Can Grain Yields Keep Pace?

Stiff challenges face today's breeders—and tomorrow's farmers

By JANET RALOFF

CIMMYT

Field of ordinary wheat. Inset shows an ordinary wheat plant (left) and a high-yield Buitre strain (right), still under development.

Modern agriculture constitutes nothing less than a miracle. In the United States, for instance, harvests have more than doubled over the past half century, even as the area under cultivation has held steady at about 300 million acres and the number of farmers has fallen from 6.2 million to 2.2 million.

With the world's population growing by about 2 percent annually, there are 80 million more mouths to feed each year. Just three crops—rice, wheat, and corn—provide 49 percent of the calories that people consume.

Only through increasingly intensive farming like that in the U.S. breadbasket has global agriculture been able to satisfy the world's appetite for farm products, contends Dennis T. Avery, director of the Hudson Institute's Center for Global Food Issues in Churchville, Va. Moreover, he and others point out, this intensification has allowed many fragile wildlands—from rain forests to deserts—to escape the plow.

The most spectacular cereal gains have come from corn, or maize, farming. "In 1940, my father considered 30 bushels an acre a good yield," recalls Vernon W. Ruttan, an agricultural economist at the University of Minnesota in St. Paul. "Now, it's 130 or 140 bushels." Since 1940, he points out, "corn yields have been going up 2 bushels [per acre] per year."

For rice, the steady increases started a little later and have been a little less dramatic. Since 1960, new cultivars released by the International Rice Research Institute (IRRI) in Manila, Republic of the Philippines, have achieved an average annual increase of 75 kilograms per hectare (66 pounds per acre)—gains of about 1 percent per year, notes Gurdev S. Khush, IRRI's head breeder.

The world's wheat harvests have also been climbing in recent decades, thanks to new varieties (SN: 10/5/96, p. 218) developed at the International Maize and Wheat Improvement Center (CIMMYT) 45 kilometers from Mexico City.

In many of the world's breadbaskets, however, increases in the yield of the three primary grains have slowed or even reached a plateau, observes Lester R. Brown, an agricultural economist and president of the Worldwatch Institute in Washington, D.C. For instance, neither the United States nor Mexico has seen any improvement in wheat yields for 13 years, he says. In Canada and Egypt, yields began stagnating in 1990.

"For individual grains in individual countries, the historic trends show a sobering pattern," Brown argues in the July-August WORLD WATCH. "In every farming environment where yields are increased substantially, there comes a time when the increase slows and either levels off or shows signs of doing so."

Brown's new analysis finds that even after excluding the former Soviet Union, whose recent declining yields owe as much to political instability and economic crises as to agronomic limits, he says, global gains for the first half of this decade have hovered around 1.1 percent per year. This is roughly half the rate at which the population is increasing and raises the obvious question, Brown maintains, of "whether the momentum [in yield increases] can be regained."

Personally, he's doubtful. Access to water has clearly developed into a major constraint on yield in many large areas of the world, he says—including parts of Africa, Australia, China, and the former Soviet Union. In addition, he worries that plant breeders may already "have largely exploited the untapped genetic potential" for increasing the share of energy that a plant diverts into making seed, or grain.

Many others find a stagnation in agricultural research investments at least as worrisome. Unless the rate of funding increases, they contend, the development of important new technologies may languish, causing grain yields to trail even further behind the planet's growing demand for food.

Global cereal trends fuel these concerns. Rice yields, which climbed 2.1 percent annually from 1960 through the 1980s, have slowed to just half that rate since 1990, Brown observes. Wheat yields, which rose an average of 2.6 percent yearly from 1960 to 1990, have increased just 0.1 percent during this decade. The 2.6 percent global rise in corn yields from 1950 through the 1970s fell to half that rate in the 1980s. It has since rebounded to 1.7 percent—largely, Brown says, because of belated yield surges in China and Brazil.

The overall slowdown in gains reflects a leveling off of yields in some of the major

cereal-producing countries, observes Agriculture Department agronomist Thomas R. Sinclair of the South Atlantic Area Crop Genetics and Environmental Research Unit in Gainesville, Fla. For instance, Japan's rice yields peaked at 4.7 metric tons per hectare in 1984 (1 metric ton per hectare equals 907 pounds per acre). That same year, the United Kingdom's wheat yields peaked at about 7.5 metric tons per hectare. Average U.S. corn yields have not risen much above 7.5 metric tons per hectare.

"There is no evidence of a dramatic change in the global environment that would have stabilized crop yields," Sinclair notes. In an article slated for publication later this year, he concludes, like Brown, that resource limitations may be constraining harvests to levels well below those theoretically possible.

To probe what's possible, Sinclair scoured harvest data for what he terms the "Mount Everests" of cereal yields. He turned up maize achieving 17.3 metric tons per hectare in 1982 at a site in Grand Junction, Colo., and rice reaching 15.2 metric tons per hectare in 1978 in Xiangride, China. Both records occurred in cool, high-elevation regions with exceptionally long growing seasons and virtually cloudless skies—impossible conditions for most farmers.

