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Feeding Eight Billion

Prior to 1950, growth of the food supply came almost entirely from expanding cropland area. Then as frontiers disappeared and population growth accelerated after World War II, the focus quickly shifted to raising land productivity. In the most spectacular achievement in world agricultural history, farmers doubled the grain harvest between 1950 and 1973. Stated otherwise, growth in the grain harvest during this 23-year-span matched that of the preceding 11,000 years.[1]

This was the golden age of world agriculture. Since then, growth in world food output has been gradually losing momentum as the backlog of unused agricultural technology dwindles, as soil erodes, as the area of cultivable land shrinks, and as irrigation water becomes scarce.[2]

Gains in land productivity since 1950 have come primarily from three sources—the development of higher-yielding varieties, the growing use of fertilizer, and the spread of irrigation. The initial breakthrough in breeding higher-yielding varieties 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, making it possible to double yields.[3]

With corn, now the world's leading 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.[4]

Most recently, Chinese scientists have developed commercially viable hybrid rice strains. While they have raised yields somewhat, the gains have been small compared with the earlier gains from dwarfing the rice plant.[5]

As farmers attempted to remove nutrient constraints on crop yields, fertilizer use climbed from 14 million tons in 1950 to 163 million tons in 2009. In some countries, such as the United States, several in Western Europe, and Japan, fertilizer use has now leveled off or even declined substantially in recent decades. In China and India, both of which use more fertilizer than the United States does, usage may also decline as farmers use fertilizer more efficiently.[6]

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 2.2 percent per year, but from 1990 until 2010 it went up only 1.2 percent annually.[7]

There are distinct signs of yields leveling off in the higher-yield countries that are using all available technologies. With wheat, it is hard to get more than 8 tons per hectare. This is illustrated by the plateauing of wheat yields in France (Europe's largest wheat producer), Germany, the United Kingdom, and Egypt (Africa's leading wheat grower).[8]

Japan, which led the world into the era of rising grain yields over a century ago, saw its rice yield plateau over the last decade or so as it approached 5 tons per hectare. Today yields in China are also leveling off as they reach the Japanese level.[9]

Among the big three grains, corn is the only one where the yield is continuing a steady rise in high-yield countries. In the United States, which accounts for 40 percent of the world corn harvest, yields now exceed an astonishing 10 tons per hectare. Iowa, with its super-high corn yields, now produces more grain than Canada does.[10]

Despite dramatic past leaps in grain yields, it is becoming more difficult to expand world food output for many reasons. Further gains in yields from plant breeding, even including genetic modification, do not come easily. Expanding the irrigated area is difficult. Returns on the use of additional fertilizer are diminishing in many countries.

In spite of the difficulties, 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 urban consumers with grain support prices to encourage farmers to invest in raising land productivity. The construction of fertilizer plants was moved from the public sector into the private sector, which could build them much faster. The high-yielding Mexican dwarf wheats, already tested in India, were introduced by the shipload for seed. These policy initiatives 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 so quickly.[11]

A similarly dramatic advance came in Malawi, a small country with low grain yields, after the drought of 2005 that left many hungry and some starving. In response, the government issued coupons good for 200 pounds of fertilizer to each farmer at well below the market price, along with free packets of improved seed corn, their staple food. Costing some $70 million per year and funded partly by

outside donors, this fertilizer and seed subsidy program helped Malawi's farmers nearly double their corn harvest within two years, leading to an excess of grain. Fortunately this grain could be exported profitably to nearby Zimbabwe, which was experiencing acute grain shortages.[12]

Some years earlier, Ethiopia, taking similar steps, also achieved a dramatic jump in production. But because there was no way to export the surplus, prices crashed—a major setback to the country's farmers. This experience underlines a major challenge to Africa's agricultural development, namely the lack of public infrastructure, such as roads to get fertilizer to farmers and their products to market.[13]

In Africa's more arid countries, such as Chad, Mali, and Mauritania, there is not enough rainfall to raise yields dramatically. Modest yield gains are possible with improved agricultural practices, but in many of these low-rainfall countries there has not been a green revolution for the same reasons there has not been one in Australia—namely, low soil moisture and the associated limit on fertilizer use.[14]

One encouraging practice to raise cropland productivity in semiarid Africa is the simultaneous planting of grain and nitrogen-fixing 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 can then be cut and used for fuel. This simple, locally adapted technology, developed by scientists at the World Agroforestry Centre in Nairobi, has enabled farmers to double their grain yields within a matter of years as soil fertility builds.[15]

