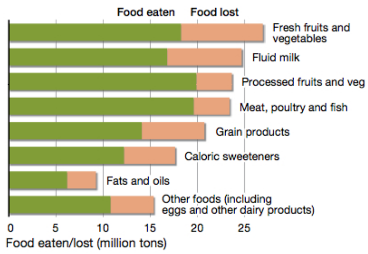


Figure 1: Food losses for different commodities. (Source: Kantor et al., 1999)

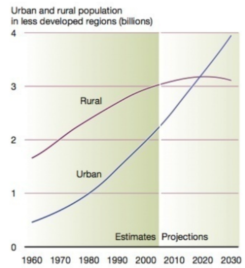


Figure 2: Urbanization in developing countries between 1960 and 2030. (Source: UN, 2007)

As noted previously, in higher income countries the problems of food waste are just as important but are fundamentally different. In the US and Europe, for example, consumer and institutional food waste are probably the most significant contributors, with most waste resulting from food being thrown away in the homes of consumers, in restaurants, or at the retail level. Still, there are indications that other waste exists even in these countries. One example illustrates the issue. In the fall of 2008, a 600-acre Colorado operation opened its fields after harvest so that people could come and glean product that had been left in the field. Some 30,000 people showed up and collected food all day.

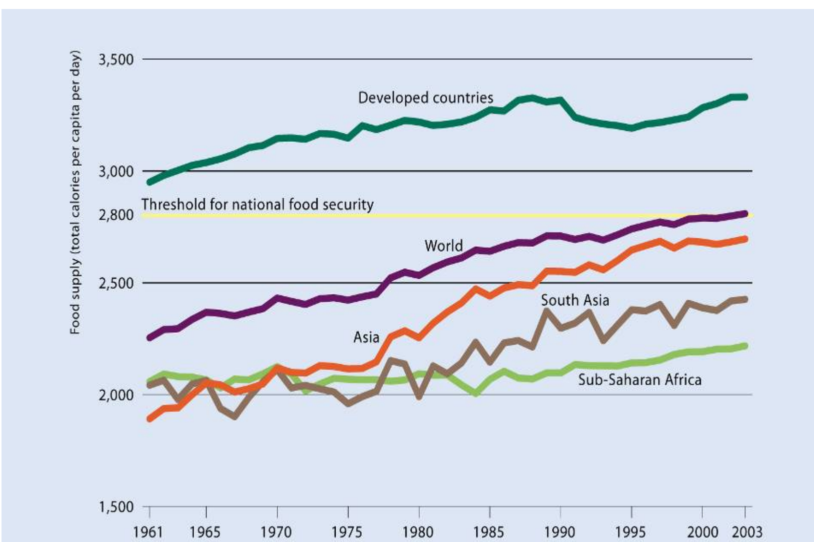
Producing sufficient food to meet global food demand by 2050 requires that we address the food waste issue in developed and developing countries. Food waste not only represents lost profits for everyone in the value chain, it also represents squandered resources, and perhaps most important, it increases the consumer price of food and reduces food security for those who cannot afford enough food. For all these reasons, there are many efforts to reduce food waste, but the business as usual scenario suggests that food is still too cheap to make waste reduction a significant priority. As food security and natural resource scarcity become more significant issues, this is likely to change, but it is hard to predict how much difference that will make by 2050. What is clear is that 95 percent of all funding for agricultural research and extension is for production, while only 5 percent is for postharvest issues (Kader 2009). This ratio needs to change.

Consumption

By 2000, an estimated 1 billion people (some 16 percent of the global population) consumed too many calories. Some 300 million of these people are considered obese according to the World Health Organization (2009). It is often posited that reducing consumption among this segment will help to feed the world. While reducing consumption to healthier levels would have many benefits both for the individuals in question as well as society at large, it would not make many calories available for others. However, even if the one billion who consume too much, let's say on average 25 percent more calories per day than they should, actually reduce their consumption levels the calories available would represent only 4 percent of global food production in 2000. If the calories that this group consumed represented higher levels of animal protein than the global average, then the total calories that might be available from changing these consumers' consumption patterns might increase by an additional 50 percent and thus represent 6 percent of global food production.

However over consumption is not a symbolic issue. It is important from the point of view of resource use, waste, human health and global equity. (It is indeed absurd to "waste" resources through excessive consumption which in turn requires additional resources to address, e.g. health care, energy, exercise, etc.) There are two other important reasons for addressing this issue: 1) As global consumption increases around the world, it would be best if we could reduce rather than add to the numbers of people who consume more than they should, and 2) It is important to understand how much animal protein, and in what forms, is healthier for the individual and the planet.

Average daily caloric intake among developed countries has now reached 3,300 (see graph below), which is 500 more than the 2,800 that is accepted as the FAO threshold for national food security. This suggests that even when individuals are not overweight, they are burning excess calories to maintain their weight. It might be better from a global environmental and equity perspective to simply consume less from the outset.



Source: FAO 2006b.

Figure 5: Daily caloric intake from 1961-2003. (Source: FAO 2006b)

Better management practices

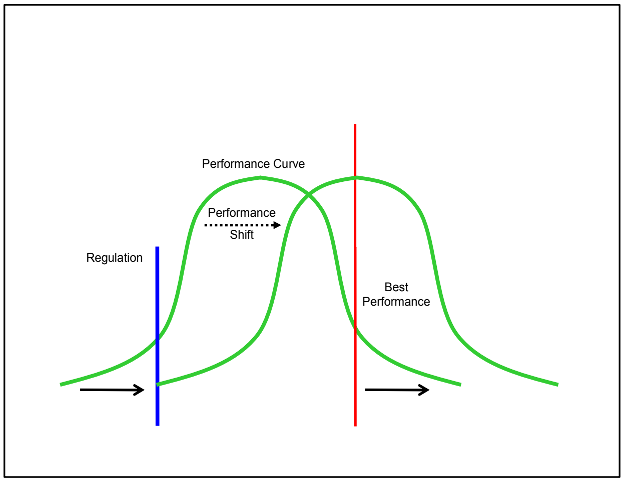
Better management practices (BMP's) are those practices that farmers use to increase production, reduce costs, reduce waste or impacts, and increase profits. Which BMP's are "better" depends. There is no one size fits all. BMP's are constantly evolving—mostly as farmers try to solve problems, save money, increase production, or make higher profits. Today's BMP is tomorrow's norm, and the day after that the practice that is being eliminated.

