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# *Feeding Eight Billion People Well*

As we prepare to feed a world population of 8 billion within the next two decades, we are entering a new food era. Early signs of this are the record-high grain prices of the last few years, the restriction on grain exports by exporting countries, and the acquisition of vast tracts of land abroad by grain-importing countries. And because some of the countries where land is being acquired do not have enough land to adequately feed their own people, the stage is being set for future conflicts between the so-called land grabbers and hungry local people.

The leaders in this land acquisition movement—Saudi Arabia, South Korea, and China—are all facing growing food insecurity. Saudi Arabia's wheat harvest is shrinking as it loses irrigation water to aquifer depletion. South Korea, heavily dependent on corn imports to sustain its livestock and poultry production, sees its principal supplier—the United States—diverting more corn to fuel production for cars than to exports. China is losing irrigation water as its aquifers are depleted and its mountain glaciers disappear.<sup>1</sup>

The growing competition for land across national boundaries is indirectly competition for water. In effect, land acquisi-

tions are also water acquisitions. As Sudan sells or leases land to other countries, for example, the water to irrigate this land will likely come from the Nile, leaving less for Egypt.

Attention has focused on oil insecurity, and rightly so, but it is not the same as food insecurity. An empty gas tank is one thing, an empty stomach another. And while there are substitutes for oil, there are none for food.

In the world food economy, as in the energy economy, achieving an acceptable balance between supply and demand now includes reducing demand as well as expanding supply. It means accelerating the shift to smaller families to reduce future population size. For those in affluent countries, it means moving down the food chain. And for oil-insecure countries, it means finding substitutes for oil other than fuel from food crops.

As noted early on, securing future food supplies now goes far beyond agriculture. In our crowded, warming world, policies dealing with energy, population, water, climate, and transport all directly affect food security. That said, there are many things that can be done in agriculture to raise land and water productivity.

### **Raising Land Productivity**

Investment in agriculture by international development agencies has lagged badly over the last two decades. Some of the stronger developing countries, such as China and Brazil, moved ahead on their own, but many suffered.<sup>2</sup>

Prior to 1950, expansion of the food supply came almost entirely from expanding cropland area. Then as frontiers disappeared and population growth accelerated after World War II, the world quickly shifted to raising land productivity. Between 1950 and 2008 grain yields nearly tripled, climbing from 1.1 to 3.2 tons per hectare. In one of the most spectacular achievements in world agricultural history, farmers doubled the grain harvest between 1950 and 1973. Stated otherwise, during this 23-year-span, growth in the grain harvest equaled that of the preceding 11,000 years.<sup>3</sup>

After several decades of rapid rise, however, it is now becoming more difficult to raise land productivity. From 1950 to 1990, world grainland productivity increased by 2.1 percent per year, but from 1990 until 2008 it went up by only 1.3 percent annually.<sup>4</sup>

Gains in land productivity have come primarily from three sources—the growing use of fertilizer, the spread of irrigation, and the development of higher-yielding varieties. As farmers attempted to remove nutrient constraints on crop yields, fertilizer use climbed from 14 million tons in 1950 to 175 million tons in 2008. In some countries, such as the United States, several in Western Europe, and Japan, fertilizer use has leveled off. It may do so soon in China and India as well, for each of them now uses more fertilizer than the United States does.<sup>5</sup>

Farmers remove soil moisture limits on crop yields by irrigating, using both surface water from rivers and underground water. World irrigated area increased from 94 million hectares in 1950 to 278 million hectares in 2000. Since then, it has increased very little. Future gains from irrigation will likely come more from raising irrigation efficiency than from expanding irrigation water supplies.<sup>6</sup>

The third source of higher land productivity is higher-yielding varieties. The initial breakthrough came when Japanese scientists succeeded in dwarfing both wheat and rice plants in the late nineteenth century. This decreased the share of photosynthate going into straw and increased that going into grain, often doubling yields.<sup>7</sup>

With corn, now the world's largest grain crop, the early breakthrough came with hybridization in the United States. As a result of the dramatic advances associated with hybrid corn, and the recent, much more modest gains associated with genetic modification, corn yields are still edging upward.<sup>8</sup>

Most recently, Chinese scientists have developed commercially viable hybrid rice strains. While they have raised yields, the gains have been small compared with the earlier gains from dwarfing the rice plant.<sup>9</sup>

