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Feeding Everyone Well

In November 1965, U.S. Secretary of Agriculture Orville Freeman asked if I would draft a plan to get India's agriculture moving. The monsoon had failed that summer, leaving India to face a potential famine of historic proportions. India had been neglecting its agriculture in favor of industrial development and had no grain reserves. As one official in New Delhi put it, "Our reserves are in the grain elevators in Kansas."

President Lyndon Johnson was concerned, because he knew that the United States could not feed India's growing population over the long term. He wanted a plan for India to develop its agriculture and an agreement that India would implement the plan promptly in exchange for massive food relief. Since I was working as an Asian agricultural analyst in the U.S. Department of Agriculture and was familiar with India, having spent part of 1956 living in villages there, I was chosen to draft the plan.

The key steps for India to take were straightforward. The first was to shift from an urban-oriented policy of ceiling prices for

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grain that discouraged investment in agriculture to a rural-oriented policy of support prices that would encourage farmers to invest in improving their land and other output-expanding measures. The second step was to move the fertilizer industry out of the government sector, where it took up to nine years to build a fertilizer plant, into the private sector, where plants could be built in two years. The third was to harness the abundant underground water resources for irrigation. The fourth was to disseminate quickly the high-yielding wheats that had already been tested and approved for use in India.

During the year following signature of the agreement, the United States shipped a fifth of its wheat crop to India to offset the poor harvest. Two ships left U.S. ports each day laden with grain for India—part of the largest movement of grain between two countries in history. Between 1965 and 1973, India doubled its wheat harvest, a record gain for a major country. The agricultural plan succeeded beyond our hopes as India became self-sufficient in grain.[1]

The plan I drafted in November 1965 was not difficult. Any number of people could have come up with such a scheme because the needed steps were so obvious. Today, however, with its population projected to grow by 563 million by 2050, India is facing a far more complex challenge. Achieving a humane balance between food and people may now depend more on the success of family planners in accelerating the shift to smaller families than on farmers. In India, as in the world as a whole, soil erosion, aquifer depletion, and climate change are the principal threats to the sustainability of agriculture, to building the food sector of an eco-economy.[2]

Expanding food production to feed the world's growing numbers will be far more difficult during this half-century than it was over the last. During the last half of the twentieth century, the world's farmers nearly tripled grain production, boosting it from 631 million tons in 1950 to 1,835 million tons in 2000. This half-century gain was nearly double that from the beginning of agriculture, some 11,000 years ago, until 1950.[3]

Impressive though this achievement was, most of the progress was cancelled by population growth. Today, 1.1 billion of the world's 6.1 billion people are still undernourished and underweight. Hunger and the fear of starvation quite literally shape their lives.[4]

Eradicating the hunger that exists today and feeding those to be added tomorrow is a worthy challenge, one made all the more difficult because two of the world's three food systems—rangelands and oceanic fisheries—are already being pushed to or even beyond their sustainable yields. The output of croplands has not yet reached its limit, but the rise in cropland productivity has slowed over the last decade.

In its most basic form, hunger is a productivity problem. Typically people are hungry because they do not produce enough food to meet their needs or because they do not earn enough money to buy it. The only lasting solution is to raise their productivity—a task complicated by the ongoing shrinkage in both the cropland area and irrigation water per person in developing countries.

A Status Report

As noted, 1.1 billion people are undernourished and underweight. The meshing of this number with a World Bank estimate of 1.3 billion living in poverty, defined as those living on $1 a day or less, comes as no surprise. Poverty and hunger go hand in hand.[5]

Gains in eradicating hunger in East Asia and Latin America leave most of those who are still hungry concentrated in the Indian subcontinent and sub-Saharan Africa. In these regions, most of the hungry live in the countryside. The World Bank reports that 72 percent of the world's 1.3 billion poor live in rural areas. Most of them are undernourished, sentenced to a short life. These rural poor usually live not on the productive irrigated plains but on the semiarid/arid fringes of agriculture or in the upper reaches of watersheds on highly erodible, steeply sloped land. Eradicating hunger depends on stabilizing these fragile ecosystems.[6]

Demographically, most of the world's poor live in countries with rapidly growing populations, where poverty and population growth are reinforcing each other. The Indian subcontinent, for example, is adding 21 million people a year, the equivalent of another Australia. By mid-century, the population of this region—already the hungriest on earth—is expected to include another 900 million people.[7]

No single factor bears so directly on the prospect of eradicating hunger in this region as population growth. In rural societies, when a farm passes from one generation to the next, it is typically subdivided among the children. With the second generation of rapid population growth and subsequent land fragmentation, farms are shrinking to the point where they can no longer support the people living on them.

