from Lester R. Brown, *Plan B 2.0 Rescuing a Planet Under Stress and a Civilization in Trouble* (NY: W.W. Norton & Co., 2006).

9

Feeding Seven Billion Well

In April 2005, the World Food Programme and the Chinese government jointly announced that food aid shipments to China would stop after the end of the year. For a country where hundreds of millions of people were chronically hungry a generation ago, this was a landmark achievement. China's success in largely eradicating hunger can be traced to the wholesale reduction in poverty associated with the eightfold expansion in its economy since the economic reforms of 1978 and the 50-percent jump in its grain harvest between 1977 and 1986.[1]

While hunger has been disappearing in China, it has been spreading in sub-Saharan Africa and parts of the Indian subcontinent. As a result, the number of people who are hungry has increased from a recent historical low of 820 million in 2000 to 852 million in 2002.[2]

One key to the threefold expansion in the world grain harvest since 1950 was the rapid adoption in developing countries of high-yielding wheats and rices developed in Japan and hybrid corn from the United States. The spread of these highly productive seeds, combined with a tripling of irrigated area and a ninefold increase in world fertilizer use, tripled the world grain harvest. Growth in irrigation and fertilizer use essentially removed soil moisture and nutrient constraints on crop yields in much of the world.[3]

But now the world's farmers face enormous additional demand for farm products from the projected addition of some 70 million people a year, the desire by some 5 billion people to consume more livestock products, and the potential of millions of motorists turning to farm-produced fuel crops to supplement tightening supplies of gasoline and diesel fuel. On the supply side, farmers are faced with shrinking supplies of irrigation water, rising temperatures, the loss of cropland to nonfarm uses, rising fuel costs, and a dwindling backlog of yield-raising technologies. For those who like to be challenged, this is a good time to be a farmer or an agronomist.[4]

Rethinking Land Productivity

Efforts to raise cropland productivity are slowing as the backlog of unused agricultural technology shrinks. The loss of momentum in efforts to raise cropland productivity is worldwide. Between 1950 and 1990, world grain yield per hectare climbed by 2.1 percent a year. From 1990 to 2000, however, it rose only 1.2 percent annually. This is partly because the yield response to the additional application of fertilizer is diminishing and partly because irrigation water supplies are limited. During the current decade, the rise in land productivity may slow even more.[5]

This calls for fresh thinking on how to raise cropland productivity. One simple way of doing this, where soil moisture permits, is to increase the area multicropped—land that produces more than one crop per year. In North America and Western Europe, which in the past have restricted cropped area to control surpluses, there is some potential for double cropping that has not been fully exploited. Indeed, the tripling in the world grain harvest since 1950 is due in part to impressive increases in multiple cropping in Asia. Some of the more common combinations are wheat and corn in northern China, wheat and rice in northern India, and the double or triple cropping of rice in southern China, southern India, and nearly all the rice-growing countries in Southeast Asia.[6]

The double cropping of winter wheat and corn in the North China Plain boosted China's grain production to the U.S. level beginning two decades ago. Winter wheat grown there yields close to 4 tons per hectare. Corn averages 5 tons. Together these two crops, grown in rotation, can yield 9 tons of grain per hectare per year. China's double-cropped rice yields 8 tons per hectare.[7]

Forty years ago, North India produced only wheat, but with the advent of the earlier maturing high-yielding wheats and rices, the wheat could be harvested in time to plant rice. This wheat/rice combination is now widely used throughout the Punjab, Haryana, and parts of Uttar Pradesh. The wheat yield of 3 tons and rice yield of 2 tons combine for 5 tons of grain per hectare, helping to feed India's 1.1 billion people.[8]

The area that can be multicropped is limited by the supply of irrigation water and, in some areas, by a lack of enough labor to quickly harvest one crop and plant another. The loss of low-cost rural labor to industrialization can sharply reduce multiple cropping and therefore the harvested area. In Japan, for example, the grain harvested area peaked at nearly 5 million hectares in 1960 largely because the country's industrious farmers were harvesting two crops per year. As of 2005, Japan's harvested area had dropped to 2 million hectares in part because of cropland conversion to nonfarm uses, but mostly because of a steady decline in double cropping over the decades as rising wages in industry pulled workers away from agriculture. The cheap labor needed to cultivate small plots intensively has disappeared. Even a rice support price four times the world market level could not keep enough workers in agriculture to support extensive multicropping.[9]