Most BMP's are invented by farmers and then adapted and adopted by others. For the most part public policies do not encourage better practices, much less improved performance. Increasingly, however, some government agencies globally are beginning to look at how they can encourage producers to adopt BMP's in order to either reduce key impacts or increase productivity or product quality. For the most part, however, public policies have not been driven by the same goals as those of producers, traders, retailers, brands or even NGO's. In order to reduce key impacts, it would be helpful if the policies of public and private institutions were mutually reinforcing. For example, if government policies, permits and regulations encouraged the reduction of the same impacts as private voluntary standards and the purchase conditions from the private sector, then it would be easier to shift the entire performance curve, at least in the country in question. However, this requires consensus about the most significant impacts by both public and private actors.

Government permits and regulations aimed at reducing key impacts can encourage the adoption of specific practices that tend to encourage the development of next generation BMP's because they set performance bars that encourage innovation rather than compliance (e.g. the adoption of a specific practice). Still, in the information age, there is tremendous room for improvement. At this time, it can take 8-10 years to identify BMP's developed by producers, test them, adapt them to different growing conditions, undertake proper field trials, publish the results, and then disseminate them. This all takes far too long—at some point the BMP in question has already been superseded by a newer, better one somewhere else.

What is also clear is that many, if not most, BMP's pay for themselves. That is, they repay the initial investment immediately or within a short time. In fact, if properly sequenced so that the profitable ones precede the ones that cost, the net financial impact can usually be positive, although this can vary.

When BMP's are applied variably with even the best genetics, seed technology and inputs, they can result in widely differing results. The results depend on the crop, farmer capacity and local conditions (e.g. soils, water, temperature, etc.). In the end, if you give 100 farmers the same practice (see figure), you will get a hundred different results. If all the farmers live in the same area, use the same technology, have the same background and more or less the same local conditions, the range of performance will be less than it will be globally. However, the range



will always exist and even in a local region the best producer can be two to ten times as productive as the worst. Globally the best producers can be a 100 times better than the worst. Eco-labels tend to focus on rewarding the best producers, and governments tend to focus on regulating the worst. From a food production and environmental perspective, however, it is probably far more important to move the worst producers and even the middle ones rather than the best ones.

4. Productivity Implications and Trends of Business as Usual in a Wider Context

Producers, input suppliers and researchers cannot double production by 2050 on their own. They will depend on an enabling environment that can be supported by both government and the private sector, particularly retailers and brands, but also input suppliers such as fertilizer and seed companies as well as banks. For its part government policies can either encourage or discourage increased food production as well as more sustainable production practices. With a strategic mix of policies to stimulate and/or reward innovation, government can encourage increases in productivity, the adoption of better practices, and the reduction of waste.

Interest and exchange rates

Governments set interest rates and foreign exchange rates. Both are fundamental issues for producers as they have impacts on markets and overall competitiveness, as well as the cost of inputs. The availability of credit and its overall cost are key factors in how much producers will invest in their crop each year. In some cases it influences how much is planted. In others it influences the quantity and quality of inputs used or the longer term investments in infrastructure, storage or conservation practices (e.g. the purchase of equipment, terracing, planting trees, etc.). Interest rates can also help give producers access to credit that can make them competitive or not in global markets. This can result either from reduced production costs or from the ability to hold product longer in order to supply markets year round.

Governments also control the policies that shape foreign exchange rates. Such rates not only determine the cost of imported inputs but also whether products from one country are competitive with those from another. In the 1990s, for example, Brazil kept its foreign exchange rates pegged to the dollar and artificially high. As a result, its exports were expensive. Once that policy changed, Brazil became the agricultural producer for the world. Now, however, the country's economy is so strong that the value of its currency is high in its own right, and it is once again making it less competitive on international markets.

Policies on environmental issues

The wild cards for government over the next few decades are likely to be climate change and water. How governments address these two issues will have tremendous implications for food production. As governments begin to develop their overall climate change plans and begin to look for legitimate carbon sequestration sources and GHG mitigation strategies, farmers and rangers are likely to get more attention. The development of systems that measurably and permanently sequester carbon or reduce emissions will make food production more sustainable.

Government policies about water also will be key over the next 40 years. In many parts of the world, water will more and more be the limiting factor for agriculture. Government will likely be faced with tough choices—who will get increasingly limited supplies of freshwater, what will they be allowed to do with it, and what will they have to pay for it? As noted previously, what is clear is that at this time very few farmers anywhere in the world pay the replacement cost of water. Given that water availability will become more variable in some areas and persistently scarce in others, most governments are simply not going to be able to continue with a business as usual strategy around water. It is not clear how they will balance the needs of people, food production, industry and the environment. However, it is likely that once again the environment will be the biggest loser.

Subsidy policies

Unfortunately, many government policies, including in such developed countries as Europe, Japan and the United States, continue to subsidize production of basic commodities through a range of programs. Production is supported directly through policies that focus on price supports, producer income guarantees, credit and other inputs such as water for soil amendments, on-farm income, exports or insurance against losses. Protective tariffs also restrict the import of products that can be produced less expensively in other countries and would therefore undermine local producers. But these practices are not limited to developed countries. India, Pakistan and a number of other developing countries subsidize or in other ways protect crops that are considered essential to their economies or the welfare of their farmers. And if all this is happening during periods of economic growth, prosperity and relative stability, what is likely to happen during periods where there is considerable volatility, where production is variable, or when there is not enough food? The business as usual case for government will most likely be to protect food producers and consumers alike. But, increasingly it may be hard to do both.

Ensuring raw material availability

The policies of government tend to be domestic but can be felt around the world. The policies of the private sector, by contrast, tend to be global but have specific impacts in different countries. For the private sector, as food becomes more scarce it is pretty clear that prices will increase. Given that there will be pressure to keep consumer prices down, margins are likely to decline. However, regardless of price, the more significant issue is availability—without raw materials it is hard to make a product.

As food becomes scarcer, the private sector will find ways to line up supply. Today companies are already advancing credit and key inputs in exchange for the right to purchase products. In some cases, these are traders; in others they are input suppliers (e.g. seed, agrochemical or fertilizer companies). Other companies are beginning to develop longer term supply chain contracts, locking in 60 percent or more of their product needs for one or more years at a time. One company has developed a 17-year supply contract with fruit producers in Turkey to provide raw materials for product line expansion into the EU market. Since the producers are shifting from annual crops to perennials, a longer term contract was needed to convince them to take a chance and shift to tree crops. The price is negotiated on an annual basis. However, in addition to the fruit, the company purchases the carbon that is sequestered in the trees to offset the carbon it takes to transport the fruit to market. In short, there is a trend away from spot market purchases to longer term contracts. The exception to this is to fill unexpected gaps.