Between 1970 and 1990, the number of farms in India with less than 2 hectares (5 acres) of land increased from 49 million to 82 million. Assuming that this trend has continued since then, India now has more than 90 million farms of less than 2 hectares. If each family has six members, then 540 million people—over half of India's population—are trapped in a precarious balance with the land.[8]

In Bangladesh, average farm size has already fallen below 1 hectare. According to one study, Bangladesh's "strong tradition of bequeathing land in fixed proportions to all male and female heirs has led to increasing landlessness and extreme fragmentation of agricultural holdings." In addition to the millions who are now landless, millions more have plots so small that they are effectively landless.[9]

Africa, with the world's fastest population growth, is facing a similar reduction in cropland per person. For example, as Nigeria's population goes from 114 million today to a projected 278 million in 2050, its per capita grainland—most of it semiarid and unirrigated—will shrink from 0.15 hectares to 0.06 hectares. Nigeria's food prospect, if it stays on this population trajectory, is not promising.[10]

Further complicating efforts to expand food production are water shortages. As noted earlier, almost all of the 3.2 billion people to be added to world population in the next 50 years will be born in countries already facing water shortages, such as India, Pakistan, and those in the Middle East and semiarid Africa. In India, water tables are already falling in large areas as demand exceeds the sustainable yield of aquifers. For many countries facing water scarcity, trying to eradicate hunger while population continues to grow rapidly is like trying to walk up a down escalator.[11]

Even as the world faces the prospect of adding 80 million people a year over the next two decades, expanding food production is becoming more difficult. In each of the three food systems—croplands, rangelands, and oceanic fisheries—output expanded dramatically during most of the twentieth century's last half. Now this is changing.

Between 1950 and 2000, as noted earlier, world production of grain nearly tripled. Production per person climbed nearly 40 percent as growth in the grain harvest outstripped that of population.

The rising tide of grain production improved nutrition for much of humanity, but after 1984 growth in production slowed, falling behind that of population. By 2000, production per person had dropped 11 percent from the peak. (See Table 7–1.) The decline is concentrated in Africa, where rapid population growth has simply outrun grain production, and in the former Soviet Union, where the economy has shrunk by half since 1990 and living standards have deteriorated.[12]

Table 7–1. *World Production Per Person of Grain, Beef and Mutton, and Seafood, 1950–2000*

Food	Growth Period	Growth	Decline Period	Decline
		(percent)		(percent)
Grain	1950–84	+ 38	1984–2000	– 11
Beef and Mutton	1950–72	+ 44	1972–2000	– 15
Seafood	1950–88	+112	1988–98	– 17

Source: See endnote 12.

Roughly 1.2 billion tons of the world grain harvest are consumed directly as food, with most of the remaining 635 million tons (36 percent) consumed indirectly in livestock, poultry, and aquacultural products. The share of total grain used for feed varies widely among the "big three" food producers—ranging from a low of 4 percent in India to 25 percent in China and 65 percent in the United States.[13]

Over the last half-century, the soaring world demand for animal protein was satisfied largely by expanding the output of meat from rangelands and of seafood from oceanic fisheries. World production of beef and mutton increased from 24 million tons in 1950 to 65 million tons in 2000, a near tripling. Most of the growth, however, occurred from 1950 to 1972, when output went up 44 percent. Since 1972, beef and mutton production per person has fallen by 15 percent.[14]

An estimated four fifths of the beef and mutton produced worldwide in 2000, roughly 52 million tons, comes from animals that forage on rangelands. With the world's rangelands now being grazed at or beyond capacity, future gains in output will likely be limited.[15]

The growth in the oceanic fish catch exceeded even that of beef and mutton, climbing from 19 million tons in 1950 to 86 million tons in 1998, the last year for which data are available. This fourfold growth was also concentrated in 1950–88, a time during which the annual growth in the catch—at 3.8 percent—was easily double that of world population. As a result, the oceanic fish catch per person climbed from 8 kilograms in 1950 to 17 kilograms in 1988. Since then, it has fallen by some 17 percent. The new reality is that fishers and ranchers can no longer satisfy much of the growing demand for food. For the first time since civilization began, farmers must try to meet future food needs on their own.[16]

Raising Cropland Productivity

In a world where there is little new land to plow, raising the productivity of existing cropland is the key to feeding the 80 million people added each year. It is also essential for protecting the earth's ecosystem. If farmers had not been able to nearly triple land productivity since 1950, it would have been necessary to clear half of the world's remaining forestland for food production.

There are at least three ways of raising cropland productivity: raise the yield per crop, increase the number of crops per year through multiple cropping, and get more out of the existing harvest by "processing" crop residues through ruminants to produce meat and milk.

Raising world cropland productivity is becoming progressively more difficult. Over the last century or so, plant breeders dramatically boosted the genetic yield potential of wheat, rice, and corn—the leading grains. At the heart of this effort was an increase in the share of the plant's photosynthate, the product of photosynthesis, going to the seed. While the originally domesticated wheats did not use much more than 20 percent of their photosynthate to produce seed, today's highly productive varieties devote half or more to seed formation. The theoretical upper limit is estimated at 60 percent since the plant's roots, stem, and leaves also require photosynthate.[17]

Realizing the genetic potential of the new seeds depends on alleviating any nutrient or moisture constraints on yields. Fertilizers are designed to remove the limits imposed by nutrient deficiencies. As cities have grown over the past century, there has been a massive disruption of the nutrient cycle, making it more difficult to return the nutrients in human waste to the land, and leaving the world ever more dependent on fertilizer. In earlier times, when food was produced and consumed locally, nutrients were automatically recycled back onto the land in the form of livestock and human waste. But as cities developed, as the world shifted from a subsistence economy to a market economy, and as international trade expanded, farmers offset the growing loss of nutrients with fertilizer.

