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Grain Yields Starting to Plateau

From the beginning of agriculture until the mid-twentieth century, growth in the world grain harvest came almost entirely from expanding the cultivated area. Rises in land productivity were too slow to be visible within a single generation. It is only within the last 60 years or so that rising yields have replaced area expansion as the principal source of growth in world grain production.[1]

The transition was dramatic. Between 1950 and 1973 the world's farmers doubled the grain harvest, nearly all of it from raising yields. Stated otherwise, expansion during these 23 years equaled the growth in output from the beginning of agriculture until 1950. The keys to this phenomenal expansion were fertilization, irrigation, and higher-yielding varieties, coupled with strong economic incentives for production.[2]

The first country to achieve a steady, sustained rise in grain yields was Japan, where the yield takeoff began in the 1880s. But for a half-century or so, it was virtually alone. Not until the mid-twentieth century did the United States and Western Europe launch a steady rise in grain yields. Shortly thereafter many other countries succeeded in boosting grain yields.[3]

The average world grain yield in 1950 was 1.1 tons per hectare. In 2011, it was 3.3 tons per hectare—a tripling of the

1950 level. Some countries, including the United States and China, managed to quadruple grain yields, and all within a human life span.[4]

Some of the factors influencing grain yields are natural, while others are of human origin. Natural conditions of inherent soil fertility, rainfall, day length, and solar intensity strongly influence crop yield potentials. Several areas of cropland with inherently high fertility are found widely scattered around the world: in the U.S. Midwest (often called the Corn Belt), Western Europe, the Gangetic Plain of India, and the North China Plain. It is the incredibly deep and rich soils of the U.S. Midwest that enables the United States to produce 40 percent of the world corn crop and 35 percent of the soybean crop. The state of Iowa, for instance, produces more grain than Canada and more soybeans than China.[5]

The area west of the Alps, stretching across France to the English Channel and up to the North Sea, is also naturally very productive land, enabling densely populated Western Europe to produce an exportable surplus of wheat.[6]

The region in northern India spanning the Punjab and the Gangetic Plain is India's breadbasket. And the North China Plain produces half of China's wheat and a third of its corn.[7]

Aside from inherent soil fertility, the level and timing of rainfall, which vary widely among geographic regions, also strongly influence the productivity of land. Much of the world's wheat, which is drought-tolerant, is grown without irrigation in regions with relatively low rainfall. Most wheat in the United States, Canada, and Russia, for example, is grown under these dryland conditions. Wheat is often grown in areas too dry or too cold to grow corn or rice.[8]

Another natural factor that plays a major role in crop yields is day length. One reason that the United Kingdom and Germany have such high wheat yields is because they have a mild climate, compliments of the Gulf Stream, and can grow winter wheat. This wheat, planted in the fall, reaches several inches in height and then goes dormant as temperatures drop. With the arrival of spring, it grows rapidly, maturing during the longest days of the year in a high-latitude region that has very long days in May, June, and July. Wheat yields in these two northerly countries are close to 8 tons per hectare, somewhat higher than the 7 tons in France, simply because they are at a slightly higher latitude and thus have longer summer days.[9]

The big differences between the United States and Western Europe are soil moisture and day length. In the United States, most wheat grows in the semiarid Great Plains, whereas in Europe it is produced on the well-watered, rainfed wheat fields of France, Germany, and the United Kingdom. The average U.S. wheat yield is scarcely 3 tons per hectare. But in Western Europe, wheat yields can range from 6 to 8 tons per hectare.[10]

Just as long days promote high yields, the short days closer to the equator lead to relatively low yields. The advantage of the subtropical regions, however, is that they allow more than one crop per year, assuming sufficient soil moisture in the dry season. In land-scarce southern China, India, and other tropical/subtropical countries in Asia, double- or triple-cropping of rice is not uncommon. So although the yield per harvest is lower, the yield per year is much higher.[11]

In northern India, for example, winter wheat with a summer rice crop is the dominant high-yielding combination. In China, combining winter wheat with corn as the summer crop in an annual cycle, plus the double cropping of rice, enables the country to produce the world's largest grain harvest on a relatively modest area of arable land.[12]