There are distinct signs of yields leveling off in the higher-yield countries that are using all available technologies. With wheat, the first of the big three grains to be cultivated, it appears that once the yield reaches 7 tons per hectare it becomes difficult to go much higher. This is borne out by the plateauing of wheat yields at that level in France, Europe's largest wheat producer, and in Egypt, Africa's largest producer.<sup>10</sup>

In the Asian rice economy, the highest yields are in Japan, China, and South Korea. All three have moved above 4 tons per

hectare, but moving above 5 tons is difficult. Japan reached 4 tons per hectare in 1967 but has yet to reach 5 tons. In China, rice yields appear to be plateauing as they approach the Japanese level. South Korea has leveled off right around 5 tons.<sup>11</sup>

Among the three grains, corn is the only one where the yield is continuing to rise in high-yield countries. In the United States, which accounts for 40 percent of the world corn harvest, yields are now approaching an astonishing 10 tons per hectare. Even though fertilizer use has not increased since 1980, corn yields continue to edge upward as seed companies invest huge sums in corn breeding. Iowa, with corn yields among the world's highest, now produces more grain than Canada does.<sup>12</sup>

Despite dramatic past leaps in grain yields, it is becoming more difficult to expand world food output. There is little productive new land to bring under the plow. Expanding the irrigated area is difficult. Returns on the use of additional fertilizer are diminishing in many countries.

Agricultural endowments vary widely by country. Achieving high grain yields means having an abundance of soil moisture, either from rainfall, as in the corn-growing U.S. Midwest and wheat-growing Western Europe, or from irrigation, as in Egypt, China, and Japan. Countries with chronically low soil moisture, as in Australia, much of Africa, and the Great Plains in North America, have not experienced dramatic grain yield advances. U.S. corn yields today are nearly four times wheat yields, partly because wheat is grown under low rainfall conditions. India's wheat yields are now close to double those of Australia not because India's farmers are better but because they have more water to work with.<sup>13</sup>

Some developing countries have dramatically boosted farm output. In India, after the monsoon failure of 1965 that required the import of a fifth of the U.S. wheat crop to avoid famine, a highly successful new agricultural strategy was adopted. It included replacing grain ceiling prices that catered to the cities with grain support prices to encourage farmers to invest in raising land productivity. The construction of fertilizer plants was moved from the government sector into the private sector, where the plants could be built quickly. The high-yielding wheats that were developed in Mexico and that had already been tested in India were introduced by the shipload. This combination of positive devel-

opments enabled India to double its wheat harvest in seven years. No major country before or since has managed to double the harvest of a staple food in such a short period of time.<sup>14</sup>

A similar situation developed in Malawi, a country of 15 million people, after the drought of 2005 that left many hungry and some starving. In response, the government issued coupons to small farmers, entitling them to 200 pounds of fertilizer at a greatly reduced price, and free packets of improved seed corn, the national food staple. Costing some \$70 million per year and funded partly by outside donors, this fertilizer and seed subsidy program helped nearly double Malawi's corn harvest within two years, leading to an excess of grain. Fortunately this grain could be profitably exported to nearby Zimbabwe, which was experiencing acute grain shortages.<sup>15</sup>

Some years earlier, a similar initiative had been undertaken in Ethiopia. It too led to a dramatic growth in production. But because there was no way either to distribute the harvest to remote areas or to export the surplus, this led to a crash in prices—a major setback to the country's farmers and to Ethiopia's food security. This experience also underlines a major challenge to agricultural development in much of Africa, namely the lack of infrastructure, such as roads to get fertilizer to farmers and their products to market.<sup>16</sup>

In the more arid countries of Africa, such as Chad, Mali, Mauritania, and Namibia, there is not enough rainfall to raise yields dramatically. Modest yields are possible with improved agricultural practices, but in many of these countries there has not been a green revolution for the same reason there has not been one in Australia—namely, low soil moisture and the associated limit on fertilizer use.