As world fertilizer use climbed from 14 million tons in 1950 to 141 million tons in 2000, in some countries it began to press against the physiological limits of plants to absorb nutrients. In response, fertilizer use has leveled off in the United States, Western Europe, Japan, and now possibly China. In these countries, applying additional nutrients has little effect on production. Some parts of the world, such as the Indian subcontinent and Latin America, can still profitably use additional fertilizer. But for the world as a whole, the rapid growth in fertilizer use—the engine that helped triple the world grain harvest since 1950—is now history.[18]

Where fertilizer use is excessive, nutrient runoff into rivers and oceans can lead to algal blooms that then use up all available oxygen in the water as the algae decompose, creating dead zones with no sea life. Food output on land is expanding in part at the expense of that from the oceans.[19]

The accumulation of nitrates in underground water supplies in Western Europe led to European Union regulations to restrict fertilizer use. In Denmark, farmers are required to compile an annual nitrogen balance for the application and crop use of nitrogen. If this balance, submitted to the government each year, shows excessive runoff, farmers can be fined. The state of Iowa, concerned about nitrogen in underground water, levied a tax on fertilizer to discourage its excessive use.[20]

Just as fertilizer removes nutrient constraints on production, irrigation can remove moisture constraints, enabling plants to realize their full genetic potential. In some cases, irrigation simply boosts land productivity, but in others it permits dry season cropping or an expansion of cropping onto arid land.

While the world as a whole has nearly tripled land productivity since 1950, some countries have done even better. Over the last half-century, China, France, the United Kingdom, and Mexico have quadrupled wheat yield per hectare. India has nearly done the same. And the United States has quadrupled its corn yield.[21]

For several decades scientists generated a steady flow of new technologies designed to raise land productivity, but this flow is now ebbing. In some countries, farmers are now literally looking over the shoulder of scientists at agricultural experiment stations. In countries where yields have already tripled or quadrupled, it is becoming difficult for farmers to continue raising yields. For example, wheat yields in the United States have increased little since 1983. Rice yields in Japan have risen little since 1984.[22]

Even some developing countries are now experiencing a plateauing of grain yields. Between 1961 and 1977, rice yields in South Korea increased nearly 60 percent, but during the quarter-century since they have risen by only 1 percent. Similarly, wheat yields in Mexico climbed from 0.9 tons per hectare in 1950 to 4.4 tons in 1982, a rise of nearly fivefold. Since then there has been little change. (See Figure 7–1.) As the rise in land productivity levels off in more and more countries, expanding global grain output will become progressively more difficult.[23]

Over the last half-century, the world's farmers nearly tripled land productivity, but now future gains in productivity are more difficult to come by. Farmers managed to double the 1950 grain yield of 1 ton per hectare by 1982, when they surpassed 2 tons. By 2000 they were at 2.8 tons, close to a tripling of the 1950 yield. But the rise in yields is slowing.[24]

Raising crop yields is primarily a biological challenge, not un-

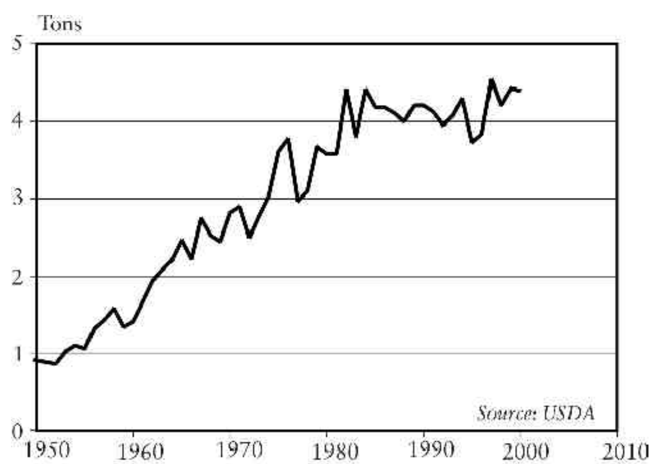

Figure 7–1. *Wheat Yield Per Hectare in Mexico, 1950–2000*

like increasing athletic performances. Somewhere in antiquity, someone ran a mile in less than six minutes. Well before the first modern-day Olympics, held in 1896, runners were covering a mile in under five minutes. In 1954, Roger Bannister broke the four-minute barrier. A half-century has passed since then, but no one talks about running a three-minute mile. We have reached the point where cutting another minute from our mile time may be physiologically impossible.[25]

We are faced with a similar situation with grain yields. For the world's farmers, going from an average of 1 ton per hectare to 2 was easy. Getting from 2 tons to nearly 3, where we are now, was much more difficult. For the world to move from 3 to 4 tons per hectare may be almost as difficult as going from a four-minute to a three-minute mile. If so, family planners will be under a lot of pressure to slow population growth.

For the world as a whole, the rise in land productivity has slowed markedly since 1990. From 1950 until then, world grain yield per hectare rose 2.1 percent a year. Between 1990 and 2000, however, the annual gain was only 1.1 percent. (See Table 7–2.)

Biotechnology is often cited as a potential source of higher yields, but although biotechnologists have been engineering new plant varieties for two decades, they have yet to produce a single variety of wheat, rice, or corn that can dramatically raise yields. The reason is that conventional plant breeders had already done most of the things they could think of to raise grain yields. Biotechnology's contributions are more likely to come in developing crop varieties that reduce insecticide use, are more drought-tolerant, or are more salt-tolerant. If genetic engineers can breed salt-tolerant varieties, it would alleviate water shortages. Perhaps the largest question hang-

Table 7–2. *Gains in World Grain Yield Per Hectare, 1950–2000*

Year	Yield Per Hectare[1]	Annual Increase
(tons)	(percent)	
1950	1.06	
1990	2.47	2.1
2000	2.75	1.1

[1] Yield for 1990 is three-year average.