There are several advantages to longer term contracts provided prices are not locked in so that one partner is disadvantaged. One advantage of longer term contracts for all signatories is that they reduce transaction costs. Producers can also reduce their cost of credit as well as various other inputs because they now have guaranteed markets so they pose fewer risks for their creditors. In fact, financial institutions and input suppliers are beginning to look at longer term contracts that are on par with and sometimes even linked directly to longer term supply contracts.

Supply chain management

Supply chain management strategies are becoming more complicated, especially for commodities that are traded in bulk. In general, retailers and brands are demanding far more information about the products they are buying and how they were produced. They are interested in longer term relationships with suppliers. Very few retailers and brands want to buy directly from producers (e.g. cut out the traders); few will want to tie up so much money for so long. However, their desire for transparency and, above all, information about the supply chain does change the basic role that traders have played in the past. Still, traders will of course continue to buy and sell commodities and provide the service of just in time delivery.

Retailers and brands will most likely require even more transparency regarding where their products come from in the future. Retailers and brands control very few of the environmental or social impacts that are embedded in the raw materials that they purchase. Most data suggest that depending on the impact, no retailer or brand controls more than 15 percent of any of the key impacts—usually the figure is much less. However, they are considered responsible for those impacts. Moreover, retailers and brands have deeper pockets so that if there are any health and safety or serious environmental or reputational issues associated with the product, they will be held accountable.

For some time, companies have been responding to supply chain issues individually. However, it is now clear that no company is large enough by itself to improve the performance of entire supply chains. Increasingly, companies are beginning to work together to identify and reduce not only health and safety issues associated with common commodities, but also key environmental and social impacts and disease and pathogen issues as well.

Innovative retailers, manufacturers and brands are beginning to identify mutually rewarding incentives to work with their suppliers. One opportunity that voluntary carbon markets offer is for retailers and brands to purchase carbon in addition to the basic commodities. These two values can be “bundled” together. This is a way that a buyer can address an issue it may well be required to by law in the near term by buying carbon as well as commodities from their suppliers. The advantage of this system is that it reduces transaction costs while reinforcing key relationships. It also tends to support longer term supply contracts between buyers and sellers. Any system developed to bundle carbon and commodities would also have to work not just for the producer and buyer, but for everyone in between, in particular the traders.

Whether producers like it or not, as food becomes scarce, they are likely to be more directly engaged with the buyers of their products. The business as usual case at this time is that supply chains are actually getting longer and longer, while the number of players along them is decreasing and the information that is being required is rapidly increasing. This will continue to be the case. Even though more than 90 percent of food is still consumed in the country of production, the amount that is traded internationally has increased in the last decade and that trend will continue.

5. The Environmental Legacy of Agriculture and the Consequences of Business as Usual

Every use of resources has impacts. Agriculture is no exception. With more and more expected from agriculture, the question going forward is which impacts are acceptable. The levels of impact that are acceptable per farmer, per consumer or per hectare when there are six billion people are not the same as when there are nine billion people who, on average, consume twice as much. That said, it is not clear that the impacts of feeding six billion people are sustainable. WWF's Living Planet Index suggests that by 2008, we were living at 1.3 planets. The largest share of the impacts that push us beyond one planet are those associated with food production. So if food production is not currently sustainable, how will we be able to double it by 2050 while making it more sustainable? It is important to understand where we are on the journey of sustainability. For that reason, this section will provide a quick overview of the most significant negative impacts of agriculture to date, acknowledging that agriculture can have positive as well as negative impacts.

Up to this point, farming and ranching have had the largest negative environmental impacts of any human activities on the planet. While practices have improved globally, the impacts of agriculture remain unacceptably high. At one level it is very simple; our practices are simply not improving as fast as (much less faster than) our population, and consumption is growing.

The impacts of agriculture are cumulative, both spatially and temporally. The first producer rarely has unacceptable environmental impacts. However, the thousandth or ten thousandth can have. Similarly, poor farming practices one year or even in one generation can reduce the ability to produce sustainably over time. However, when they go on year after year, generation after generation, then the cumulative impacts can be unacceptable. For example, somewhere in the world every year, farmland becomes so severely degraded that it is abandoned, and producers move on to farm other areas. With more people and more consumption these impacts will only become more pronounced. In order to contain the impacts of agriculture, we need continuous improvement.

Food production depends on healthy ecosystems and ecosystem services for water, air, temperature moderation, climate, pollination and soil fertility for future generations. Some producers have found ways to maintain some basic ecosystem services, but most erode them over time, beginning of course with biodiversity loss which is quickly followed by soil loss. Agriculture can have positive environmental impacts, but only very rarely are the ecosystems services created by farming and ranching more robust than those they replaced. Agriculture, in fact, can have a negative impact on those very same systems on which it depends. The following are the key impacts of agriculture on the environment. They are offered here as a global baseline for a business as usual scenario moving forward to 2050.

Habitat conversion and biodiversity loss

Nowhere are the environmental impacts of agriculture clearer than with habitat loss. Increased consumption (whether driven by population growth or changes in diet) and the concomitant increase required from food production are the largest causes of habitat conversion and biodiversity loss on the planet. According to the FAO, agriculture and ranching currently occupy directly about 33 percent of the terrestrial area of the planet. However, if the areas that are not acceptable for producing food with today's technology are eliminated (e.g. deserts, mountains, lakes and rivers, etc.), then the land currently used for food production represents about 58 percent of all the land on the planet. With 12 percent of all the land on the planet in national parks, then the amount of habitable land used for food production or in national parks could be as much as 70 percent of all the land on the planet.

The loss of natural habitat for food production is a long standing issue—and it's getting worse. From 1961, the FAO data show that green revolution technology reduced the area of habitat conversion to 0.4 percent per year over the next three decades. Over the past decade, however, with increased global consumption, the conversion of natural habitat has increased so that it is adding 0.6 percent of land to the amount used each year for food production. If the rate of conversion of the last 10 years were to continue over the next 40 years, another 24 percent of the 30 percent of remaining natural habitat would be incorporated into the agricultural estate by 2050.