The shrinking backlog of unused agricultural technology and the resulting loss of momentum in raising yields worldwide signals 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 strains 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.[16]

Another way to raise land productivity, where soil moisture permits, is to expand the land area that produces more than one crop per year. Indeed, the tripling of 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.[17]

The spread of corn-wheat double cropping on the North China Plain helped boost China's grain production to rival that of the United States. In northern India, the grain harvest 40 or so years ago 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.[18]

Another often overlooked influence on productivity is land tenure. 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.[19]

In summary, while grain production is falling in some countries, either because of unfolding water shortages or spreading soil erosion, the overwhelming majority of

nations still have a substantial unrealized production potential. The challenge is for each country to fashion agricultural and economic policies to realize that 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.

With water shortages constraining food production growth, the world needs a campaign to raise water productivity similar to the one that nearly tripled land productivity over the last half-century. Data on the efficiency of surface water projects—that is, dams that deliver water to farmers through a network of canals—show that crops never use all the irrigation water simply because some 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."[20]

China's irrigation plan is to raise efficiency from 43 percent in 2000 to 55 percent in 2020. Key measures include raising the price of water, providing incentives for adopting more irrigation-efficient technologies, and developing the local institutions to manage this process.[21]

Raising irrigation efficiency typically means shifting from the less-efficient flood or furrow systems to overhead sprinklers or to drip irrigation, the gold standard of irrigation efficiency. Switching from flood or furrow to low-pressure sprinkler systems reduces water use by an estimated 30 percent, while switching to drip irrigation typically cuts water use in half.[22]

Drip irrigation also raises yields because it provides a steady supply of water with minimal losses to evaporation. In addition, it reduces the energy needed to pump water. 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. 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.[23]

In recent years, small-scale drip-irrigation systems—literally an elevated 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.[24]

Sandra Postel of the Global Water Policy Project 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.[25]

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. Farmers in many countries 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 is that the cost of maintaining the irrigation sys-

tem is assumed locally, reducing the drain on the treasury.[26]

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 growing is being phased out around Beijing because rice is such a thirsty crop. Similarly, Egypt restricts rice production in favor of wheat. Any measures that raise crop yields on irrigated land also raise irrigation water productivity.[27]

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 obvious steps, in addition to adopting more water-efficient irrigation practices, include using more water-efficient industrial processes. Recycling urban water supplies is another obvious step in countries facing acute water shortages. And because coal-fired power plants use so much water for cooling, shifting to wind farms eliminates a major drain on water supplies.[28]

Another way to raise both land and water productivity is to produce animal protein more efficiently. With some 35 percent of the world grain harvest (760 million tons) used to produce animal protein, even a modest reduction in meat consumption or gain in efficiency can save a large quantity of grain.[29]

World consumption of animal protein is everywhere on the rise. Meat consumption increased from 44 million tons in 1950 to 272 million tons in 2009, more than doubling annual consumption per person to nearly 90 pounds. The rise in consumption of milk and eggs is

equally dramatic. Wherever incomes rise, so does meat consumption, reflecting a taste that apparently evolved over 4 million years of hunting and gathering.[30]

As the oceanic fish catch and rangeland beef production have both leveled off, the world has shifted to grain-based production of animal protein to expand output. The efficiency with which various animals convert grain into protein varies widely. With cattle in feedlots, it takes roughly 7 pounds of grain to produce a 1-pound gain in live weight. For pork, the figure is over 3 pounds, 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.[31]

Global beef production, most of which comes from rangelands, grew less than 1 percent a year from 1990 to 2007 and has plateaued since. Pork production grew by 2 percent annually, and poultry by 4 percent. World pork production, half of it now in China, overtook beef production in 1979 and has continued to widen the lead since then. Poultry production eclipsed beef in 1995, moving into second place behind pork.[32]

Fast-growing, grain-efficient fish farm output may also soon overtake beef production. In fact, aquaculture has been the fastest-growing source of animal protein since 1990, expanding from 13 million tons then to 52 million tons in 2008, or 8 percent a year.[33]

Public attention has focused on aquacultural operations that are environmentally inefficient or disruptive, such as the farming of salmon, a carnivorous species that is typically fed fishmeal. But these operations account for less than one tenth of world fish farm output. Worldwide, 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.[34]