The shrinking backlog of unused agricultural technology and the associated loss of momentum in raising yields is worldwide, signaling a need for fresh thinking on how to raise cropland productivity. One way is to breed crops that are more tolerant of drought and cold. U.S. corn breeders have developed corn varieties that are more drought-tolerant, enabling corn production to move westward into Kansas, Nebraska, and South Dakota. For example, Kansas, the leading U.S. wheat-producing state, now produces more corn than wheat. Similarly, corn production is moving northward in North Dakota and Minnesota.<sup>17</sup>

Another way to raise land productivity, where soil moisture permits, is to expand the area of land that produces more than one crop per year. Indeed, the tripling in the world grain harvest from 1950 to 2000 was due in part to widespread 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 and southern India.<sup>18</sup>

The spread of double cropping of winter wheat and corn on the North China Plain helped boost China's grain production to where it now rivals that of the United States. Winter wheat grown there yields 5 tons per hectare. Corn also averages 5 tons. Together these two crops, grown in rotation, can yield 10 tons per hectare per year. China's double-cropped rice yields over 8 tons per hectare.<sup>19</sup>

Forty or so years ago, grain production in northern India was confined largely to wheat, but with the advent of the earlier maturing high-yielding wheats and rices, wheat could be harvested in time to plant rice. This 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 1.2 billion people.<sup>20</sup>

In North America and Western Europe, which in the past have restricted cropped area to control surpluses, there may be some potential for double cropping that has not been fully exploited. In the United States, the end of idling cropland to control production in 1996 opened new opportunities for multiple cropping. The most common U.S. double cropping combination is winter wheat with soybeans in the summer. Since soybeans fix nitrogen in the soil, making it available to plants, this reduces the amount of fertilizer applied to wheat.<sup>21</sup>

A concerted U.S. effort to both breed earlier-maturing varieties and develop cultural practices that would facilitate multiple cropping could 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 more 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 an oilseed crop. Elsewhere, Brazil and Argentina, which have extensive frost-free growing seasons, commonly multicrop wheat or corn with soybeans.<sup>22</sup>

One encouraging effort to raise cropland productivity in Africa is the simultaneous planting of grain and leguminous trees. At first the trees grow slowly, permitting the grain crop to mature and be harvested; then the saplings 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.<sup>23</sup>

Another often overlooked issue is the effect of land tenure on productivity. In China, this issue was addressed in March 2007 when the National People's Congress passed legislation protecting property rights. Farmers who had previously occupied their land under 30-year leases would gain additional protection from land confiscation by local officials who, over the years, had seized land from some 40 million farmers, often for construction. Secure land ownership encourages farmers to invest in and improve their land. A survey by the Rural Development Institute revealed that farmers in China with documented land rights were twice as likely to make long-term investments in their land, such as adding greenhouses, orchards, or fishponds.<sup>24</sup>

In summary, while grain production is falling in some countries, either because of unfolding water shortages or spreading soil erosion, the overwhelming majority still have a substantial unrealized production potential. The challenge is for each country to fashion agricultural and economic policies in order to realize its unique potential. Countries like India in the late 1960s or Malawi in the last few years give a sense of how to exploit the possibilities for expanding food supplies.

### **Raising Water Productivity**

With water shortages constraining food production growth, the world needs an effort to raise water productivity similar to the

one that nearly tripled land productivity over the last half-century. 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 efficiency is central to raising water productivity overall.<sup>25</sup>

Data on the efficiency of surface of water projects—that is, dams that deliver water to farmers through a network of canals—show that crop usage of irrigation water never reaches 100 percent simply because some irrigation water evaporates, some percolates downward, and some runs off. 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.”<sup>26</sup>

Irrigation water efficiency is affected not only by the type and condition of irrigation systems but also by soil type, temperature, and humidity. In hot arid regions, the evaporation of irrigation water is far higher than in cooler humid regions.

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.<sup>27</sup>

Raising irrigation efficiency typically means shifting from the less efficient flood or furrow systems to overhead sprinklers or 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.<sup>28</sup>

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 a surplus of labor and a shortage of water. 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 1–3 percent of irrigated land in India and China and on roughly 4 percent in the United States.<sup>29</sup>

In recent years, small-scale drip-irrigation systems—literally a bucket with flexible plastic tubing to distribute the water—have been developed to irrigate small vegetable gardens with roughly 100 plants (covering 25 square meters). Somewhat larger systems using drums irrigate 125 square meters. In both cases, the containers are elevated slightly, so that gravity distributes the water. Large-scale 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 raising yields, they can dramatically raise incomes of smallholders.<sup>30</sup>

Sandra Postel estimates that drip technology has the potential to profitably irrigate 10 million hectares of India's cropland, nearly one tenth of the total. She sees a similar potential for China, which is now also expanding its drip irrigated area to save scarce water.<sup>31</sup>