Source: USDA, *Production, Supply, and Distribution,* electronic database, Washington, DC, updated May 2001.

ing over the future of biotechnology is the possible long-term environmental and human health effects of using genetically modified crops.

Land productivity can also be raised by increasing the number of crops per year, where temperature and soil moisture permit. In China, for instance, double cropping winter wheat and corn is widespread, enabling farmers in the North China Plain to harvest two high-yielding grain crops each year. In northern India, the double cropping of winter wheat and summer rice is now commonplace, a key to sustaining India's population of 1 billion. Argentina and the United States both double crop winter wheat with a summer crop of soybeans.[26]

Although the United States occupies a latitude similar to that of China, double cropping is not nearly as common, partly because until recently farmers' eligibility for government support prices depended on restricting the area planted, which discouraged multiple cropping. While there was surplus land, there was little reason to seriously consider double cropping or to develop the technologies that would facilitate it.

At present, roughly 10 percent of the 30-million-hectare U.S. soybean crop is double-cropped with winter wheat. If world food supplies tighten, this area could be expanded substantially, providing a strategic assist in increasing the food supply.[27]

Raising cropland productivity is the key to saving the world's remaining forests. If the world's farmers cannot raise land productivity enough to satisfy the future growth in demand for food, then further clearing of forests for agriculture will be unavoidable.

Raising Water Productivity

Over the last half-century, world irrigated area tripled, climbing from 90 million hectares in 1950 to nearly 270 million in 2000. Most of the growth occurred from 1950 to 1978, when irrigation expanded faster than population and boosted irrigated land per person from 0.037 hectares to 0.047 hectares, an increase of one fourth. After 1978, however, the growth in irrigation slowed, falling behind that of population and shrinking the irrigated land per person 8 percent. (See Figure 7–2.)[28]

In the years immediately ahead, the combination of aquifer depletion and the diversion of irrigation water to nonfarm uses may end the historical growth in irrigated area. If so, it will be more difficult

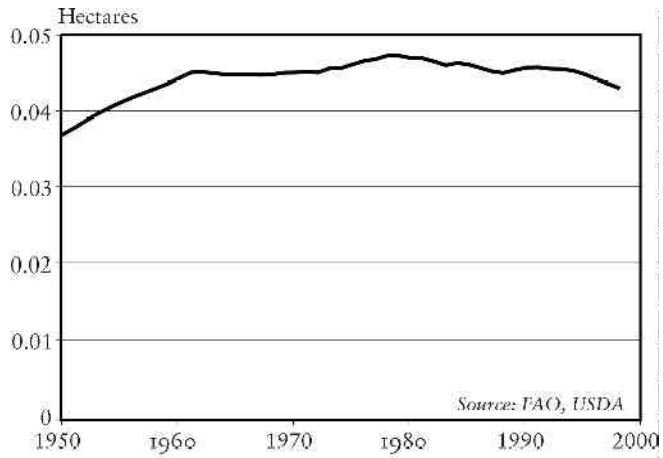

Figure 7–2. *World Irrigated Area Per Person, 1950–98*

to feed 3 billion more people.

In many countries, the competition for water between the countryside and cities is intensifying, underlining the value of raising water productivity. Although projections of the future diversion of irrigation water to residential and industrial uses do not exist for most countries, a World Bank forecast for South Korea—a relatively well watered country—gives some sense of what may lie ahead. Like many countries, Korea is now using virtually all available water. The Bank calculates that if the Korean economy grows 5.5 percent annually until 2025, growth in water withdrawals for residential and industrial use will reduce the yearly supply remaining for irrigation from 13 billion to 7 billion tons. Rising water prices and associated gains in water productivity will likely ameliorate the loss of water for irrigation, but this analysis nonetheless shows how difficult it may be for some countries even to maintain existing irrigated area.[29]

Farmers everywhere face an uphill battle in the competition for water since the economics of water use do not favor agriculture. Industry can often pay 50 to 100 times as much for water as farmers do. Wherever economic growth and the creation of jobs are a central preoccupation of political leaders, scarce water will likely go to industry.[30]

In addition, countries that are overpumping, including key food-producing ones such as China, India, and the United States, will lose irrigation water as aquifers are depleted. Once the rising demand for water surpasses the sustainable yield of an aquifer, the gap between demand and sustainable yield widens each year. As it does, the annual drop in the water table also increases each year, accelerating depletion of the aquifer and setting the stage for an abrupt fall in the food supply.[31]

The need for water in the Indian subcontinent is already outrunning the supply. Water tables are falling in much of India, including the Punjab, the country's breadbasket. (See Chapter 2.) The excessive use of water is encouraged by heavy electricity subsidies to farmers, who use electric pumps for irrigation.[32]

In sub-Saharan Africa, the potential for irrigation is limited simply because so much of the continent is arid or semiarid. The greater promise here may lie in water harvesting and systematically building soil organic matter so that soils can absorb and retain more of the low rainfall. The construction of earthen terraces supported by rocks retains water and reduces soil erosion. Leguminous trees planted as windbreaks reduce wind erosion and add nitrogen and organic matter to the soil.

The world water situation today is similar to that with cropland at the middle of the last century: the opportunities for developing new supplies are fast disappearing. By 1950, the frontiers of agricultural settlement had largely vanished, leaving little productive new land to plow. In response, governments launched a broad-based effort to raise land productivity, one that included price supports for farm commodities that encouraged farmers to invest in yield-raising inputs and land improvements, heavy public investment in agricultural research to raise crop yields, and the building of public institutions to support this effort—from agricultural extension services to farm credit banks. Societies mobilized a wide array of resources that doubled land productivity between 1950 and 1984.