Over the past few years, Sinclair has homed in on factors that appear to limit yields in deep, rich soils in the heart of the U.S. Corn Belt. Focusing on harvests in Champaign County, Ill.—where maize yields have held steady at or below 7.5 tons per hectare since 1986—he and Russell C. Muchow of the CSIRO Cunningham Laboratory in Brisbane, Australia, correlated corn yields with soil moisture and concluded that from 1965 to 1988, most of the variation in yields there traced to the availability of water.

Sinclair also found data suggesting that even though farmers in industrialized countries could boost crop yields by applying more fertilizer, many have reached a point where the cost of doing so outweighs the value of the harvestable bonus. These nitrogen-linked yield plateaus "seem to be something entirely new," he says. For the first time, growers appear willing to make an economic trade-off and accept less than optimal yields.

Brown interprets such data as an indication that growers may be hitting a limit on what a cereal's genetics will allow it to do in the farm environment. As such, he worries about whether yields will ever resume a robust climb.

Most breeders are more sanguine, though far from complacent.

Khush, for instance, remains cautiously optimistic about prospects for rice, a cereal that provides 23 percent of the global population's calories. For 7 years, his team has been hard at work developing a new crop—popularly known as superrice—for irrigated plots, which produce about 90 percent of the world's rice.

Scheduled for commercial release around 2001, superrice sports a new architecture, one that diverts a greater share of the plant's carbohydrates into grain and a lesser share to stems and leaves. IRRI has inserted genes into the plant to confer resistance to several diseases and insect pests. Khush says that the resulting crop should offer yields at least 20 percent higher than today's.

Like IRRI, CIMMYT is working to alter the architecture of plants. New wheat varieties that set larger grain-producing heads should improve harvests. However, CIMMYT breeders expect the biggest gains from their exploitation of heterosis, or hybrid vigor, in the initial progeny of crossbred plants.

Yield-boosting heterosis declines by a few percent with each succeeding generation of plants, notes Sanjaya Rajaram, director of the center's wheat programs. Because today's farmer buys seeds that are the 7th to 10th generation of a hybridization, he says, any hybrid vigor is long gone.

His team is working to offer farmers affordable first-generation seeds—akin to hybrid corn. The key to making this possible, he believes, is a chemical treatment that sterilizes the male parts of plants, preventing self-pollination and thus allowing inexpensive production of a first generation of hybrids.

"We have already measured the hybrid vigor in these plants, so we know we can increase yields by 20 percent," Rajaram told SCIENCE NEWS. However, he notes, "we do not yet have the techniques to make it commercial."

Most crop analysts concede that the availability of water is a big and growing obstacle to improved yields. In most cases, however, there is sufficient water to grow plants, it's just managed ineffectively, Rajaram observes. Avery agrees, pointing out that reinvigorating wheat yields may require irrigating more of the fields—"however, not with flood irrigation that's 30 percent efficient." He points out that currently available technology can use water three times as efficiently.

Two organizations, the International Center for Agricultural Research in Dry Areas and the International Crops Research Institute for the Semi-Arid Tropics, headquartered in Syria and India, respectively, are working to develop low-cost water conservation and other technologies to raise the productivity of parched farmlands. An estimated 1.6 billion people—many of them among the poorest on Earth—live in such areas.

Development of new cultivars of popular cereals, especially plants with much shorter growing seasons, ranks high on the agenda of these centers. Such crops would permit farmers to bring in harvests before annual droughts take hold or to reap two harvests in what had been a single growing season.

Rajaram points to another promising program at CIMMYT: a worldwide epidemiology service to evaluate local or regional disease and pest problems—and their potential for spreading. "We'd like, for instance, to know what's happening in Ethiopia so we can forewarn the farmer and government agency in Kenya, and vice versa," he says.

Though this type of forecasting has sometimes been employed on a local or district level, to date it hasn't been enlisted to scout for problems that cross national borders or threaten an entire continent, Rajaram says. To develop this program effectively, he says, CIMMYT will need more money than its $15 million wheat budget can spare. As it is, "our budget has declined in real terms—by perhaps 30 percent since 1990."

IRRI, CIMMYT, and the two research centers specializing in arid regions are part of the Consultative Group on International Agricultural Research (CGIAR)—16 institutions with a combined budget of about $320 million annually. Economic rates of return to donor nations for their investments in these centers "have consistently run at 30 to 40 percent per year, with no tendency to fall," notes Pierre Crosson, a natural resource economist with Resources for the Future in Washington, D.C.

Yet CGIAR funding has not grown since 1991. Indeed, Khush notes that IRRI's $33 million budget for this year is $5 million smaller than last year's. If this trend continues at CGIAR centers, Crosson says, "achievement of an agricultural production system that can sustainably meet rising global food demand over the next several decades becomes increasingly problematical."

Adds Ruttan, developing new cultivars isn't enough. To keep yield rates growing, there must be cadres of researchers within the crop-raising countries to fine-tune breeds for local conditions. In many politically unstable regions, he says, such a local research capacity no longer exists.

Clearly, cereal breeders and farmers have their work cut out for them. However, Khush believes, "if we manage our resources properly and continue to put money into research, we should be able to meet world food needs for at least the next 30 years."

Indeed, agronomist Paul E. Waggoner of the Connecticut Agricultural Experiment Station in New Haven believes that if "we simply do a respectable job" of husbanding agricultural resources, "we should be able to continue feeding the world on our present acreage or something close to that." □