In the Punjab, with its extensive double cropping of wheat and rice, fast-falling water tables led the state farmers' commission in 2007 to recommend a delay in transplanting rice from May to late June or early July. This would reduce irrigation water use by roughly one third, since transplanting would coincide with the arrival of the monsoon. The resulting reduction in groundwater use would help stabilize the water table, which has fallen from 5 meters below the surface down to 30 meters in parts of the state.<sup>32</sup>

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

Mexico is a leader in developing water users associations. As of 2008, farmers associations managed more than 99 percent of the irrigated area held in public irrigation districts. One advantage of this shift for the government is that the cost of main-

taining the irrigation system is assumed locally, reducing the drain on the treasury. This means that associations often need to charge more for irrigation water, but for farmers the production gains from managing their water supply themselves more than outweigh this additional outlay.<sup>33</sup>

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, covering much of the country. As of 2009, China has more than 40,000 water users associations to locally manage water resources and to maximize water use efficiency. Many other countries now have similar bodies. Although the first groups were organized to deal with large publicly developed irrigation systems, some recent ones have been formed to manage local groundwater irrigation as well. Their goal is to stabilize the water table to avoid aquifer depletion and the economic disruption that it brings to the community.<sup>34</sup>

Low water productivity is often the result of low water prices. In many countries, subsidies lead to irrationally low water prices, creating the impression that water is abundant when in fact it is scarce. As water becomes scarce, it needs to be priced accordingly.

A new mindset is needed, a new way of thinking about water use. For example, shifting to more water-efficient crops wherever possible 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.<sup>35</sup>

Any measures that raise crop yields on irrigated land also raise the productivity of irrigation water. For people consuming unhealthy amounts of livestock products, moving down the food chain reduces water use. In the United States, where the 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. For 300 million Americans, such a reduction would cut grain use by 30 million tons and the need for irrigation water by 30 billion tons.<sup>36</sup>

Bringing water use down to the sustainable yield of aquifers and rivers worldwide involves a wide range of measures not only in agriculture but throughout the economy. The more obvi-

ous steps, in addition to more water-efficient irrigation practices and water-efficient crops, include adopting more water-efficient industrial processes and using both more water-efficient household appliances and those such as the new odorless dry-compost toilets that use no water at all. Recycling urban water supplies is another obvious step in countries facing acute water shortages.

### Producing Protein More Efficiently

Another way to raise both land and water productivity is to produce animal protein more efficiently. With some 36 percent (750 million tons) of the world grain harvest used to produce animal protein, even a modest gain in efficiency can save a large quantity of grain.<sup>37</sup>

World meat consumption increased from 44 million tons in 1950 to 260 million tons in 2007, more than doubling annual consumption per person from 17 kilograms to 39 kilograms (86 pounds). Consumption of milk and eggs has also risen. In every society where incomes have risen, so has meat consumption, reflecting a taste that evolved over 4 million years of hunting and gathering.<sup>38</sup>

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. Within the meat economy, both health concerns and price differences are shifting consumer demand from beef and pork to poultry and fish, sources that convert grain into protein most efficiently.

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 over 3 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.<sup>39</sup>

Global beef production, most of which comes from rangelands, grew less than 1 percent a year from 1990 to 2007. Growth in the number of cattle feedlots was minimal. Pork production grew by 2 percent annually, and poultry by nearly 5 per-

cent. World pork production, nearly half of it now in China, overtook beef production in 1979 and has continued to widen the lead since then. The growth in poultry production from 41 million tons in 1990 to 88 million tons in 2007 enabled poultry to eclipse beef in 1995, moving into second place behind pork.<sup>40</sup>

Fast-growing, highly grain-efficient world fish farm output may also overtake world beef production in the next few years. In fact, aquaculture has been the fastest-growing source of animal protein since 1990, largely because herbivorous fish convert feed into protein so efficiently. Aquacultural output expanded from 13 million tons in 1990 to 50 million tons in 2007, growing by more than 8 percent a year.<sup>41</sup>

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 slightly more than 10 percent of the world's farmed fish output. Salmon are inefficient in that they are fed other fish, usually as fishmeal, which comes either from fish processing 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. Farming salmon and shrimp in offshore ponds concentrates waste, contributing to eutrophication and dead zone creation.<sup>42</sup>

Worldwide, however, 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.