Similarly, South Korea's harvested grain area has shrunk by half since peaking in 1965 primarily because of a decline in multiple cropping. Taiwan's has declined nearly two thirds since 1975. As industrialization progresses in China and India, their more prosperous regions may see similar declines in multiple cropping. In China, where incomes have quadrupled since 1980, this process already appears to be reducing production.[10]

In the United States, the lifting of planting area restrictions in 1996 opened new opportunities for multiple cropping. The most common U.S. double cropping combination is winter wheat with soybeans as a summer crop. Six percent of the soybean harvest comes from land that also produces winter wheat. Since soybeans fix nitrogen, this rotation reduces wheat farmers' need to apply fertilizer.[11]

A concerted U.S. effort to both breed earlier maturing varieties and develop cultural practices that would facilitate multiple cropping could substantially boost crop output. If China's farmers can extensively double crop wheat and corn, then U.S. farmers, at a similar latitude and with similar climate patterns, could do the same if agricultural research and farm policy were reoriented to support it.

Western Europe, with its mild winters and high-yielding winter wheat, might also be able to double crop more with a summer grain, such as corn, or with an oilseed crop. Elsewhere, Brazil and Argentina have an extended frost-free growing season that supports extensive multicropping, often wheat or corn with soybeans. The availability of chemical fertilizers also facilitates multiple cropping.[12]

In many countries, including the United States, most of those in Western Europe, and Japan, fertilizer use has reached a level where using more has little effect on crop yields. There are still some places, however, such as most of Africa, where additional fertilizer would help boost yields. Unfortunately, sub-Saharan Africa lacks the infrastructure to transport fertilizer economically to the villages where it is needed. As a result of nutrient depletion, grain yields in much of sub-Saharan Africa are falling.[13]

One encouraging response to this situation in Africa is the simultaneous planting of grain and leguminous trees. The trees start to grow slowly, permitting the grain crop to mature and be harvested. Then the trees grow quickly to several feet in height, dropping leaves that provide nitrogen and organic matter—both sorely needed in African soils. The wood is then cut and used for fuel. This simple, locally adapted technology, developed by scientists at the International Centre for Research in Agroforestry in Nairobi, has enabled farmers to double their grain yields within a matter of years as soil fertility builds.[14]

Despite local advances, the overall loss of momentum in expanding food production is unmistakable. It will force us to think about both limiting the growth in demand and using the existing harvest more productively. On the demand side, achieving an acceptable worldwide balance between food and people may now depend on stabilizing population as soon as possible, reducing the unhealthily high consumption of livestock products in industrial countries, and restricting the conversion of food crops to automotive fuels. But we must also think more broadly about land productivity, considering not only the individual crop but how to increase multiple cropping and how to get more out of existing harvests.

Raising Water Productivity

Since it takes 1,000 tons of water to produce 1 ton of grain, it is not surprising that 70 percent of world water use is devoted to irrigation. Thus, raising irrigation water efficiency is central to raising water productivity overall. Using more water-efficient irrigation technologies and shifting to crops that use less water can help expand the irrigated area, even with a limited water supply. Eliminating water subsidies and energy subsidies that encourage wasteful water use allows water prices to rise to market levels. Higher water prices encourage all water users to use water more efficiently. Institutionally, local rural water users associations that directly involve those using the water in its management have raised water productivity in many countries.[15]

The world now needs to launch an effort to raise water productivity similar to the one that nearly tripled grainland productivity during the last half of the twentieth century. Land productivity is typically measured in tons of grain per hectare or bushels per acre. A comparable indicator for irrigation water is kilograms of grain produced per ton of water. Worldwide, that average is now roughly 1 kilogram of grain per ton of water used.[16]

Some data have been compiled on water irrigation efficiency at the international level for surface water projects—that is, dams that deliver water to farmers through a network of canals. Crop usage of irrigation water never reaches 100 percent simply because some irrigation water evaporates from the land surface, some percolates downward, and some runs off.[17]