The doubling of grainland productivity in little more than a generation is one of the remarkable scientific feats of the modern age. As the new century begins, a similar broad-based effort is needed to raise water productivity. There are several avenues to raising water productivity, but the key is pricing water at closer to market value, a step that leads to systemic advances in efficiency. China, facing acute water shortages, has recently announced a plan to raise water prices each year over the next five years. The attraction of market pricing is that it is systemic, promoting more-rational water use throughout the economy.

With 70 percent of the water that is diverted from rivers or pumped from underground being used for irrigation, any gains in irrigation water efficiency have benefits that extend far beyond agriculture. Indeed, getting enough water for cities and industry while maintaining food production may be possible only if irrigation productivity is systematically raised worldwide.[33]

The use of more water-efficient irrigation practices is the key. There are many ways to irrigate crops, including furrow, flood, overhead sprinkler, and drip irrigation. Furrow irrigation, probably the earliest form, is used with row crops, with a small trench being cut near each row of plants. Flood irrigation, traditionally used on rice, is now being reconsidered since recent research indicates that at least in some situations periodic flooding will produce the same yield as continuous flooding, but use much less water.[34]

Overhead sprinkler irrigation, which is widely used in the U.S. southern Great Plains, is often coupled with the use of underground water. The circles of green crops that can be seen when flying over this region during the summer are created with water from center-pivot overhead sprinklers that use well water to irrigate. (In this region, most of the water is drawn from the Ogallala aquifer—essentially a fossil aquifer since its recharge is limited.) Shifting from a high-pressure to a low-pressure overhead sprinkler system can boost irrigation efficiency from 65 percent to 80 percent. Shifting to a low-energy precision application sprinkler system can raise it to 90 percent or better.[35]

Drip irrigation technology, pioneered in Israel, is the most efficient of all irrigation systems. It typically uses a plastic hose with small holes or emitters, which either rests on the soil surface or is installed several inches below it. Sandra Postel and her colleagues report that studies in several countries show drip irrigation reducing water use by 30–70 percent. And because it provides a steady supply of water carefully geared to crop needs, it raises yields by 20–90 percent. The combination of reduced water use and higher yields can easily double water productivity, an attractive prospect.[36]

In the past, this high-cost, labor-intensive form of irrigation was used only on high-value crops such as fruits and vegetables. But this is now changing. New low-cost drip irrigation systems designed specifically for small farms, typically with a payback period of one year, are opening broad new horizons for expansion. Because they are more labor-intensive, these drip systems are well adapted to small holdings where labor is more plentiful. Postel reports that India has an estimated 10 million hectares that can profitably be irrigated with drip systems. There may be a similar potential in China.[37]

Another way to raise water productivity is to shift to more water-efficient crops. For example, wheat typically produces half again as much grain per unit of water as rice does. This is why Egypt restricts rice planting in favor of wheat.[38]

As a general matter, the higher the yield of a crop, the more productive the water use. For example, a rice crop that yields four tons per hectare uses little more water than one that yields two tons per hectare simply because so much of the water used to produce rice is lost through evaporation from the water surface. Simply put, raising land productivity also raises water productivity.

Restructuring the Protein Economy

The demand for meat—beef, pork, poultry, and mutton—typically rises with income, perhaps driven by the taste for meat acquired during our 4 million years as hunter-gatherers. This innate hunger for animal protein, which manifests itself in every society, has lifted the world demand for meat each year for 40 consecutive years. One of the most predictable trends in the global economy, world meat production climbed from 44 million tons in 1950 to 233 million tons in 2000, more than a fivefold increase. (See Figure 7–3.) This growth, roughly double that of population, raised meat intake per person worldwide from 17 kilograms to 38 kilograms.[39]

Once the limits of rangelands and fisheries are reached, then the growing demand for animal protein can be satisfied by feeding cattle in feedlots or fish in ponds; by expanding the production of pork, poultry, and eggs, all largely dependent on feed concentrates; or by producing more milk.

In this new situation, the varying efficiency with which grain is converted into protein—beef, pork, poultry, and fish—is shaping production trends. Cattle in feedlots require roughly 7 kilograms of feed concentrate per additional kilogram of live weight. For pigs, the ratio is nearly 4 to 1. Chickens are much more efficient, with a 2-to-1 ratio. Fish, including both herbivorous and omnivorous species, require less than 2 kilograms of grain concentrate per kilo-

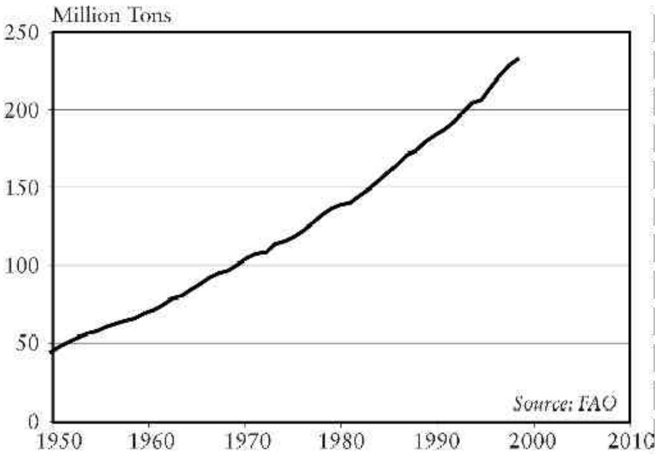

Figure 7–3. *World Meat Production, 1950–2000*

gram of gain.[40]

There are three ways to increase animal protein supply without consuming more grain: improve the efficiency of grain conversion into animal protein; shift from the less efficient forms of conversion, such as beef or pork, to the more efficient ones, such as poultry or farmed fish; and rely on ruminants to convert more roughage into either meat or milk.