China accounts for 62 percent of global fish farm production. Its output is dominated by finfish (mostly carp), which are grown in inland freshwater ponds, lakes, reservoirs, and rice paddies, and by shellfish (mostly oysters, clams, and mussels), which are produced mostly in coastal regions.<sup>43</sup>

Over time, China has developed a fish polyculture using four types of carp that feed at different levels of the food chain, in effect emulating natural aquatic ecosystems. Silver 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, each fill-

ing a particular niche. This multi-species system, which converts feed into high-quality protein with remarkable efficiency, allowed China to produce some 14 million tons of carp in 2007.<sup>44</sup>

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 31 million tons—is double that of poultry, making it the first large country where fish farming has eclipsed poultry farming.<sup>45</sup>

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.<sup>46</sup>

With incomes now rising in densely populated Asia, other countries are following China's aquacultural lead. Among them are 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, which now produces more than 1 million tons of fish and shrimp.<sup>47</sup>

In the United States, catfish are the leading aquacultural product. U.S. annual catfish production of 515 million pounds (1.6 pounds per person) is concentrated in the South. Mississippi, with half the country's output, is the U.S. catfish capital.<sup>48</sup>

When we want high-quality protein, we typically look to soybeans, as either 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.

In 2008, the world's farmers produced 213 million tons of soybeans—1 ton for every 10 tons of grain produced. Of this, some 20 million tons were consumed directly as tofu or meat substitutes. The bulk of the remaining 193 million tons, after some was saved for seed, was crushed in order to extract 36 million tons of soybean oil, separating it from the highly valued, high-protein meal.<sup>49</sup>

The 150 million or so tons of protein-rich soybean meal that

remain after the oil is extracted are fed to cattle, pigs, chickens, and fish. 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. 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.<sup>50</sup>

The heavy use of soybean meal to boost the efficiency of feed use 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. It also explains why world soybean production has increased 13-fold since 1950.<sup>51</sup>

Mounting pressures on land and water resources have led to the evolution of some promising new animal protein production systems that are based on roughage rather than grain, such as milk production in India. Since 1970, India's milk production has increased fivefold, jumping from 21 million to 106 million tons. In 1997 India overtook the United States to become the world's leading producer of milk and other dairy products.<sup>52</sup>

The spark for this explosive growth came in 1965 when an enterprising young Indian, Verghese Kurien, organized the National Dairy Development Board, an umbrella organization of dairy cooperatives. The dairy co-op's principal purpose was to market the milk from tiny herds that typically averaged two to three cows each, thus providing the link between the growing market for dairy products and the millions of village families who each had only a small marketable surplus.<sup>53</sup>

Creating the market for milk spurred the fivefold 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 nearly one cup today represents a major advance.<sup>54</sup>

What is so remarkable is that India has built the world's largest dairy industry almost entirely on crop residues—wheat straw, rice straw, and corn stalks—and grass gathered from the roadside. Even so, the value of the milk produced each year now exceeds that of the rice harvest.<sup>55</sup>

A second new protein production model, one that also relies on ruminants and roughage, has evolved in four provinces in

eastern China—Hebei, Shangdong, Henan, and Anhui—where double cropping of winter wheat and corn is common. Although 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.<sup>56</sup>

These four crop-producing provinces in China, dubbed the Beef Belt by officials, use crop residues to produce much more beef 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, thus boosting both land and water productivity. Similar systems can be adopted in other countries as population pressures intensify, as demand for meat and milk increases, and as farmers seek new ways to convert plant products into animal protein.<sup>57</sup>

The world desperately needs new more-efficient protein production techniques such as these. Meat consumption is growing almost twice as fast as population, egg consumption is growing more than twice as fast, and growth in the demand for fish—both from the oceans and from fish farms—is also outpacing that of population.<sup>58</sup>

While the world has had decades of experience in feeding an additional 70 million people each year, it has no experience with some 3 billion people striving to move up the food chain. For a sense of what this translates into, consider what has happened in China, where record economic growth has in effect telescoped history, showing how rapidly diets change when incomes rise. As recently as 1978, meat consumption in China consisted mostly of modest amounts of pork. Since then, consumption of meat, including pork, beef, poultry, and mutton, has climbed severalfold, pushing China's total meat consumption far above that of the United States.<sup>59</sup>