Water policy analysts Sandra Postel and Amy Vickers found that "surface water irrigation efficiency ranges between 25 and 40 percent in India, Mexico, Pakistan, the Philippines, and Thailand; between 40 and 45 percent in Malaysia and Morocco; and between 50 and 60 percent in Israel, Japan, and Taiwan." Irrigation water efficiency is affected not only by the type and condition of irrigation systems but also by soil type, temperature, and humidity. In arid regions with high temperatures, the evaporation of irrigation water is far higher than in humid regions with lower temperatures.[18]

In a May 2004 meeting, China's Minister of Water Resources Wang Shucheng outlined for me in some detail the plans to raise China's irrigation efficiency from 43 percent in 2000 to 51 percent in 2010 and then to 55 percent in 2030. The steps he described included raising the price of water, providing incentives for adopting more irrigation-efficient technologies, and developing the local institutions to manage this process. Reaching these goals, he felt, would assure China's future food security.[19]

Raising irrigation water efficiency typically means shifting from the less efficient flood or furrow system to overhead sprinklers or to drip irrigation, the gold standard of irrigation efficiency. Switching from flood or furrow to low-pressure sprinkler systems reduces water use by an estimated 30 percent, while switching to drip irrigation typically cuts water use in half.[20]

As an alternative to furrow irrigation, a drip system also raises yields because it provides a steady supply of water with minimal losses to evaporation. Since drip systems are both labor-intensive and water-efficient, they are well suited to countries with underemployment and water shortages, allowing farmers to raise their water productivity by using labor, which is often in surplus in rural communities.[21]

A few small countries—Cyprus, Israel, and Jordan—rely heavily on drip irrigation. Among the big three agricultural producers, this more-efficient technology is used on less than 1 percent of irrigated land in India and China and roughly 4 percent of such land in the United States.[22]

In recent years, the tiniest small-scale drip-irrigation systems—virtually a bucket with flexible plastic tubing to distribute the water—have been developed to irrigate a small vegetable garden with roughly 100 plants (covering 25 square meters). Somewhat larger drum systems irrigate 125 square meters. In both cases, the containers are elevated slightly, so that gravity distributes the water. Somewhat larger drip systems using plastic lines that can be moved easily are also becoming popular. These simple systems can pay for themselves in one year. By simultaneously reducing water costs and increasing yields, they can dramatically raise incomes of smallholders.[23]

Sandra Postel believes that the combination of these drip technologies at various scales has the potential to profitably irrigate 10 million hectares of India's cropland, or nearly one tenth of the total. She sees a similar potential for China, which is now also expanding its drip irrigation area to save scarce water.[24]

Institutional shifts—specifically, moving the responsibility for managing irrigation systems from government agencies to local water users associations—can facilitate a more efficient use of water. Farmers in many countries are organizing locally so they can assume this responsibility. Since local people have an economic stake in good water management, they tend to do a better job than a distant government agency.[25]

Mexico is a leader in this movement. As of 2002, farmers associations managed more than 80 percent of Mexico's publicly irrigated land. One advantage of this shift for the government is that the cost of maintaining the irrigation system is assumed locally, reducing the drain on the treasury. This also means that associations often need to charge more for irrigation water. Even so, for farmers the production gains from managing their water supply more than outweigh this additional expenditure.[26]

In Tunisia, where water users associations manage both irrigation and residential water, the number of associations increased from 340 in 1987 to 2,575 in 1999. Many other countries now have such bodies managing their water resources. Although the early groups were organized to deal with large publicly developed irrigation systems, some recent ones have been formed to manage local groundwater irrigation as well. They assume responsibility for stabilizing the water table with the goal of avoiding aquifer depletion and the economic disruption that it brings to the community.[27]

Low water productivity is often the result of low water prices. In most countries, prices are irrationally low, belonging to an era when water was an abundant resource. As water becomes scarce, it needs to be priced accordingly. Provincial governments in northern China are raising water prices in small increments to discourage waste. A higher water price affects all water users, encouraging investment in more water-efficient irrigation technologies, industrial processes, and household appliances.[28]

What is needed now is a new mindset, a new way of thinking about water use. For example, shifting to more water-efficient crops wherever possible also boosts water productivity. Rice production is being phased out around Beijing because rice is such a thirsty crop. Similarly, Egypt restricts rice production in favor of wheat.[29]

Any measures that raise crop yields on irrigated land also raise the productivity of irrigation water. Similarly, anything that increases the efficiency with which grain is converted into animal protein in effect increases water productivity.