Part of the pressure to expand production onto new lands is the degradation and loss of land that was previously farmed. Sundquist (2000) estimates that soil erosion and other forms of land degradation now rob the world of 70,000-140,000 km2/year of arable land. Similarly, Sundquist (2000) estimates that 20,000-40,000 km2/year of arable land is lost globally through infrastructure and urban development.

Land degradation and the loss of ecosystem services

In the past, agriculture and ranching practices have degraded land so that it was no longer useful for production. Degraded and abandoned lands all have one thing in common—extensive soil erosion and the loss of organic matter and soil carbon. It has lost its ability to support a wide range basic ecosystem services or biodiversity. Once severely degraded land is abandoned, producers move to new agricultural frontiers to find additional land to convert for agriculture or ranching.

The reason lands become degraded and abandoned are numerous. One important reason is that the land was not suitable for agriculture or ranching in the first place. From an environmental perspective the most wasteful thing a producer can do is clear land and then abandon it within a year or two because it was inappropriate for farming. In some cases, the crops being produced (e.g. those that were known to the producers or for which there were markets) were not suited for the soils or climate. Another issue is that farmers often either do not know or at least do not use practices that would allow them to avoid key impacts. In the past, the lack of BMP's or technologies may have been because they simply did not exist at the time or the awareness of them was not distributed well globally. However, at this time technologies, BMP's, and alternative crops exist that can reduce the most significant impacts of agriculture in most regions.

It could be argued that any food production system that does not generate more soil than it loses is being degraded. By that standard, most farmland globally is currently being degraded. Over the past 150 years, half of all the topsoil on the planet has been lost globally. In Africa, some estimates suggest that one percent of top soil has been lost per year in the last 40 years. New technologies and practices have allowed farmers to reduce soil erosion. Some in fact have the ability to increase organic matter at rates that are faster than it is lost. As the scarcity of arable soil globally becomes better understood, there will be far more attention paid to maintaining it rather than mining it. However, if these overall trends continue globally, land will continue to be degraded and abandoned over the next forty years. Thus, the business as usual scenario is hardly the desired outcome if we want any natural habitat in the future.

Tillage and soil health: With the possible exceptions of the ax, chainsaw or fire, No single agriculture practice has produced more environmental damage than the plow. Axes, chainsaws, bulldozers and fire clear forests and release carbon, but plowing and cultivation result in the continued loss of soil and soil carbon and the release of CO_2 year after year. However, the impact isn't limited to production and expansion—several studies have shown that the largest impact of agriculture on freshwater and marine organisms (more even than agrochemical toxicity) is silt and suspended solids from soil erosion, which cause stress in organisms like coral. Scientists have shown that stress induced from soil erosion can cause coral bleaching to occur at 10 degrees cooler temperature than it would otherwise.

Water use

Water use is another significant environmental impact of global food production. Of all human activities, food production is both the single largest user and polluter of water. Water scarcity is now common in many parts of the planet, and scarcity is increasing at alarming rates. As a result, in the last century a dozen or so rivers globally do not have water year round. As noted in Section 3, over the past century, even as the percentage of total water use by agriculture declined, the total amount actually increased five-fold. This trend is expected to continue, and by 2030, the proportion used by agriculture is expected to decline to 65 percent, as the total volume used for agriculture and food production increases. And in emerging markets, water used for industrial and domestic uses is expected to increase more quickly (Burger 2009), so this will likely result in conflicts over water in many regions.

At this time, over one billion people lack access to water, and over 2.4 billion lack access to basic sanitation (UNDP 2005). By 2050, at least one in four people is likely to live in countries affected by chronic or recurrent shortages of freshwater. According to the most alarming projection, nearly two billion people in 48 countries will face water scarcity by 2050 (UNWWAP 2003).

Some might argue that not all water matters equally. Most experts, for example, would agree that blue water—lakes, ponds, rivers, aquifers, groundwater etc.—is more important than green water—rainfall. Dams that prevent year round stream flows can be devastating to downstream biodiversity. It is also clear that pumping water from aquifers that are ossified or when water is withdrawn more quickly than underground water tables are replenished is not sustainable.

But even rainfall is more complicated than it may appear. When water falls from the sky, it either runs off directly into streams or other water bodies or is absorbed by the soil. It can then either filter through the soil to aquifers or be taken up by plants. It then evaporates. That is a natural water cycle. Does it really matter whether rain falls on natural habitat or on fields? Often, probably not. But if the farmers' crops are "thirsty," i.e. they require more water than natural vegetation did prior to its clearing and the use of the land for food production, then the crops are likely to take up more of the rainfall and leave less for nature. Or, if crops do not take up the rainfall or hold the water in the soil as previous habitat did then the downstream flow will be more variable than before, and this could affect downstream marine and freshwater ecosystems and the biodiversity that depends on them. While nature tends to be resilient, very minor changes can disrupt balances that have evolved over millennia. For example, water taken from the Zambezi River Zambia for hydroelectric power and irrigation reduced stream flow into the Indian Ocean to such a degree that the recruitment of juvenile shrimp declined so much that it was the single largest threat to the Mozambique shrimp industry.

Pumping water for irrigation also requires significant energy. In the US an astonishing 85 percent of electricity on farms is estimated to be used to pump groundwater for crop irrigation (http://www.eesi.org/080109_water_energy). The connection between water and energy and carbon is only beginning to be understood.

In short, humans now use about 50 percent of all available freshwater. Water use in agriculture has become more efficient, but many estimate that 40-50 percent of all water used for agriculture is wasted (Clay 2004). Improved efficiency will certainly reduce the amount of water that is wasted, but given the dramatic increases in production required to meet food consumption needs over the next 40 years, efficiency may well not be enough.

Modeling predictions: Some estimates suggest that doubling food production will require another 20 percent increase in global water use for agriculture—even if we develop and deploy more efficient technology. With regard to water use, business as usual will not even allow us to maintain our current levels of food production by 2050 if the variability of rainfall is anything like the Intergovernmental Panel on Climate Change (IPCC) climate change models predict.

Several studies and crop simulation models, for example, investigated the impact of changing in-season temperature variability as well as precipitation (World Bank 2008; Reilly 2001). The overwhelming conclusion is that crop yields will decline as temperature variability increases and that the capacity of the soil to store water strongly mediates crop response to changes in variable precipitation. Sandy soils are far more vulnerable to rainfall variability.