Not surprisingly, the economics of the varying conversion rates is accelerating growth in output among the more efficient converters. The world's existing feedlots are being maintained, but there is little new investment in feedlots simply because of the higher cost of fed beef. From 1990 to 2000, world beef production increased only 0.5 percent a year compared with 2.5 percent for pork. The most rapidly growing source of meat during this period was poultry, expanding at 4.9 percent annually. (See Table 7–3.)[41]

The oceanic fish catch has not increased appreciably since 1990, thus falling far behind the soaring growth in demand for seafood. In response, aquacultural output expanded from 13 million tons of fish in 1990 to 31 million tons in 1998, growing by more than 11 percent a year. Even if aquacultural growth slows somewhat during the current decade, world aquacultural output is still on track to overtake the production of beef by 2010.[42]

China is the leading aquacultural producer, accounting for 21 million tons of the global output in 1998. Its output is rather evenly

Table 7–3. *World Growth in Animal Protein Production, by Source, 1990–2000*

Source	Annual Rate of Growth
	(percent)
Aquaculture[1]	11.4
Poultry	4.9
Pork	2.5
Beef	0.5
Oceanic fish catch[1]	0.1

[1] 1990–98 only.
Source: See endnote 41.

divided between coastal and inland areas. Coastal output is dominated by shellfish—mostly oysters, clams, and mussels. It also includes small amounts of shrimp or prawns and some finfish. Coastal aquaculture is often environmentally damaging because it depends on converting wetlands into fish farms or because it concentrates waste, leading to damaging algal blooms.[43]

Except for shellfish, most of China's aquacultural output is produced inland in ponds, lakes, reservoirs, and rice paddies. Some 5 million hectares of land are devoted exclusively to fish farming, much of it to carp polyculture. In addition, 1.7 million hectares of riceland produce rice and fish together.[44]

Over time, China has evolved a 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 that settles to the bottom. Most of China's aquaculture is integrated with agriculture, enabling farmers to use agricultural wastes, such as pig manure, to fertilize ponds, thus stimulating the growth of plankton. Fish polyculture, which typically boosts pond productivity over that of monocultures by at least half, also dominates fish farming in India.[45]

As land and water become ever more scarce, China's fish farmers are feeding more grain concentrates in order to raise pond productivity. Between 1990 and 1996, China's farmers raised the annual pond yield per hectare from 2.4 tons of fish to 4.1 tons.[46]

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. catfish production of 270,000 tons (600 million pounds) is concentrated in four states: Mississippi, Louisiana, Alabama, and Arkansas. Mississippi, with some 45,000 hectares (174 square miles) of catfish ponds and easily 60 percent of U.S. output, is the catfish capital of the world.[47]

Public attention has focused on aquacultural operations that are environmentally disruptive, such as the farming of salmon, a carnivorous species, and shrimp. Yet these operations account for only 1.5 million tons of output. World aquaculture is dominated by herbivorous species, importantly carp in China and India, but also catfish in the United States and tilapia in several countries.[48]

Just as aquaculture is supplementing the fish catch, new practices are evolving to efficiently expand livestock output. Although rangelands are being grazed to capacity and beyond, there is a large unrealized potential for feeding agricultural residues—rice straw, wheat straw, and corn stalks—to ruminants, such as cattle, sheep, and goats. This can mean that a given grain crop yields a second harvest—the meat or the milk that is produced with the straw and corn stalks. Ruminants have a highly sophisticated digestive system, one that can convert straw and corn stalks into meat and milk without using the grain that can be consumed by humans. At present, most human food comes from the photosynthate going into the seed of cereals, but by feeding animals straw and corn stalks, the photosynthate that goes into stems and leaves also can be converted into food.[49]

In India, both water buffalo, which are particularly good at converting coarse roughage into milk, and cattle figure prominently in the dairy industry. India has been uniquely successful in converting crop residues into milk, expanding production from 20 million tons in 1961 to 79 million tons in 2000—a near fourfold increase. Following a path of steady growth, milk became India's leading farm product in value in 1994. In 1997, India overtook the United States to become the world's leading milk producer. (See Figure 7–4.) Remarkably, it did so almost entirely by using farm byproducts and crop residues, avoiding the diversion of grain from human consumption to cattle.[50]

Between 1961 and 2000, India's milk production per person

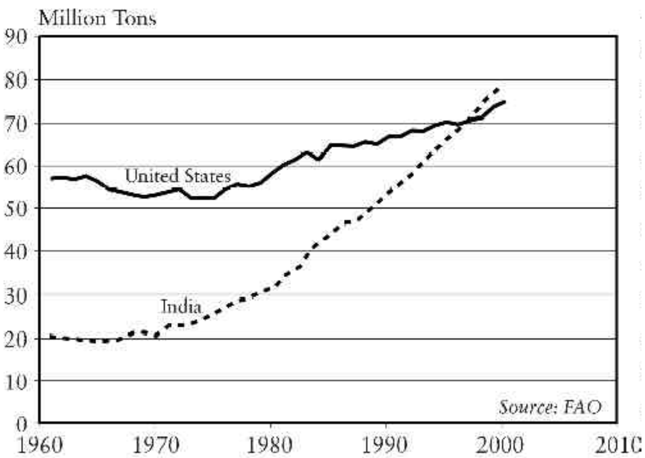

Figure 7–4. *Milk Production in the United States and India, 1961–2000*

increased from 0.9 liters per week to 1.5 liters, or roughly a cup of milk per day. Although this is not a lot by western standards, it is a welcome expansion in a protein-hungry country.[51]