For people consuming unhealthy amounts of livestock products, moving down the food chain means not only a healthier diet and reduced health care costs but also a reduction in water use. In the United States, where annual consumption of grain as food and feed averages some 800 kilograms (four fifths of a ton) per person, a modest reduction in the consumption of meat, milk, and eggs could easily cut grain use per person by 100 kilograms. Given that there are now nearly 300 million Americans, such a reduction would cut grain use by 30 million tons and irrigation water use by 30 billion tons.[30]

Reducing water use to a level that can be sustained by aquifers and rivers worldwide involves a wide range of measures not only in agriculture but throughout the economy. The more obvious steps, in addition to more water-efficient irrigation practices and more water-efficient crops, include adopting more water-efficient industrial processes and using more water-efficient household appliances. One of the less conventional steps is to shift from outdated coal-fired power plants, which require vast amounts of water for thermal cooling, to wind power—something long overdue in any case because of climate disruption. Recycling urban water supplies is another obvious step to consider in countries facing acute water shortages.

Producing Protein More Efficiently

The second way to raise both land and water productivity is to produce animal protein more efficiently. With some 38 percent (about 730 million tons) of the world grain harvest used to produce animal protein, the potential for more-efficient grain use is large.[31]

World meat consumption increased from 47 million tons in

1950 to 260 million tons in 2005, more than doubling consumption per person from 17 kilograms to 40 kilograms. Consumption of milk and eggs has also risen. In every society where incomes have risen, meat consumption has too, perhaps reflecting a taste that evolved over 4 million years of hunting and gathering.[32]

As both the oceanic fish catch and the production of beef on rangelands have leveled off, the world has shifted to grain-based production of animal protein to expand output. And as the demand for animal protein climbs, the mix of protein products consumed is shifting toward those that convert grain into protein most efficiently, the lower-cost products. Health concerns have also prompted a shift from beef and pork to poultry and fish.

The efficiency with which various animals convert grain into protein varies widely. With cattle in feedlots, it takes roughly 7 kilograms of grain to produce a 1-kilogram gain in live weight. For pork, the figure is close to 4 kilograms of grain per kilogram of weight gain, for poultry it is just over 2, and for herbivorous species of farmed fish (such as carp, tilapia, and catfish), it is less than 2. As the market shifts production to the more grain-efficient products, it raises the productivity of both land and water.[33]

Global beef production, most of which comes from rangelands, grew less than 1 percent a year from 1990 to 2005. Growth in the number of cattle feedlots was minimal. Pork production grew by 2.5 percent annually, and poultry by nearly 5 percent. The rapid growth in poultry production, going from 41 million tons in 1990 to 80 million tons in 2005, enabled poultry to eclipse beef in 1995, moving it into second place behind pork. (See Figure 9–1.) World pork production, half of it in China, overtook beef production in 1979 and has continued to widen the lead since then. World beef production, constrained by both grazing limits and the inefficient feedlot conversion by cattle, is continuing to expand, but slowly. Indeed, within the next decade or so, fast-growing, highly grain-efficient aquacultural output may overtake beef production.[34]

The big winner in the animal protein sweepstakes has been aquaculture, largely because herbivorous fish convert feed into protein so efficiently. Aquacultural output expanded from 13 million tons in 1990 to 42 million tons in 2003, growing by more