Solar intensity also plays an important role in determining the upper limits of crop yields. Rice yields in Japan, among the highest in Asia, are well below those in California. This is not because California's rice farmers are more

skilled than their Japanese counterparts but because Japan's rice harvest grows mostly during the monsoon season, when there is extensive cloud cover, while California's rice fields bask in bright sunlight.[13]

Within this framework of natural conditions that help determine yields, plant breeders have made impressive progress in exploiting the yield potential. Japan has been a long-time leader. The originally domesticated wheats and rices tended to be taller, enabling them to compete with weeds for sunlight. But with weed control either by hand or mechanical cultivation, Japanese plant breeders realized that the tall grain could be shortened. By shortening the straw, a greater share of the plant's photosynthate could be diverted to forming seeds, the edible part.[14]

After Japanese "dwarf" wheats were introduced into the northwestern United States, Norman Borlaug, an agronomist based in Mexico, obtained some of the seeds in the early 1950s. He then introduced these dwarf wheats into other countries, including India and Pakistan, for testing under local growing conditions. Almost everywhere they were introduced they would double or even triple the yields of those from traditional wheat varieties. In Mexico, the dwarf wheats led to a quantum jump in wheat yields, nearly fourfold from 1950 to 2011.[15]

Given the dramatic advances for the early dwarf wheats, in 1960 a similar effort with rice was launched at the newly created International Rice Research Institute (IRRI) at Los Baños in the Philippines. Under the leadership of Robert Chandler, scientists there drew on the experience with wheat to come up with some high-yielding dwarf rice varieties that were, like the wheats, widely adopted. IR8, one of the early strains, easily doubled yields in many countries. It was the first of many new highly productive rice strains to come from IRRI.[16]

The new dwarf wheats and rices had the genetic potential to respond well to both irrigation and fertilizer. When fertilizer was applied to the old tall-strawed varieties, the plant would often fall over in a storm or even a heavy rain as the head of grain became heavier, leading to harvest losses. The new short, stiff-strawed varieties could support a much larger head of grain without toppling over.[17]

In the 1930s, plant breeders in the United States were raising yields of corn with high-yielding hybrid varieties. It was discovered that, with the right combination of parent stock, hybridization could dramatically increase yields. As the new hybrids spread in the United States, corn yields began to climb, quintupling between 1940 and 2010.[18]

In contrast to wheat and rice, where dwarfing held the key to raising yields, corn breeders have worked in recent decades to develop hybrids that would tolerate crowding, enabling farmers to grow more corn plants per acre. And since each plant typically produces one ear of corn, more plants mean more corn. A half-century ago farmers typically grew perhaps 10,000 corn plants per acre. Today states with adequate soil moisture have plant populations of 28,000 or more per acre.[19]

Although people often ask about the potential to raise grain yields using genetic modification, success has thus far been limited. This is largely because plant breeders using traditional approaches were successful in doing almost everything plant scientists could think of to raise yields, leaving little potential for doing so through genetic modification.[20]

The tripling of world irrigated area since 1950 has also helped raise grain yields by helping high-yielding crops realize their full genetic potential. And because irrigation removes moisture constraints, it also facilitates the greater use of fertilizer.[21]

When German chemist Justus von Liebig demonstrated in 1847 that the major nutrients that plants removed from the soil could be applied in mineral form, he set the stage for

the development of a new industry and a huge jump in world food production a century later. Of the 16 elements plants require to be properly nourished, three—nitrogen, phosphorus, and potassium—totally dominate the world fertilizer industry. World fertilizer use climbed from 14 million tons in 1950 to 177 million tons in 2010, helping to boost the world grain harvest nearly fourfold.[22]

As the world economy evolved from being largely rural to being highly urbanized, the natural nutrient cycle was disrupted. In traditional rural societies, food is consumed locally, and human an animal waste is returned to the land, completing the nutrient cycle. But in highly urbanized societies, where food is consumed far from where it is produced, using fertilizer to replace the lost nutrients is the only practical way to maintain land productivity. It thus comes as no surprise that the growth in fertilizer use closely tracks the growth in urbanization, with much of it concentrated in the last 60 years.[23]