Under moderate to medium estimates of rising global temperatures (1–3°C) over the next 50 years, crop climate models predict a small impact on global agricultural production because the negative impacts on tropical and mostly developing countries will be offset by gains in temperate and largely industrial countries. This begs the question, however, of whether we have the political will or the infrastructure to ship food around the world. An even bigger question is whether those countries that are deficient in food production would have the means to buy food at any price much less the higher prices that are likely in a world of finite resources.

In tropical countries, even moderate warming (1°C for wheat and maize and 2°C for rice) can significantly reduce yields. For temperature increases above 3°C, the Fourth Assessment of the IPCC that has just been released expects yield losses to occur everywhere and be particularly severe in tropical regions (World Bank 2008). In short, some of the potential impacts of climate change suggest that the business as usual scenario may not be the worst case scenario.

Greenhouse gas contributions (including methane, embedded $C0_2$, N, etc.)

Agriculture is the largest producer of GHG's each year. The GHG contribution of agriculture from all sources is estimated at between 25 and 40 percent of all human-produced GHG's. The single largest contributor is deforestation, accounting for 15-20 percent of global GHG total (WWF 2008)], methane from livestock (8 percent), the volatilization of CO_2 (e.g. from decaying biomass, cultivation, drained peat soils and wetlands, burning crop residues, and for clearing prior to planting or harvesting), the production and use of agrochemicals and other inputs, and direct energy use (e.g. machinery use, drying).

Pollution

Agriculture appears to be the largest source of pollution on the planet. While most countries do not measure agriculture pollution, both the US Environmental Protection Agency (EPA) and the UK government have found that agriculture is the largest source of pollution in those countries. It is likely that it is an even larger source of pollution in developing countries, at least those with small industrial bases. In essence, pollution is inefficient. It represents lost inputs, nutrients or soil that will either reduce production or have to be replaced at some point in the future to maintain a productive base. In short, pollution costs farmers money. In the future, various types of agricultural pollution will increasingly be regulated and most likely taxed. Global attempts to reduce carbon and GHG emissions are likely to move in that direction. Regarding carbon and GHG's more generally, efforts to reduce emissions could also result in incentives for farmers who are able to sequester carbon and avoid GHG emissions. This could become another source of income. How significant will depend both on the products and the practices used to produce them.

Agrochemicals and toxicity

Agriculture uses more chemicals by volume than any other industry. Agrochemicals fall into two general categories—pesticides (e.g. pesticides, herbicides, fungicides and fumigants) and fertilizers. The overall impact of agrochemicals depends on the toxicity of the product as well as when, how and how often it is applied. Toxicity, however, does not just refer to its impact on humans, but rather the impacts on a wide range of organisms. Increasingly, work is being undertaken to show the impacts on freshwater and marine organisms—impacts that have not been as well understood in the past. From this perspective, the toxicity of natural pesticides which are used in organic production can be even more toxic to other organisms than many of their synthetic counterparts. This subject should get more attention as we look at the potential contribution and impact of organic food production systems. From 1960 to 1995 global nitrogen use from all sources increased seven fold and phosphorous use increased 3.5 times. With business as usual in agriculture, global agrochemical use will increase three-fold by 2050. In addition to the impacts of such use, the question is will there be enough of these inputs to meet global demand.

Unfortunately, the effectiveness of agrochemicals, whether pesticides or fertilizers, can decrease over time if they are used too frequently or not managed through rotation. This has led producers to change the amount and timing of applications as well as rotate the specific agrochemicals applied to avoid resistance. As it is, however, researchers estimate that less than half of agrochemicals applied globally either contribute to the growth of the target crop or the elimination of target pests. Because such inputs are expensive, there is every reason for producers to use them more efficiently.

6. Broader Implications of a Food Insecure World

Landscape, watershed and cumulative impact

While most of the analytical focus to date has been on the direct impacts of food production on the actual areas of production, business as usual will result in food shortages for an increasing portion of the population. In this business as usual scenario, the environment will lose every time. If the choice comes down to cutting a tree in order to feed your child, the tree doesn't stand a chance. In all likelihood, the business as usual case will result in an increasing disregard for conservation—short term thinking will prevail, and food will be the priority. The natural environment will at best be seen as a luxury that we cannot afford. In reality, what we cannot afford is to let this happen.

The immediacy of food shortages will most likely result in larger scale environmental impacts that will be ignored due to the increasing urgency of food production needs. In the name of food, much will be accepted as inevitable if not forgiven. Desperate times will produce desperate measures resulting in increased habitat conversion, biodiversity loss, pollution, degradation and even desertification, salinization of soils, and water shortages. And these impacts will not be limited to the land. Fisheries will be depleted from overfishing and mismanagement while the fecundity and fertility of fish populations will be further affected by freshwater, coastal and marine pollution from terrestrial agriculture and livestock operations.

In short, if all the world does is to retreat into food production as a security issue, then this will ironically undermine the very environmental services on which global food security depends.

These are trans-boundary issues—not something one producer or even one government can address unilaterally. The business as usual case is that today few governments are managing the natural resources required for food production sustainably today within their own countries. None of them are working together to effectively manage the planetary systems that will be required to address food security issues in the future. Unless the world rises to the challenge of increasing the productivity of agriculture through a combination of genetic change, better practices, innovation and improved animal husbandry then the contributions that crop and animal breeding could provide to long-term, sustainable human welfare, including contributing positively to environmental sustainability and the diversity of life, will be lost.

Food and national security

Some 70 percent of the estimated 9.1 billion people on the planet in 2050 will live in cities. Thus, by 2050, more people will be living in cities than were alive in 2000. Further complicating this picture is that more people will be alive in Africa and Asia than are alive on the planet today. Global solutions for food will not be found primarily in Europe or the United States or even in Australia or Latin America for that matter. The focus must be on Africa and Asia.

Relative impact in rural and urban areas: In a business as usual case, however, people living in cities do not produce their basic calories. They depend on markets to supply them with almost all of their food. However, in that same scenario with present trends continuing, nearly twice as many people living in cities (1-1.25 billion) as in the countryside (500-750 million) will not have sufficient calories even though they might spend 60-70 percent of their income on food. Food shortages result immediately in higher prices. Over time—in some situations, a very short amount of time—that translates into famine and riots whether in rural or urban areas.