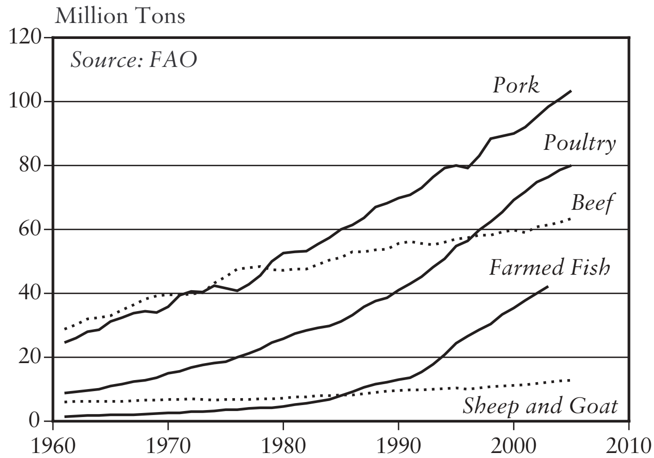

Figure 9–1. *World Meat Production by Type, 1961–2005*

than 10 percent a year. China, the leading producer, accounts for an astounding two thirds of global output. Aquacultural production in China is dominated by finfish (mostly carp), which are produced inland in freshwater ponds, lakes, reservoirs, and rice paddies, and by shellfish (mostly oysters, clams, and mussels), which are produced mostly in coastal regions.[35]

China's aquaculture is often integrated with agriculture, enabling farmers to use agricultural wastes, such as pig or duck manure, to fertilize ponds, thus stimulating the growth of plankton on which the fish feed. Fish polyculture, which commonly boosts pond productivity over that of monocultures by at least half, is widely practiced in both China and India.[36]

As land and water for fish ponds become even scarcer, China's fish farmers are feeding fish more grain concentrates, including soybean meal, to raise pond productivity. Using this technique, China's farmers raised the annual pond yield per hectare from 2.4 tons of fish in 1990 to 4.1 tons in 1996.[37]

In the United States, catfish, which require less than 2 kilograms of feed per kilogram of live weight, are the leading aquacultural product. U.S. annual catfish production of 600 million pounds (about two pounds per person) is concentrated in four states: Mississippi, Louisiana, Alabama, and Arkansas. Mississippi, with easily 60 percent of U.S. output, is the catfish capital of the world.[38]

Public attention has focused on aquacultural operations that are environmentally inefficient or disruptive, such as the farming of salmon, a carnivorous species, and shrimp. These operations account for 3.6 million tons of output, less than 9 percent of the global farmed fish total, but they are growing fast. Salmon are inefficient in that they are fed other fish, usually as fishmeal, which comes either from fish processing plant wastes or from low-value fish caught specifically for this purpose. Shrimp farming often involves the destruction of coastal mangrove forests to create areas for the shrimp.[39]

World aquaculture is dominated by herbivorous species—mainly carp in China and India, but also catfish in the United States and tilapia in several countries—and shellfish. This is where the great growth potential for efficient animal protein production lies.[40]

When we think of soybeans in our daily diet, it is typically as tofu, veggie burgers, or other meat substitutes. But most of the world's fast-growing soybean harvest is consumed indirectly in the beef, pork, poultry, milk, eggs, and farmed fish that we eat. Although not a visible part of our diets, the incorporation of soybean meal into feed rations has revolutionized the world feed industry, greatly increasing the efficiency with which grain is converted into animal protein.[41]

In 2005, the world's farmers produced 220 million tons of soybeans—1 ton for every 9 tons of grain produced. Of this, some 15 million tons were consumed directly as tofu or meat substitutes. The bulk of the remaining 205 million tons, after some was saved for seed, was crushed in order to extract 33 million tons of soybean oil, separating it from the highly valued, high-protein meal. By 2006, perhaps 2 million tons (7 percent) of these 33 million tons will be heading to service stations as biodiesel.[42]

The 144 million tons of soybean meal that remain after the oil is extracted is fed to cattle, pigs, chicken, and fish, enriching their diets with high-quality protein. Combining soybean meal with grain in roughly one part meal to four parts grain dramatically boosts the efficiency with which grain is converted into animal protein, sometimes nearly doubling it.[43]

The world's three largest meat producers—China, the United States, and Brazil—now all rely heavily on soybean meal as a protein supplement in feed rations. In the United States, which has long used soybean meal to upgrade livestock and poultry feed, the soybean meal share of feed rations climbed from 8 percent in 1964 to roughly 18 percent in recent years.[44]

For Brazil, where the shift began in the late 1980s, soybean meal now makes up roughly 21 percent of the feed mix. In China, the realization that feed efficiency could be dramatically boosted with soymeal came several years later. Between 1991 and 2002, the soymeal component of feed there jumped from 2 percent to 20 percent. For fish, whose protein demands are particularly high, China incorporated some 5 million tons of soymeal into the 16 million tons of grain-based fish feed used in 2003.[45]