The big three grain producers—China, India, and the United States—account for 58 percent of world fertilizer use. In the United States, the growth in fertilizer use came to an end in 1980, but—in an encouraging sign—grain yields have continued to climb. China's fertilizer use climbed rapidly in recent decades but has leveled off since 2007. While China uses nearly 50 million tons of fertilizer a year and India uses nearly 25 million tons, the United States uses only 20 million tons.[24]

Given that China and the United States each produce roughly 400 million tons of grain, the grain produced per ton of fertilizer in the United States is more than double that of China. This is partly because American farmers are much more precise in matching application with need, but also partly because the United States is far and away the world's largest soybean producer. The soybean, being a legume, fixes nitrogen in the soil that can be used by subsequent crops. U.S. farmers regularly plant corn and soybeans in a two-year rotation, thus reducing the amount of nitrogen fertilizer that has to be applied for the corn.[25]

In most countries outside of sub-Saharan Africa, grain yields have doubled, tripled, or even quadrupled. Aside from having some of the world's inherently least fertile soils and a largely semiarid climate, sub-Saharan Africa lacks the infrastructure and modern inputs needed to support modern agriculture.[26]

Recent experience in Malawi, however, illustrates the potential for improvement. After a drought in 2005, many of the country's 13 million people were left hungry or 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. Funded partly by outside donors, this fertilizer and seed subsidy program helped nearly double Malawi's corn harvest within two years, enabling it to export grain and boost farmers' incomes. With economic incentives and access to modern inputs, principally higher-yielding seed and fertilizer, farmers in sub-Saharan Africa can easily double yields.[27]

At 10 tons per hectare, U.S. corn yields are the highest of any major grain anywhere. In Iowa, with its deep soils and near-ideal climate for corn, some counties harvest up to 13 tons per hectare. In China, yields of each of its "big three" grains—wheat, rice, and corn—now range between 4 and 6 tons. Wheat yields in India have more than quadrupled since 1950, climbing to 3 tons per hectare. Remember, all grain yields in India are lower than in the United States, Europe, or China because India is close to the equator, where yields are restricted by short day length.[28]

Rising yields are the key to expanding the grain harvest.

Since 1950, over 93 percent of world grain harvest growth has come from raising yields. Expanding area accounts for the other 7 percent.[29]

Impressive though the growth is over the last 60 years, the pace has slowed during the last two decades. Between 1950 and 1990, the world grain yield increased by an average of 2.2 percent a year. From 1990 to 2011, the annual rise slowed to 1.3 percent. In some agriculturally advanced countries, the dramatic climb in yields has come to an end as yields have plateaued.[30]

For example, the rice yield per hectare in Japan, after climbing for more than a century, has not increased at all over the last 17 years. It is not that Japanese farmers do not want to continue raising their rice yields. They do. With a domestic support price far above the world market price, raising yields in Japan is highly profitable. The problem is that Japan's farmers are already using all the technologies available to raise land productivity.[31]

Like Japan, South Korea's rice yield also has plateaued. Interestingly, it plateaued at almost exactly the same level as the rice yield in Japan did, and while Japan's plateauing began in 1994, South Korea's began in 1996. The constraints on rice yields appear to be essentially the same in both countries. Yields there have hit a glass ceiling, a limit that is apparently imposed by day length, solar intensity, and, ultimately, the constraints of photosynthetic efficiency. Japan and South Korea together produce 12 million tons of rice annually, 3 percent of the world rice harvest.[32]

A similar situation is developing with wheat in Europe. In France, Germany, and the United Kingdom, wheat yields have been flat for more than a decade. Eight tons per hectare appears to be the biological upper limit for wheat yields in the United Kingdom and Germany. For France, located several degrees southward, and thus with somewhat shorter summer days, it is closer to 7 tons. (See Figure 7–1.) These three countries—France, Germany, and the United Kingdom—together produce 80 million tons of wheat, roughly 12 percent of the world wheat harvest.[33]

One thing that has become clear is that grain yield per hectare, like any biological growth process, cannot continue rising indefinitely. It has its limits. Once we remove nutrient constraints by applying fertilizer and we remove soil moisture constraints wherever possible by irrigating, then it is the potential of photosynthesis and the local climate that ultimately limit crop yields.[34]