Rural populations have a long history of dealing with food insecurity. They reduce what they sell to markets, they share food with friends and relatives, they reduce their consumption, they strip the environment and eat things they would normally not touch, and they eventually eat their seed. At this point, farmers and the rural landless and their families are displaced. They leave their farms and become refugees, moving to places where they have relatives or cultural connections or have been led to believe that they will have access to food or where they think they can at least live off the environment. When famines hit one or two regions of the world, this strategy can be somewhat effective, though millions of refugees and famine victims have died in the search of food or waiting for food handouts in the past 50 years. In the business as usual scenario, global food surpluses have been reduced over time, and at some point in the near future, certainly before 2050, we will have periods with food shortages at a global level and in multiple places simultaneously. In short, it is not clear that the world would be able to rise to the challenge to address severe food shortages induced by climate change simultaneously in four to six regions of the world. This would be an entirely new phenomenon.

The reality of food shortages in rural areas is fundamentally different than that of urban areas. Urban residents have far less ability to tighten their belts during food shortages. People need to eat. Starving people become desperate, which over time, means political turmoil, the overthrow of governments, and if chronic or persistent, failed states and even massive displacement and migrations. And while food insecurity for the poor can lead to vulnerability and even conflict, once working class and middle class people are affected by food shortages and long term changes in their diets, it will lead to political change. At the very least, urban food shortages will lead to increased conflict, militarization, authoritarianism and, over time, failed states.

Reactions of governments: The initial reaction of governments to food shortages will be protectionism—circle the wagons and ensure food production within the country. Government actions could take the form of tariffs and trade barriers that would protect domestic producers from foreign competition and allow countries to be more self-sufficient. Some countries with few resources to produce food could also support the acquisition of land or other food production assets outside of their country. Countries might manipulate foreign exchange rates to improve their ability to retain food domestically or obtain it from abroad.

With very few exceptions, none of these strategies actually address the underlying problem, specifically producing and making accessible more food using fewer inputs. All are stop-gap measures that will raise the actual or hidden costs of food, divert necessary funds from improving food production and food production systems, or increase social programs that build assets and provide opportunities to the food deficit poor and their children.

In a finite world, a strategy aimed at protecting what is rather than creating what is likely to be demanded in the medium to long term (e.g. fighting over the existing pie rather than increasing its size) will not help solve the problem of reconciling the needs of the planet with the food needs of the people living on it. Moreover, such a strategy will likely lead to increased conflicts both within states as well as between them. Any existing domestic, regional or global conflict will escalate as a result of shortages of food, land or water resulting in increased expenditures for weapons and security. More importantly, they will result in refugees and displaced populations that will most certainly disrupt food production and distribution systems, exacerbating the very problems that resulted in conflict.

If food insecurity leads to conflicts and war, what would it cost? In 2008, world military expenditures were estimated at approximately $1.464 trillion (SIPRI 2009). There are two important factors regarding this figure. First, US military expenditures represented just under half of the estimated expenditures globally. Second, for most developing countries military expenditures are more about internal conflicts and control than about conflicts with other countries. Going forward, for sake of argument, let's say that conflicts over food result in an increase of military expenditures. If we leave out US expenditures, military expenditures amount to about $750 billion per year. If conflicts over food amount to an increase in military expenditures of 5 percent, then they would come to $37.5 billion. Put another way, wouldn't it be more productive to spend at least some of this budget in ways that would allow us to avoid food shortages to begin with rather than address the crises they produce?

Nutrition and human health

Under the business as usual scenario and with the current trends holding for the next 40 years, one in six people (more than 1.5 billion) will suffer from food shortages and malnutrition. There are several consequences that will arise from this situation. Malnourished people will have a decreased life expectancy, will be less productive during life than they otherwise would have been and will be more susceptible to disease.

Studies have also shown that women who are malnourished will have higher incidence of infant mortality and are more likely to give birth to children with diminished mental capacity. Mental development of a child is affected by the mother's nutritional status both during pregnancy as well as up to three to six months after birth. Another likely implication of maternal malnutrition and the impact on children is that while one in six in the global population suffer from malnutrition, it is likely that poorer, more marginal groups will have higher birth rates and account for one in five or even one in four of all births globally. The impacts of fetal malnourishment are thus likely to be even greater.

In short, precisely at a time in human history when mental acumen and intellectual capacity are in increasing demand and even required for many entry level positions in different sectors, a significant percentage of the population will have mental capacity that is diminished from what it would have been due to fetal or very early childhood malnutrition. Building assets and capacity within such a generation will, as a consequence, be even more difficult than it has been up to this point.

Furthermore, as food availability decreases, an increasing percentage of the global population will begin to eat "down" the food chain, i.e. they will substitute cheaper, less nutritious foods for more expensive ones. In general they will substitute starches for proteins. While there is considerable evidence that the wealthiest people on the planet may eat both too much and too "high" on the food chain, that is a different issue. Lack of protein, whether animal or vegetable, not only contributes to malnourishment but also mental development. As food availability decreases and prices increase, the poor will be forced to eat what they can afford—and even then it will probably be too little.

Finally, as reiterated throughout this chapter, food production requires water, and increasing food production will require more water. At this time some 2 billion people have insufficient water and many of them are the same people who have insufficient food. Water conflicts will intensify considerably over the next 40 years and food production is likely to be at the heart of many if not most of those conflicts. And for society, the increasing issue will be that the same two billion people likely will be denied access to both adequate water and food.

Trade and development issues

On a planet with finite resources, trade will continue to play an important role in ensuring that production deficits and food security issues can be met at a global level. While less than 10 percent of global food production is traded across borders, the portion that is traded tends to dampen price volatility, at least in comparison to what it would likely have been without the ability to trade food surpluses. Thus, trade itself will be an increasingly important food strategy in a world where volatility is increasing either because of climate change or because of a mismatch in local supply and demand, and where consumption outstrips the ability of local producers to respond either because of time lags, overall resource constraints, or changes in consumption preferences.

However, what is also clear is that regions of the world that are well endowed with natural resources that enable them to produce surpluses can also be very low cost producers. This is true of Australia, Brazil, New Zealand, Thailand, and the United States. It will be extremely important to find the right balance where such countries augment local production rather than undermine it to the point that local agriculture is no longer viable. What is clear at this time is that global food security is too important to be left to the responsibility of any single country or even small block of exporting countries. Furthermore, regardless of how productive some countries are and how well they are endowed with the resources to produce food, no single country or even block of countries can come anywhere near to feeding everyone on the planet. Similarly, in the past, in countries with large at-risk populations as refugees and famine victims, we have seen that subsidized or donated food can actually undermine the very agriculture and marketing systems that could allow local producers to get back on their feet.