With this phenomenal growth, soybean meal both replaced some grain in feed and increased the efficiency with which the remaining grain was converted into livestock products. This also helps explain why the share of the world grain harvest used for feed has not increased over the last 20 years even though production of meat, milk, eggs, and farmed fish has climbed. And it explains why world soybean production jumped from 16 million tons in 1950 to 220 million tons in 2005, a 13-fold increase. While the potential for raising feed efficiency with soybean meal has now been largely realized in key food-producing countries, there are still many developing countries that have not yet fully exploited its potential.[46]

New Protein Production Systems

Mounting pressures on the earth's land and water resources to produce livestock, poultry, and fish feed have led to the evolution of some promising new animal protein production models, one of which is milk production in India. Since 1970, India's milk production has increased more than fourfold, jumping from 21 million to 95 million tons. In 1998, India overtook the United States to become the world's leading producer of milk and other dairy products. (See Figure 9–2.)[47]

The spark for this explosive growth came in 1965 when an enterprising young Indian, Dr. Verghese Kurien, organized the National Dairy Development Board, an umbrella organization of dairy cooperatives. The dairy coop's principal purpose was to market the milk from tiny herds that typically averaged two

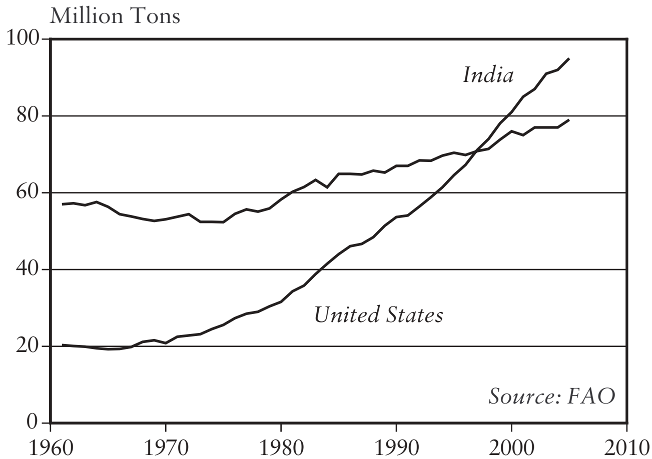

Figure 9–2. *Milk Production in India and the United States, 1961–2005*

to three cows each, providing the link between the growing appetite for dairy products and the millions of village families who had only a small marketable surplus.[48]

Creating the market for milk spurred the fourfold growth in output. In a country where protein shortages stunt the growth of so many children, expanding the milk supply from less than half a cup per person a day 30 years ago to more than a cup represents a major advance.[49]

What is so remarkable is that India has built the world's largest dairy industry almost entirely on roughage—wheat straw, rice straw, corn stalks, and grass collected from the roadside. Even so, the value of the milk produced each year now exceeds that of the rice harvest.[50]

A second new protein production model, one that also relies on ruminants, has evolved in four provinces of central Eastern China—Hebei, Shangdong, Henan, and Anhui—where double cropping of winter wheat and corn is common. Once the winter wheat ripens in early summer, it is harvested quickly so the seedbed can be prepared for the corn. Similarly, once the corn is harvested in the fall, the seedbed is quickly prepared to sow the wheat. Although the wheat straw and cornstalks are often used as fuel for cooking, villagers are shifting to other sources of energy for this, which lets them feed the straw and cornstalks to cattle. Supplementing this roughage with small amounts of nitrogen in the form of urea allows the microflora in the complex four-stomach digestive system of cattle to convert roughage into animal protein efficiently.[51]

These four crop-producing provinces in China, dubbed the Beef Belt by officials, produce much more beef, using crop residues—wheat and rice straw and corn stalks—than the vast grazing provinces in the northwest do. The use of crop residues to produce milk in India and beef in China lets farmers reap a second harvest from the original grain crop, boosting both land and labor productivity.[52]

Over time, China has also developed a remarkably efficient fish polyculture using four types of carp that feed at different levels of the food chain, in effect emulating natural aquatic ecosystems. Silver carp and bighead carp are filter feeders, eating phytoplankton and zooplankton respectively. The grass carp, as its name implies, feeds largely on vegetation, while the common carp is a bottom feeder, living on detritus. These four species thus form a small ecosystem, with each filling a particular niche. This multi-species system, which converts feed into high-quality protein with remarkable efficiency, yielded some 13 million tons of carp in 2002.[53]