China accounts for 62 percent of global fish farm out-

put. Its output is dominated by finfish (mostly carp), which are grown in inland freshwater ponds, lakes, reservoirs, and rice paddies, and by shellfish (oysters and mussels), which are produced mostly in coastal regions. A multi-species system, using four types of carp that feed at different levels of the food chain, commonly boosts pond productivity over that of monocultures by at least half. China's fish farm output of 32 million tons is nearly triple U.S. beef output of 12 million tons.[35]

Soybean meal is universally used in mixing feed for livestock, poultry, and fish. In 2010 the world's farmers produced 254 million tons of soybeans. Of this, an estimated 30 million tons were consumed directly as tofu or other meat substitutes. Some 220 million tons were crushed, yielding roughly 40 million tons of soybean oil and 170 million tons of highly valued high-protein meal.[36]

Combining soybean meal with grain in a one-to-four ratio dramatically boosts the efficiency with which grain is converted into animal protein, sometimes nearly doubling it. Virtually the entire world, including the three largest meat producers—China, the United States, and Brazil—now relies heavily on soybean meal as a protein supplement in feed rations.[37]

The heavy use of soybean meal to boost feed efficiency helps explain why the production of meat, milk, eggs, and farmed fish has climbed even though the 35 percent share of the world grain harvest used for feed has decreased slightly over the last 20 years. It also explains why world soybean production has multiplied 15-fold since 1950.[38]

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 110 million tons in 2009.

In 1997 India overtook the United States to become the world's leading producer of milk and other dairy products.[39]

What is so remarkable is that India has built the world's largest dairy industry based not on grain but almost entirely on crop residues—wheat straw, rice straw, and corn stalks—and grass gathered from the roadside. The value of India's annual milk output now exceeds that of its rice harvest.[40]

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. These provinces, dubbed the Beef Belt by Chinese officials, use crop residues to produce much of China's beef. This 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.[41]

While people in developing countries are focusing on moving up the food chain, in many industrial countries there is a growing interest in fresh, locally produced foods. In the United States, this interest is driven both by concerns about the climate effects of transporting food from distant places and by the desire for fresh food that supermarkets with long supply chains can no longer deliver. This is reflected in the growth of both home gardens and local farmers' markets.[42]

With the fast-growing local foods movement, diets are becoming more locally shaped and more seasonal. In the United States, this trend toward localization can be seen in the recent rise in farm numbers. Between the agricultural census of 2002 and that of 2007, the number of farms increased by nearly 80,000 to roughly 2.2 million. Many of the new farms, mostly smaller ones—and a growing share of them operated by women—cater to

local markets. Some produce fresh fruits and vegetables exclusively for farmers' markets. Others, such as goat farms that produce milk, cheese, and meat, produce specialized products. With many specializing in organic food, the number of organic farms in the United States jumped from 12,000 in 2002 to 18,200 in 2007.[43]

Many market outlets are opening up for local U.S. produce. Farmers' markets, where local farmers bring their produce for sale, increased from 1,755 in 1994 to over 6,100 in 2010, more than tripling over 16 years. These markets facilitate personal ties between producers and consumers that do not exist in the impersonal confines of a supermarket.[44]

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. Supermarkets are increasingly contracting seasonally with local farmers when produce is available. For example, in late 2010 Walmart announced a plan to buy more produce from local farmers for its stores. Upscale restaurants emphasize locally grown food on their menus. Some year-round food markets are evolving that supply only locally produced foods, including not only fresh produce but also meat, milk, cheese, eggs, and other farm products.[45]

Home gardening was given a big boost in the spring of 2009 when First Lady Michelle Obama worked with children from a local school to dig up a piece of the White House lawn to start a vegetable garden. There was a precedent for this: Eleanor Roosevelt planted a White House victory garden during World War II. Her initiative encouraged millions of victory gardens, which eventually grew 40 percent of the nation's fresh produce.[46]

Although it was much easier to expand home gardening during World War II, when the United States was much more rural, 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 a meaningful contribution.[47]

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 now seen by many local governments as an essential service, like providing playgrounds or parks.[48]

Urban gardens are gaining popularity throughout the world. A program organized by the U.N. Food and Agriculture Organization (FAO) to help cities in developing countries establish urban garden programs is being well received. In five cities in the Democratic Republic of the Congo, for example, it has helped 20,000 gardeners improve their vegetable growing operations. Market gardens in Kinshasa, the country's capital, produce an estimated 80,000 tons of vegetables per year, meeting 65 percent of the city's needs.[49]