The dairy industry structure in India is unique in that the milk is produced almost entirely by small farmers, who have only one to three cows. Milk production is integrated with agriculture, involving an estimated 70 million farmers for whom it is a highly valued source of supplemental income. Dairying, even on a small scale, is a labor-intensive process, including gathering the roughage where cows are stall-fed, milking them, and transporting the milk to market. Ownership of a few cows or buffalo also means a supply of manure for cooking fuel and for fertilizer. If India can introduce new energy sources for cooking, it will free up more cow manure for fertilizer.[52]

China also has a large potential to feed corn stalks and wheat and rice straw to cattle or sheep. As the world's leading producer of both rice and wheat and the second ranked producer of corn, China annually harvests an estimated 500 million tons of straw, corn stalks, and other crop residues. At present, much of this either is burned, simply to dispose of it, or is used in villages as fuel. Fortunately, China has vast wind resources that can be harnessed to produce electricity for cooking, thus freeing up roughage for feeding additional cattle or sheep.[53]

The ammoniation of crop residues (that is, the incorporation of nitrogen) in the roughage helps the microbial flora in the rumen of the cattle and sheep to digest the roughage more completely. The use of this technology in the major crop-producing provinces of east central China—Hebei, Shandong, Henan, and Anhui—has created a "Beef Belt." Beef output in these four provinces now dwarfs that of the grazing provinces of Inner Mongolia, Qinghai, and Xinjiang.[54]

Ruminants also produce soil-enriching manure that not only returns nutrients to the soil, but also adds organic matter, which improves both soil aeration and water retention capacity, thus enhancing soil productivity. Roughage-based livestock systems are almost necessarily local in nature because roughage is too bulky to transport long distances.

Satisfying the demand for protein in a protein-hungry world where water scarcity is likely to translate into grain scarcity is a challenge to agricultural policymakers everywhere. If grain becomes scarce, as now seems likely, other countries, such as the United States, Canada, and France, may follow India's example of using ruminants to systematically convert more crop residues into food.

Eradicating Hunger: A Broad Strategy

This chapter began by noting that sustaining a sufficient growth in food output to eradicate hunger will now take a superhuman effort both within agriculture and in related activities outside that sector. Soil erosion, aquifer depletion, and climate change threaten future food production. Food security may depend as much on the efforts of family planners as on farmers and as much on the decisions made in ministries of energy that shape future climate trends as on decisions made in ministries of agriculture. The difficulty in eradicating hunger is matched only by the urgency of doing so.

In countries where farm size is shrinking fast, raising land productivity deserves even greater priority than in the past. And increasingly, raising water productivity is the key to further gains in land productivity. Governments running the risk of an abrupt drop in food production as a result of aquifer depletion may be able to avoid such a situation only by simultaneously slowing population growth and raising water productivity in order to stabilize water tables.

Stabilizing population is as essential as it is difficult. If rapid population growth continues, it will lead to further fragmentation of land holdings, as well as to hydrological poverty on a scale that is now difficult to imagine. Hundreds of millions of people will not have enough water to meet their most basic needs, including food production. Chapter 10 discusses further the urgent need to stabilize world population.

With the rise in land productivity slowing, continuing rapid population growth makes eradicating rural hunger much more difficult, if not impossible. Perhaps the single most important thing India, for example, can do to enhance its future food security is to accelerate the shift to smaller families. This would enable it to move to the low-level U.N. population projection instead of the medium-level one, thereby adding only 289 million people instead of 563 million in the next 50 years.[55]

As the backlog of unused agricultural technology shrinks, providing enough food will increasingly depend on strengthening international agricultural research assistance. Appropriations for agricultural research are lagging far behind needs. For some farmers, the technology pipeline is running dry. More locally oriented investment in agricultural research that will help expand multiple cropping and intercropping could pay large dividends.

Raising grain yield per hectare in the two regions where the world's hungry are concentrated will not be easy. India's wheat yield, for example, has already tripled since 1960. The rise in rice yield, which went from just under 1 ton per hectare in 1965 to 1.9 tons in 1993, has slowed. Lifting land productivity in India is constrained by the country's proximity to the equator. Day length during the summer is relatively short, and since rice is typically grown during the summer monsoon season, when cloud cover is heavy, solar intensity is low.[56]

Now that water scarcity is becoming a constraint on efforts to expand world food production, the time has come for an all-out effort to raise water productivity. Such a campaign could be patterned on the earlier effort to raise land productivity, involving a wide range of government initiatives—including research on raising productivity, water pricing that will reflect the value of water, government loans for farmers' attempts to raise water productivity, and the training of agricultural extension agents to help farmers in this effort.

As water scarcity translates into food scarcity, countries everywhere need to reexamine the potential for multiple cropping. This is particularly true for a country like the United States, where crop acreage limits have traditionally discouraged multiple cropping.