### The Localization of Agriculture

In the United States, there has been a surge of interest in eating fresh local foods, corresponding with mounting concerns about the climate effects of consuming food from distant places and about the obesity and other health problems associated with junk food diets. This is reflected in the rise in urban gardening, school gardening, and farmers' markets.<sup>60</sup>

With the fast-growing local foods movement, diets are

becoming more locally shaped and more seasonal. In a typical supermarket in an industrial country today it is often difficult to tell what season it is because the store tries to make everything available on a year-round basis. As oil prices rise, this will become less common. In essence, a reduction in the use of oil to transport food over long distances—whether by plane, truck, or ship—will also localize the food economy.

This trend toward localization is reflected in the recent rise in the number of farms in the United States, which may be the reversal of a century-long trend of farm consolidation. Between the agricultural census of 2002 and that of 2007, the number of farms in the United States increased by 4 percent to roughly 2.2 million. The new farms were mostly small, many of them operated by women, whose numbers in farming jumped from 238,000 in 2002 to 306,000 in 2007, a rise of nearly 30 percent.<sup>61</sup>

Many of the new farms cater to local markets. Some produce fresh fruits and vegetables exclusively for farmers' markets or for their own roadside stands. Others produce specialized products, such as the goat farms that produce milk, cheese, and meat or the farms that grow flowers or wood for fireplaces. Others specialize in organic food. The number of organic farms in the United States jumped from 12,000 in 2002 to 18,200 in 2007, increasing by half in five years.<sup>62</sup>

Gardening was given a big boost in the spring of 2009 when U.S. First Lady Michelle Obama worked with children from a local school to dig up a piece of lawn by the White House to start a vegetable garden. There was a precedent. Eleanor Roosevelt planted a White House victory garden during World War II. Her initiative encouraged millions of victory gardens that eventually grew 40 percent of the nation's fresh produce.<sup>63</sup>

Although it was much easier to expand home gardening during World War II, when the United States was largely a rural society, there is still a huge gardening potential—given that the grass lawns surrounding U.S. residences collectively cover some 18 million acres. Converting even a small share of this to fresh vegetables and fruit trees could make an important contribution to improving nutrition.<sup>64</sup>

Many cities and small towns in the United States and England are creating community gardens that can be used by those who would otherwise not have access to land for gardening.

Providing space for community gardens is seen by many local governments as an essential service, like providing playgrounds for children or tennis courts and other sport facilities.<sup>65</sup>

Many market outlets are opening up for local produce. Perhaps the best known of these are the farmers' markets where local farmers bring their produce for sale. In the United States, the number of these markets increased from 1,755 in 1994 to more than 4,700 in mid-2009, nearly tripling over 15 years. Farmers' markets reestablish personal ties between producers and consumers that do not exist in the impersonal confines of the supermarket. Many farmers' markets also now take food stamps, giving low-income consumers access to fresh produce that they might not otherwise be able to afford. With so many trends now boosting interest in these markets, their numbers may grow even faster in the future.<sup>66</sup>

In school gardens, children learn how food is produced, a skill often lacking in urban settings, and they may get their first taste of freshly picked peas or vine-ripened tomatoes. School gardens also provide fresh produce for school lunches. California, a leader in this area, has 6,000 school gardens.<sup>67</sup>

Many schools and universities are now making a point of buying local food because it is fresher, tastier, and more nutritious and it fits into new campus greening programs. Some universities compost kitchen and cafeteria food waste and make the compost available to the farmers who supply them with fresh produce.

Supermarkets are increasingly contracting with local farmers during the season when locally grown produce is available. Upscale restaurants emphasize locally grown food on their menus. In some cases, year-round food markets are evolving that market just locally produced foods, including not only fruit and vegetables but also meat, milk, cheese, eggs, and other farm products.<sup>68</sup>

Food from more distant locations boosts carbon emissions while losing flavor and nutrition. A survey of food consumed in Iowa showed conventional produce traveled on average 1,500 miles, not including food imported from other countries. In contrast, locally grown produce traveled on average 56 miles—a huge difference in fuel investment. And a study in Ontario, Canada, found that 58 imported foods traveled an average of 2,800 miles. Simply put, consumers are worried about food

security in a long-distance food economy. This trend has led to a new term: locavore, complementing the better known terms herbivore, carnivore, and omnivore.<sup>69</sup>