There is however another phenomenon that has been common in the past when countries are facing either food shortages or global recessions—this is the tendency to protect one's own markets by restricting trade rather than using trade to turn the situation around more quickly. (See section on *Food and national security*.) For many countries this is seen as a way to ensure their own food supply first by employing a number of different restrictions without regard to food produced in other countries. Increasingly, food is a global issue. To be most effective moving forward, we will have to develop global strategies and plans for food security rather than individual country ones.

Another international trade issue became apparent with the recent run up of commodity prices from 2006-2008. As commodities become scarce, their prices increase. This means that there is also money to be made by speculators. Regardless of how much impact one thinks speculators had on recent commodity price spikes, it is clear that speculation does have impacts. In a world of increasing market and climate uncertainty, it is likely that food prices will become more volatile as we move toward 2050. Therefore, it is quite likely that speculation will play an increasing role in the availability of food as well as its price, given that uncertainty is only likely to increase. Some companies are working with the supply chains and directly with producers to address this issue through longer, multi-year contracts that make everyone less dependent on spot markets. While speculation and futures contracts certainly have a role to play in food markets and getting market signals right, they can also be destructive. To the extent that speculators intervene in markets, they can increase the cost of food without benefiting either producers, consumers or overall food security.

Social conflict and power struggles

Similar to any increasingly valuable resource, as the resource becomes scarce those who have more of it or the potential to produce more will have increasing global power. Food will be no exception. Food insecurity will contribute to global power shifts and, most likely, resource wars. As the resources to produce food become scarcer, poverty and malnourishment will increase, and civil unrest will escalate in food-deprived areas. Initially this will result in internal conflicts, but it will soon spill across borders, first in the form of access to water and food, but soon creating refugees and displaced people. In Africa and Asia, food security will reignite tensions along tribal or ethnic lines as states seek ways to ensure food security for urban residents and to reduce urban unrest and political instability. This will most likely come at the expense of rural and more politically marginal populations. As a consequence, lower density and politically marginal populations that have traditionally controlled large areas (e.g. indigenous peoples in the Amazon, much of Africa, and parts of South and Southeast Asia) are likely to be displaced if they and their resources are not seen as contributing to the greatest good for the greatest number of people. Land grabs will begin through private, commercial channels, but may well escalate to something more depending on the levels of food insecurity, the levels of political unrest in some countries with high urban populations, and the extent to which resource bases are degraded, relative to neighboring countries.

Regardless of the relative powerlessness of many indigenous peoples and poor rural residents, they at least have some political standing. Trees do not. Given the increasing scarcity globally of natural resources, protected areas that encompass fertile lands will be under continuous assault to eliminate their status, reduce their size, or otherwise make them available for the production of food.

Shifting cultural values about food

As food becomes more scarce and as people are unable to obtain the types of food they have come to expect, the subject of food will become an increasing focus of social and political attention. There will be an increased awareness of distribution and equity issues that will focus initially on food, but are unlikely to remain limited to that issue alone. The distinctions between those who have sufficient food and those who do not will become more obvious and the subject of increasing discussion and debate. In short, for many different reasons, global food will become more transparent.

Put another way, the issue of food will consume us. Food security will be at or near the top of the issues that people care the most about. Ethics around food production and distribution will occupy an increasing amount of public discourse. Food security will be discussed through the lens of calories vs. nutrition, real food vs. junk food, luxury food vs. subsistence food, animal vs. vegetable protein, imports vs. locally produced, food self-sufficiency vs. global interdependence, states whose resource base cannot support their populations under a business as usual scenario vs. those who can, and so on. Moral issues around food (e.g. who has it and who doesn't, who has too much and who has too little, etc.) will become more sharply focused and politicized.

When people are starving, no border is secure. What could possibly be worse than death by starvation or seeing your children die before you? The media will reflect these issues.

As food security becomes an increasing issue of concern for people and governments around the globe, science is just beginning to identify but not yet fully understand some key relationships relating to food security. These include the relationships of food production to ecosystem services and in particular the impact of food production on climate change, carbon and water. It is not yet clear whether it is better on a finite planet to produce food locally under less than perfect conditions or to import it from different parts of the world that have more favorable conditions for production. In the case of food security and nutrition, is fresh better than canned, frozen or otherwise processed? What are the key criteria for such an analysis? Under what conditions would any of these issues be better than others or any of these concerns trump others? Is it better to process food closer to the consumer or to the producer?

Which has a less negative impact on the overall availability of calories globally as well as other impacts such as energy, carbon and GHG's or water?

In a finite world, attempts to maximize any single factor may not optimize a system. Food security is probably the same. For example, there are tradeoffs between carbon and water. However, the two are linked. According to the US Geological Survey (USGS), 21 percent of all energy use in California is used to move water—a large part of that is for food production and processing. In the business as usual scenario, it is likely that the focus will be on the immediate or short term and solving specific problems rather than addressing more long-term, structural and inter-related issues.

Supply chain management within a constrained world

In a world with food insecurity, everyone in the food business will be held more accountable. This is true from producers to retailers and all the traders, processors, distributors and manufacturers in between. In addition to increased public scrutiny and transparency with regard to food availability and prices, the entire value chain will also be affected by increased variability, prices and risks. If there are fewer surpluses in traditional exporting countries to dampen food shortages in other parts of the world, volatility and prices will increase. If surpluses remain the same or even increase, if they are offset by decreasing production or increasing consumption in other countries, then food insecurity will increase as well.

In the business as usual scenario, food security will be more variable, prices will be more volatile, and risks from climate variability or unpredictability will be exaggerated. In short, the issue for the global food industry and most of the world's consumers will not be about food prices, but rather availability at all. And these factors will drive supply chain management. To the extent possible, actors along the value chain will want to reduce or dampen risks through longer-term supply contracts. Partnerships will be preferred to transactional relationships as partnerships will reduce risk and volatility and even align incentives by allowing players access to credit, inputs and markets that will tend to reduce risks.

In more developed countries and food sectors, every actor will want to lock in credit, inputs, markets or supplies to reduce risks. This is already resulting in longer term, multiple year contracts for credit, raw materials, markets, and inputs such as seed, agrochemicals. In more commercially based markets, longer-term contracts reduce risks by aligning incentives over multiple years. These types of systems are already being developed and will continue to be perfected in commercial markets and developed countries as we move toward 2050.