While poultry production has grown rapidly in China, as in other developing countries, it has been dwarfed by the phenomenal growth of aquaculture. Today aquacultural output in China—at 29 million tons—is double that of poultry, making it the first major country where aquaculture has eclipsed poultry farming. The great economic and environmental attraction of this system is the efficiency with which it produces animal protein.[54]

Although these three new protein models have evolved in India and China (both densely populated), similar systems can be adopted in other countries as population pressures intensify, as demand for meat and milk increase, and as farmers seek new ways to convert plant products into animal protein.

The world desperately needs more new protein production techniques such as these. A half-century ago, when there were only 2.5 billion people in the world, almost everyone wanted to move further up the food chain. Now that number may have doubled. Meat consumption is growing twice as fast as population, egg consumption is growing nearly three times as fast, and growth in the demand for fish—both from the oceans and from fish farms—is also outpacing that of population. Against this backdrop of growing world demand, human ingenuity in producing animal protein in ever-larger quantities and ever more efficiently will be tested.[55]

While the world has had many years of experience in feeding an additional 70 million or more people each year, it has no experience with some 5 billion people wanting to move up the food chain at the same time. For a sense of what this translates into, consider what has happened in China since the economic reforms in 1978. As the fastest-growing economy in the world since then, China has in effect telescoped history, showing how diets change when incomes rise rapidly.[56]

As recently as 1978, meat consumption was low in China, consisting mostly of modest amounts of pork. Since then, consumption of pork, beef, poultry, and mutton has climbed severalfold, pushing China's total meat consumption far above that of the United States. As incomes rise in other countries, consumers there will also want more animal protein. Considering the effect of this expanding demand on global land and water resources, along with the more traditional demand from population growth, provides a better sense of future pressures on the earth. If world grain supplies tighten in the years ahead, the competition for grain between people wanting more biofuels, those living high on the food chain, and those on the bottom rungs of the economic ladder will become both more visible and a possible source of tension within and among societies.[57]

Moving Down the Food Chain

One of the questions I am most often asked on a speaking tour is, "How many people can the earth support?" I answer with another question: "At what level of food consumption?" At the U.S. level of 800 kilograms per person per year for food and feed, the 2-billion-ton annual world harvest of grain would support 2.5 billion people. At the Italian level of consumption of close to 400 kilograms per year, the current harvest would support 5 billion people. At the nearly 200 kilograms of grain consumed per year by the average Indian, it would support a population of 10 billion.[58]

In every society where incomes rise, people move up the food chain, eating more animal protein as beef, pork, poultry, milk, eggs, and seafood. The mix of animal protein products varies with geography and culture, but the shift to more animal protein as purchasing power increases appears to be universal.

As consumption of livestock products, poultry, and farmed fish rises, grain use per person also rises. Of the roughly 800 kilograms of grain consumed per person each year in the United States, about 100 kilograms is eaten directly as bread, pasta, and breakfast cereals. But the bulk of the grain is consumed indirectly in the form of livestock, poultry, and farmed fish. By contrast, in India, where people consume just under 200 kilograms of grain per year, or roughly a pound per day, nearly all grain is eaten directly to satisfy basic food energy needs. Little is available for conversion into livestock products.[59]

Of the three countries just cited, life expectancy is highest in Italy even though U.S. expenditures on medical care per person are much higher. Those who live very low on the food chain or very high on the food chain do not live as long as those in an intermediate position. The Mediterranean diet includes meats, cheeses, and seafood, but in moderation. Nutritionally, this is the healthiest way to eat.[60]

What this means is that those living high on the food chain, such as the average American or Canadian, can consume less grain and improve health at the same time. For those who live in low-income countries like India, where diets are dominated by a starchy staple such as rice, sometimes supplying 60 percent or more of total caloric intake, eating more animal products can improve health and raise life expectancy.[61]

In addition to having the affluent sector move down the food chain by consuming fewer livestock products, the world is turning to the more grain-efficient forms of animal protein. Together these two steps have helped hold the share of the world grain harvest used for feed constant at roughly 38 percent for the last two decades.[62]