In India, the multiple-cropped area can be expanded by harvesting and storing water during the monsoon season so that more land can be cropped during the dry season. If agricultural extension workers are trained in water harvesting techniques, they can then work with local farmers to increase water storage. This will help raise yield per crop and also the crops produced per year.

With cropland becoming scarce, efforts to protect prime farmland are needed the world over. Here, Japan is the model. It has successfully protected rice paddies even within the boundaries of the city of Tokyo, thus enabling Japan to remain self-sufficient in its staple food—rice.

Similarly with soil conservation: with erosion now taking a measurable toll on food production in so many countries, the adoption of farming practices that reduce soil erosion will pay handsome dividends. The model is the United States, which has both converted highly erodible cropland back to grassland and adopted conservation practices to reduce erosion. The conversion of erodible cropland back to grassland or to trees, coupled with the adoption of conservation tillage on 37 percent of all cropped land, reduced soil erosion from 3.1 billion tons in 1982 to 1.9 billion tons in 1997.[57]

Another potential for expanding food production, one that has been neglected in many industrial countries, is the feeding of crop residues to ruminants, as described earlier. This can reduce pressure on rangelands, as it has done in India and China. This potential for a second harvest from a single crop deserves to be systematically exploited worldwide.

Recognizing that malnutrition is largely the result of rural poverty, the World Bank is replacing its long-standing, crop-centered agricultural development strategies with rural development strategies that use a much broader approach. Bank planners believe that a more systemic approach to eradicating rural poverty—one that embraces agriculture but that also integrates human capital development, the development of infrastructure, and social development into a strategy for rural development—is needed to shrink the number living in poverty. One advantage of encouraging investment in the countryside in both agribusiness and other industries is that it encourages breadwinners to stay in the countryside, keeping families and communities intact. In the absence of such a strategy, rural poverty simply feeds urban poverty.[58]

In countries such as India, where farm size is shrinking, it becomes more difficult to raise land productivity enough to provide adequate nutrition. The challenge in these areas is to mobilize capital both through domestic savings and by attracting investment from abroad to build the factories needed to provide employment and income in rural areas. This will help rural families and communities stay together. For this the model is China, which has achieved high savings rates and attracted record amounts of foreign capital.[59]

Another demand-side initiative, in addition to stabilizing population growth, is for the affluent to eat further down the food chain. The best nourished people in the world are not those living low on the food chain, such as Indians who consume roughly 200 kilograms of grain per year, or those living high on the food chain, such as Americans who consume some 800 kilograms of grain per year, mostly in the form of livestock products. It is people living at an intermediate level, such as Italians, who consume 400 kilograms of grain a year. Life expectancy in Italy—a country with the highly touted Mediterranean diet (rich in starches and fresh fruits and vegetables and only moderate amounts of livestock products)—exceeds that in both India and the United States. Even though the United States spends more on health care per person than Italy does, life expectancy in the latter is higher, apparently because of a lower consumption of livestock products. For those living high on the food chain, moving down to a more moderate level would enhance not only their health, but also the health of the planet.[60]

A half-century ago, no one was concerned about climate change. But if we cannot now accelerate the phaseout of fossil fuels, more extreme climate events may disrupt food production, threatening food security. Of particular concern is the rise in sea level that could inundate the river floodplains in Asia that produce much of the region's rice. The rise over the last century of 20 centimeters (8 inches) or more is already affecting some low-lying coastal regions. If sea level rises by 1 meter during this century, which is the upper level projected, it will take a heavy toll on food production, especially in Asia. Here the principal responsibility lies with the United States, a country whose carbon emissions are so great that it can single-handedly alter the earth's climate. If the United States does not assume a leadership role in phasing out fossil fuels, the global effort to stabilize climate is almost certain to fail.[61]

With the many countries that are facing acute land and water scarcity expecting to import growing quantities of grain, exporting countries will need to expand output to cover import needs. Over the last half-century, the growing ranks of grain-importing countries, now numbering over 100, have become dangerously dependent on the United States.[62]

This concentration of dependence applies to each of the big three grains—wheat, rice, and corn. Just five countries—the United States, Canada, France, Australia, and Argentina—account for 88 percent of the world's wheat exports. Thailand, Viet Nam, the United States, and China account for 68 percent of all rice exports. For corn, the concentration is even greater, with the United States alone accounting for 78 percent of exports and Argentina for 12 percent.[63]

With more extreme climate events in prospect, this dependence on a few exporting countries leaves importers vulnerable to climate change. If the United States were to experience a summer of severe heat and drought in its agricultural heartland like that of 1988, when grain production dropped below domestic consumption for the first time in history, chaos would reign in world grain markets simply because the near-record grain reserves that cushioned the huge U.S. crop shortfall that year no longer exist.[64]

One of the principal causes of hunger is the indifference of governments, an attitude that is often all too visible in their priorities. In some ways, India today is paying the price for its earlier indiscretions when, despite its impoverished state, it invested in a costly effort to produce nuclear weapons. After spending three times as much for military purposes as for health and family planning, India now has a nuclear arsenal capable of protecting the largest concentration of hungry people on the earth.[65]

Unless political leaders are willing to take the difficult steps to build an agricultural eco-economy, bland assertions that we must eradicate hunger are meaningless. If world leaders do not act decisively, the food situation could deteriorate rapidly in some developing countries. The risk for the low-income, grain-importing countries is that grain prices could rise dramatically, impoverishing more people in a shorter period of time than any event in history. Spreading food insecurity could lead to political instability on a scale that would disrupt global economic progress.