Climate Change and its impacts on water are likely to have supply chain management implications as well. This will not just be a production issue, either. Others in the food system will be affected as well. On the processing side, retailers, manufacturers and brands are already beginning to ask a number of questions, many of which are new. These include:

- Is it better to build a larger number of smaller processing plants to accommodate potential changes in primary production?
- Is it better to build processing plants closer to production or to the end user?
- Which is more important, water shortages, production shortages or embedded carbon and climate change?
- Is it better to build cheaper plants that are less efficient but that can be abandoned if necessary?
- Is it better to build plants that are mobile or at least that can be disassembled and moved as necessary?

Unfortunately, most food is produced and consumed in countries where food markets are less overtly commercial, subsistence production is important, information is poor, binding contracts are rare or do not exist at all, and food markets are, consequently, often more informal. And within these countries, the poorest of the poor rely far more heavily on bulk dry goods (e.g. rice, flour, beans, and maize) and marginal fresh produce that does not have a better market elsewhere. As food availability and price volatility are less predictable, food will become more valuable, and commercial markets will extend into areas where previously most production could not be profitably shipped out of the area. Increased scarcity and market prices will tend to make production possible and profitable in areas that previously were not firmly connected to external markets. Unfortunately, at least in the short term, this will increase the food insecurity of those dependant on such locally produced food for their diets, but, depending on the intermediaries and trading systems, may or may not improve the livelihoods of those who produce such food. Put another way, as food becomes scarce, peoples' immediate reaction is to try to figure out ways to obtain it. Only later, sometimes too late for many, do they focus on the hard work of how to produce more.

7. Summary and Conclusions

If we are to address both the need to feed nine billion and maintain the planet, we need to Freeze the Footprint of Food. The Earth's resources are finite. We can't escape the basic math—population times how much each of us consumes must equal the carrying capacity of the planet. If we exceed that, we are taking away not only resources but the very resource base that will be needed by our children and our grandchildren.

In fact, as noted earlier, we're living today at the level of 1.3 planets according to the WWF's Living Planet Index. This is the equivalent of eating our seed. We are very literally eating the planet. As "natural capital" it means that we are consuming the planet's principle rather than living of its interest or bounty. So, not only do we need to do more with less, we also have to find ways to restore the planet at the same time.

Every use of resources has impacts. The issue going forward will be to define which impacts and which levels of impacts are acceptable. Right now, the single largest impact of humans on the planet is to produce food. And an estimated 70 percent of the terrestrial part of the planet that can be used for food is already taken.

For the past 50 years, we have expanded food production into new areas by converting natural habitat for food production at the rate of 0.4 percent per year. For the last decade, however, as some of the key developing country economies (notably China, India, Brazil, Russia and Indonesia) have heated up, we have been converting natural habitat for food production at the rate of 0.6 percent per year. In short we have been speeding up the conversion of natural habitat and the loss of biodiversity precisely when one might assume we would have been able to increase the intensity of production by ways other than simply expanding it.

If we assume the business as usual case for expanding into natural habitat, there will be very little natural habitat left by 2050. And yet, we know that global demand for food will increase. By 2050, we will have 3 billion more people with 2.9 times as much income, consuming twice as much. In fact, the research suggests that in developing countries incomes are likely to increase more than five-fold by 2050. This will add considerable strain to the precarious balance between people and nature that already exists in those countries. Moreover, by 2050, more people will live in cities—more than are alive today. If they behave like urban residents today, they will depend on others for virtually all their food.

There is no silver bullet or single solution that will allow us to Freeze the Footprint of Food and obtain more from less. We need to work simultaneously on a number of issues. If we are successful in building "food wedges," similar to the energy wedges we need to become independent of fossil fuels, we will find ways feed people and still have a healthy planet. Eight complimentary strategies would allow us to achieve both goals. They are summarized in order of importance:

1. **Genetics**—Ten crops account for nearly 90 percent of all calories. Only two are on track to double production by 2050. We can't afford to leave genetics (e.g. traditional plant breeding, land races, hybrids, genetic engineering, or GMO's) off the table. We should be neutral about the technologies unless there are unacceptable ancillary impacts, and focus on the results desired.

2. **Better Practices**—The best producers globally are 100 times better than the worst. The best countries are 10 times better than the worst. To achieve global food security and maintain the planet, we will gain far more, both in terms of food production and reduced environmental impacts, by moving the middle and the bottom than the top.

3. **Technology**—We need to use all inputs (water, fertilizer, pesticides, energy) more efficiently. To Freeze our Footprint we will need to double our efficiency of input use. Our goal, then, globally should be triple or quadruple the efficiency of input use.

4. **Degraded land**—Instead of expanding into new areas to farm, we need to rehabilitate degraded or underperforming lands. Our goal should be 100 million hectares rehabilitated by 2030 and 250 million by 2050.

5. **Property Rights**—What farmer will plant a tree or invest in sustainability if they don't own the land? What company will invest in new technologies if their intellectual property is not protected? We need to pursue strategies that address both these issues. Perhaps foreign assistance could be linked to property rights rather than other factors as it has been to date.

6. **Waste**—Globally we waste as much as 30-40 percent of all food produced. It is a crime to waste food once we use resources to produce it. Our goal should be to cut waste in half in both developing and developed countries. To do this, we should double the percentage of funding to reduce post-harvest losses and food waste.

7. **Overconsumption**—A billion people don't have enough food while a billion people eat too much. A reasonable goal would be not only to freeze these figures, so they do not increase, and ideally to cut them each in half by 2030.

8. **Carbon**—Whether in the soil or perennial crops or trees, carbon makes agriculture more sustainable. Our goal should be to develop carbon markets that allow food producers to sell one billion MT of carbon per year by 2030. This will not only make food production more sustainable but will also make producers more financially viable.

In short, while no single strategy will solve the global food problem or ensure global food security, there is something that each of us as individuals or institutions can do, and together we can find ways to address this issue. We need to question current thinking and existing strategies. As has been demonstrated throughout this chapter, the business as usual scenario will not get us where we need to go. We need to invest time, energy, and money into this.

Failure, either for people or the planet, is simply unacceptable. No one has all the answers, but together we can solve this problem and leave our children a living planet.

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