It is widely assumed that moving from animal protein to high-quality proteins from plant sources, such as beans or tofu made from soybeans, is more land-efficient. But this is not always the case. For example, as noted earlier, with poultry it takes just over 2 kilograms of grain to produce 1 kilogram of additional live weight. For catfish, it is less than 2 kilograms of grain per kilogram of weight gain. An acre of land in Iowa can thus produce 140 bushels of corn or 35 bushels of the much lower-yielding soybean. Feeding the corn to chickens or catfish can yield more high-quality protein than growing soybeans and consuming them directly, say as tofu.[63]

It takes a good deal of land to produce soy protein, largely because plants require more metabolic energy to produce high-quality plant protein than to produce starch. But because poultry and catfish are so efficient at converting grain, eating them is more land- and water-efficient than eating soybeans is.[64]

Some countries are moving down the food chain by turning to the more grain-efficient protein sources such as aquaculture. China, with its huge aquacultural output, may be the first country where the farmed fish harvest exceeds the wild fish catch.[65]

With incomes now rising in densely populated Asia, other countries are following China's lead. Among them are India, Thailand, and Viet Nam. Viet Nam, for example, devised a plan in 2001 of developing 700,000 hectares of land in the Mekong Delta for aquaculture, with the goal of producing 1.7 million tons of fish and shrimp by 2005. It now appears likely to exceed this goal.[66]

Action on Many Fronts

Historically, the responsibility for food security rested largely with the ministry of agriculture. During the last half of the last century, ensuring adequate supplies of grain in the world market was a relatively simple matter. Whenever the world grain harvest fell short and prices started to rise, the U.S. Department of Agriculture would simply return to production part of the cropland idled under supply control programs, thus boosting output and stabilizing prices. This era ended in 1996 when the United States dismantled its annual cropland set-aside program.[67]

Ministries of agriculture bear the primary responsibility for expanding food production to satisfy the world's seemingly insatiable appetite. The fast-growing demand from the addition of 70 million mouths to feed each year, from 5 billion people wanting to move up the food chain, and now, for the first time, from the insatiable demand for farm commodities to produce automotive fuel will pose an unprecedented challenge to ministries of agriculture. At the same time they are faced with a dwindling backlog of unused agricultural technology, shrinking supplies of irrigation water, and the prospect of crop-withering heat waves. Demand growth and supply constraints together will challenge agricultural leaders as never before.

In this chapter, we have discussed some of the newer measures that can be used to raise land and water productivity. Adoption of these and other actions are obviously important, but in the new world we have entered, the policies of other ministries also bear heavily on the food security prospect.

Now with our finite planet being pushed to its limits and beyond, the capacity of health and family planning ministries to educate the public about the consequences of population growth and to meet family planning needs has become a food security issue. Whether individual couples decide to have one, two, or three children directly affects world food security.

In today's world, decisions made in ministries of energy on whether to stay with fossil fuels and continue to drive the earth's temperature upward or to shift to renewable energy sources and stabilize the earth's temperature could have a greater effect on long-term food security than any actions taken by ministries of agriculture.

And in much of the world, water is a more serious constraint on food production than land. The success, or lack thereof, of water ministries in raising water productivity will directly affect future food security and food prices.

Similarly, in a world where cropland is scarce and becoming more so, decisions made in ministries of transportation on whether to develop auto-centered systems or more diversified transport systems that rely heavily on less land-intensive transport forms, including light rail, buses, and bicycles will also affect world food security. Policies adopted by the ministers of transportation in land-scarce countries like China and India directly affect world food security.

More broadly, how far governments go in encouraging the use of scarce agricultural resources to produce commodities to be converted into automotive fuel will directly affect efforts to eradicate hunger. The question is how effective governments will be in managing this emerging competition between cars and people for food commodities.

In our increasingly crowded world, the responsibility for food security extends far beyond the ministry of agriculture, involving all ministries in the effort to fully realize the earth's sustainable food production potential. At the same time, there are many agricultural successes that can be imported by countries struggling to improve their food security. Encouragingly, the two big breakthroughs in expanding animal protein supplies—the dramatic gains in milk production in India and fish farming in China—can be replicated in many other developing countries.