Concerns about the climate effects of consuming food transported from distant locations has also led Tesco, the leading U.K. supermarket chain, to label products with their carbon footprint—indicating the greenhouse gas contribution of food items from the farm to supermarket shelf.<sup>70</sup>

The shift from factory farm production of milk, meat, and eggs by returning to mixed crop-livestock operations also facilitates nutrient recycling as local farmers return livestock manure to the land. The combination of high prices of natural gas, which is used to make nitrogen fertilizer, and of phosphate, as reserves are depleted, suggests a much greater future emphasis on nutrient recycling—an area where small farmers producing for local markets have a distinct advantage over massive feeding operations.<sup>71</sup>

### Strategic Reductions in Demand

Despite impressive local advances, the global loss of momentum in expanding food production is forcing us to think more seriously about reducing demand by stabilizing population, moving down the food chain, and reducing the use of grain to fuel cars.

The Plan B goal is to halt world population growth at no more than 8 billion by 2040. This will require an all-out population education effort to help people everywhere understand how fast the relationship between us and our natural support systems is deteriorating. It also means that we need a crash program to get reproductive health care and birth control services to the 201 million women today who want to plan their families but lack access to the means to do so.<sup>72</sup>

While the effect of population growth on the demand for grain is rather clear, that of rising affluence is much less so. One of the questions I am often asked is, "How many people can the earth support?" I answer with another question: "At what level of food consumption?" Using round numbers, at the U.S. level of 800 kilograms of grain per person annually 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, the current harvest would support 5 bil-

lion people. At the 200 kilograms of grain consumed by the average Indian, it would support 10 billion.<sup>73</sup>

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, while the bulk of the grain is consumed indirectly in the form of livestock and poultry products. 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.<sup>74</sup>

Among the United States, Italy, and India, life expectancy is highest in Italy even though U.S. medical expenditures per person are much higher. People who live very low or very high on the food chain do not live as long as those at an intermediate level. People consuming a Mediterranean-type diet that includes meat, cheese, and seafood, but all in moderation, are healthier and live longer. People living high on the food chain can improve their health by moving down the food chain. For those who live in low-income countries like India, where a starchy staple such as rice can supply 60 percent or more of total caloric intake, eating more protein-rich foods can improve health and raise life expectancy.<sup>75</sup>

Although we seldom consider the climate effect of various dietary options, they are substantial, to say the least. Gidon Eshel and Pamela A. Martin of the University of Chicago have studied this issue. They begin by noting that for Americans the energy used to provide the typical diet and that used for personal transportation are roughly the same. They calculate that the range between the more and less carbon-intensive transportation options and dietary options is each about four to one. The Toyota Prius, for instance, uses roughly one fourth as much fuel as a Chevrolet Suburban SUV. Similarly with diets, a plant-based diet requires roughly one fourth as much energy as a diet rich in red meat. Shifting from the latter to a plant-based diet cuts greenhouse gas emissions almost as much as shifting from a Suburban to a Prius would.<sup>76</sup>

Shifting from the more grain-intensive to the less grain-intensive forms of animal protein can also reduce pressure on the earth's land and water resources. For example, shifting from

grain-fed beef that requires roughly 7 pounds of grain concentrate for each additional pound of live weight to poultry or catfish, which require roughly 2 pounds of grain per pound of live weight, substantially reduces grain use.<sup>77</sup>

When considering how much animal protein to consume, it is useful to distinguish between grass-fed and grain-fed products. For example, most of the world's beef is produced with grass. Even in the United States, with an abundance of feedlots, over half of all beef cattle weight gain comes from grass rather than grain. The global area of grasslands, which is easily double the world cropland area and which is usually too steeply sloping or too arid to plow, can contribute to the food supply only if it is used for grazing to produce meat, milk, and cheese.<sup>78</sup>

Beyond the role of grass in providing high-quality protein in our diets, it is sometimes assumed that we can increase the efficiency of land and water use by shifting from animal protein to high-quality plant protein, such as that from soybeans. It turns out, however, that since corn yields in the U.S. Midwest are three to four times those of soybeans, it may be more resource-efficient to produce corn and convert it into poultry or catfish at a ratio of two to one than to have everyone heavily reliant on soy.<sup>79</sup>