Thus far the countries where rice or wheat yields have plateaued are medium-sized ones. What happens when grain yields plateau in some of the larger countries? Among the crops that are of particular concern are rice and wheat in China, which has the world's largest harvest of both, and corn in the United States, by far its largest producer. In each of these situations, the current yield is quite high and may not continue rising much longer.[35]

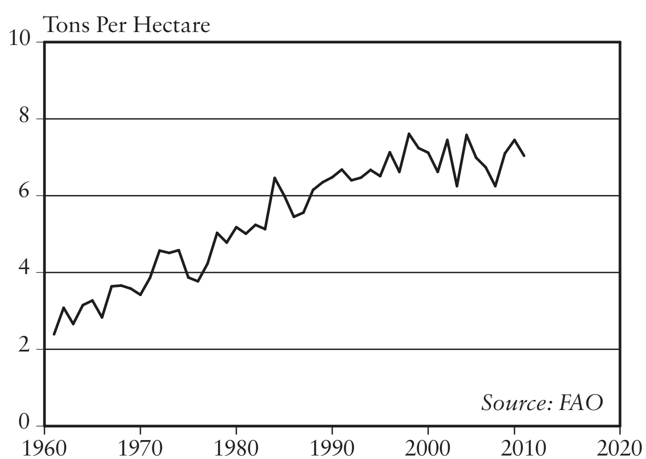

Figure 7–1. *Wheat Yields in France, 1961–2010*

Rice yields in China are now very close to those in Japan. (See Figure 7-2.) Unless Chinese farmers can somehow surpass their Japanese counterparts, which seems unlikely, China's rice yields appear about to plateau. If China hits the glass ceiling for its rice yields, then one third of the world's rice would be produced in three countries (Japan, South Korea, and China) that can no longer raise land productivity or expand the area in rice. Future gains in the rice harvest would have to come from countries that account for the remaining two thirds of the world's rice harvest, but some of these could be approaching their own glass ceilings.[36]

China's wheat may also be getting close to the glass ceiling. There are no longer many additional steps that China's farmers can take to raise yields. In a country that is already using twice as much fertilizer as the United States, it is highly unlikely that using more fertilizer will raise yields. There is little to no potential for expanding irrigation. Thus, the rapid rise in rice and wheat yields in recent decades in China may largely have run its course.[37]

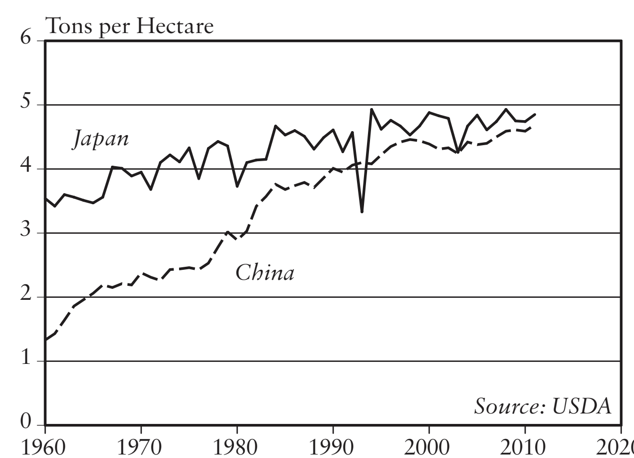

Figure 7–2. *Rice Yields in Japan and China, 1960–2011*

If China's wheat yields plateau, along with those of the three leading producers in Western Europe, nearly 30 percent of the world's wheat harvest would be grown in countries that may not be able to achieve any future meaningful gains in their output.[38]

Corn yields in the United States, currently at 10 tons per hectare, have not yet plateaued. But although corn is more photosynthetically efficient than other grains, it too has its biological limits. If the United States is approaching the point where it can no longer systematically raise corn yields, it would very much affect the global corn prospect, since the United States accounts for 40 percent of the world harvest.[39]

As yields continue to rise, more and more countries will edge ever closer to their glass ceilings. At the same time, the earth's rising temperature is making it more difficult to sustain a steady rise in grain yields. Unfortunately, these are not the only emerging constraints on efforts to expand food production.

Data, endnotes, and additional resources can be found at Earth Policy Institute, www.earth-policy.org.