In the city of El Alto near La Paz, Bolivia, FAO supports a highly successful micro-garden program for low-income families. Using small, low-cost greenhouses covering about 50 square yards each, some 1,500 households grow fresh vegetables the year round. Some of the produce is consumed at home; some is sold at local markets.[50]

School gardens are another welcome development. Children learn how food is produced, a skill often lacking in urban settings, and they may get their first taste of fresh salad greens or vine-ripened tomatoes. School gardens also provide fresh produce for school lunches. California, a leader in this area, has 6,000 school gardens.[51]

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 use. And a study in Ontario, Canada, found that 58 imported foods traveled an average of 2,800 miles. In an oil-scarce world, consumers are worried about food security in a long-distance food economy.[52]

The high prices of natural gas, which is used to make nitrogen fertilizer, and of phosphate, as reserves are depleted, suggest a much greater future emphasis on nutrient recycling—an area where small farmers producing for local markets have a distinct advantage over massive livestock and poultry feeding operations.[53]

With food, as with energy, achieving security now depends on looking at the demand side of the equation as well as the supply side. We cannot rely solely on expanding production to reverse the deteriorating food situation of recent years. This is why a basic Plan B goal is to accelerate the shift to smaller families and halt the growth in world population at 8 billion by 2040.

An American living high on the food chain with a diet heavy in grain-intensive livestock products, including red meat, consumes twice as much grain as the average Italian and nearly four times as much as the average Indian. Adopting a Mediterranean diet can cut the grain footprint of Americans roughly in half, reducing carbon emissions accordingly.[54]

Ensuring future food security was once the exclusive responsibility of the ministry of agriculture, but this is changing. The minister of agriculture alone, no matter how competent, can no longer be expected to secure food supplies. Indeed, efforts by the minister of health and family planning to lower human fertility may have a greater effect on future food security than efforts in the ministry of agriculture to raise land fertility.

Similarly, if ministries of energy cannot quickly cut

carbon emissions, the world will face crop-shrinking heat waves that can massively and unpredictably reduce harvests. Saving the mountain glaciers whose ice melt irrigates much of the cropland in China and India during the dry season is the responsibility of the ministry of energy, not solely the ministry of agriculture.[55]

If the ministries of forestry and agriculture cannot work together to restore tree cover and reduce floods and soil erosion, grain harvests will shrink not only in smaller countries like Haiti and Mongolia, as they are doing, but also in larger countries, such as Russia and Argentina—both wheat exporters.[56]

And where water shortages restrict food output, it will be up to ministries of water resources to do everything possible to raise national water productivity. With water, as with energy, the principal potential now is in increasing efficiency, not expanding supply.

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 that are much less land-intensive will directly affect world food security.

In the end, it is up to ministries of finance to 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. Since many ministries of government are involved, it is the head of state who must redefine security.

At the international level, we need to address the threat posed by growing climate volatility and the associated rise in food price volatility. The tripling of wheat, rice, corn, and soybean prices between 2007 and 2008 put enormous stresses on governments and low-income consumers. This price volatility also affects producers, since price uncertainty discourages investment by farmers.[57]

In this unstable situation, a new mechanism to stabilize world grain prices is needed—in effect, a World Food Bank (WFB). This body would establish a support price and a ceiling price for wheat, rice, and corn. The WFB would buy grain when prices fell to the support level and return it to the market when prices reached the ceiling level, thus moderating price fluctuations in a way that would benefit both consumers and producers. The principal role of the WFB governing board, representing major exporting as well as importing countries, would be to establish the price levels for acquiring and releasing grain.

One simple way to improve food security is for the United States to eliminate the fuel ethanol subsidy and abolish the mandates that are driving the conversion of grain into fuel. This would help stabilize grain prices and buy some time in which to reverse the environmental and demographic trends that are undermining our future. It would also help relax the political tensions over food security that have emerged within importing countries.

And finally, we all have a role to play as individuals. Whether we decide to 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. At the family level, we need to hold the line at two children. And if we are living high on the food chain, we can eat less grain-intensive livestock products, improving our health while helping to stabilize climate. Food security is something in which we all have a stake—and a responsibility.

Data, endnotes, and additional resources can be found on Earth Policy's Web site, at www.earth-policy.org.

IV
WATCHING THE CLOCK