Although population growth has been a source of growing demand ever since agriculture began, the large-scale conversion of grain into animal protein emerged only after World War II. The massive conversion of grain into fuel for cars began just a few years ago. If we are to reverse the spread of hunger, we will almost certainly have to reduce the latter use of grain. Remember, the estimated 104 million tons of grain used to produce ethanol in 2009 in the United States is the food supply for 340 million people at average world grain consumption levels.<sup>80</sup>

Quickly shifting to smaller families, moving down the food chain either by consuming less animal protein or by turning to more grain-efficient animal protein sources, and removing the incentives for converting food into fuel will help ensure that everyone has enough to eat. It will also lessen the pressures that lead to overpumping of groundwater and the clearing of tropical rainforests, helping us to reach the Plan B goals.

### Action on Many Fronts

In this new food era, ensuring future food security depends on elevating responsibility for it from the minister of agriculture's office to that of the head of state. The minister of agriculture, no matter how competent, can no longer be expected to secure food supplies. Policies in the ministry of energy may affect food security more than those in the ministry of agriculture do. Efforts by the minister of health and family planning to accelerate the shift to smaller families may have a greater effect on food security than efforts in the ministry of agriculture to raise crop yields.

If ministries of energy cannot quickly cut carbon emissions, as outlined earlier, the world will face crop-shrinking heat waves that can massively and unpredictably reduce harvests. A hotter world will mean melting ice sheets, rising sea level, and the inundation of the highly productive rice-growing river deltas of Asia. Saving the mountain glaciers whose ice melt irrigates much of the world's cropland is the responsibility of the ministry of energy, not the ministry of agriculture.

If the world's ministers of energy cannot collectively formulate policies to cut carbon emissions quickly, the loss of glaciers in the Himalayas and on the Tibetan Plateau will shrink wheat and rice harvests in both India and China. If ministries of water resources cannot quickly raise water productivity and arrest the depletion of aquifers, grain harvests will shrink not only in smaller countries like Saudi Arabia and Yemen but also in larger countries, such as India and China. If we continue with business as usual, these two countries, the world's most populous, will face water shortages driven by both aquifer depletion and melting glaciers.

If the ministries of forestry and agriculture cannot work together to restore tree cover and reduce floods and soil erosion, then we face a situation where grain harvests will shrink not only in smaller countries like Haiti and Mongolia, but also in larger countries, such as Russia and Argentina—both wheat exporters.

And where water is a more serious constraint on expanding food output than land, it will be up to ministries of water resources to do everything possible to raise the efficiency of water use. With water, as with energy, the principal opportuni-

ties now are in increasing efficiency on the demand side, not in expanding the supply side.

In a world where cropland is scarce and becoming more so, decisions made in ministries of transportation on whether to develop land-consuming, auto-centered transport systems or more-diversified systems, including light rail, buses, and bicycles that are much less land-intensive, will directly affect world food security.

Now in our overpopulated, climate-changing, water-scarce world, food security is a matter for the entire society and for all government ministries. Since hunger is almost always the result of poverty, eradicating hunger depends on eradicating poverty. And where populations are outrunning their land and water resources, this depends on stabilizing population.

And finally, if ministries of finance cannot reallocate resources in a way that recognizes the new threats to security posed by agriculture's deteriorating natural support systems, continuing population growth, human-driven climate change, and spreading water shortages, then food shortages could indeed bring down civilization.

Given that a handful of the more affluent grain-importing countries are reportedly investing some \$20–30 billion in land acquisition, there is no shortage of capital to invest in agricultural development. Why not invest it across the board in helping low-income countries develop their unrealized potential for expanding food production, enabling them to export more grain?<sup>81</sup>

One way to quickly reverse this deteriorating political situation is for the United States to restrict the use of grain to produce fuel for cars. Given the turmoil in world grain markets over the last three years, it is time for the U.S. government to abolish the subsidies and mandates that are driving the conversion of grain into fuel. That would help stabilize grain prices and set the stage for relaxing the political tensions that have emerged within importing countries.

And finally, we have a role to play as individuals. Whether we bike, bus, or drive to work will affect carbon emissions, climate change, and food security. The size of the car we drive to the supermarket and its effect on climate may indirectly affect the size of the bill at the supermarket checkout counter. If we are

living high on the food chain, we can move down, improving our health while helping to stabilize climate. Food security is something in which we all have a stake—and a responsibility.