The New Green Revolution

Plant scientists are tailoring crops to conditions and combining the best features of two species

by John H. Douglas

Another in a series of articles on the renewed threat of famine and what can be done to prevent it.

The Green Revolution really began around 8000 B.C., when nature did a bit of genetic engineering to produce what we now call bread wheat. Wild wheat, at the time, was an emaciated, tight-husked grain harvested together with other grasses by tribes in the Fertile Crescent of the Middle East. By accidental cross-pollination, the wild wheat apparently formed a hybrid with a type of "goat grass," which immediately caught the eye of the harvesters because of its plumper grains. Eventually this new plant, called Emmer, again crossed with a goat grass to form an even more luxuriant hybrid whose continued existence depended on man, because its husk was so loose that the whole grain would not scatter to the wind as other grass seeds do when they propagate.

Thus bread wheat was created, and with it came a primitive agriculture, based on the elementary techniques of threshing the grain to separate husks from kernels and scattering some of the kernels by hand to assure another crop. Some anthropologists cite the rudimentary experimentation that must have accompanied this process as the first origins of science.

Though agriculture may have been the first science, almost 10 millenia had to pass before its practitioners could duplicate the feat of crossing two dissimilar plant species to produce an improved, fertile hybrid. Discovery of the techniques necessary to accomplish such "broad crossing," together with increasing sophistication of conventional plant breeding methods, promises to form the basis of a new Green Revolution.

Usually the Green Revolution is dated from the mid-1940's when Norman E. Borlaug and others began the tedious work of selecting and breeding wheat, corn and rice to produce higher crop yields, better resistance to disease and pests, and in some cases, improved nutritional content. Within a few years food production was growing faster than population. Under optimum conditions, an acre of wheat could yield 10 times more grain than previously. Even countries like India and Pakistan doubled their wheat production, and the Philippines became self-sufficient in rice.

But the new crops also had their problems. Some were particularly susceptible to disease. More fertilizer and mechanization were needed: During the quarter century in which corn yields in the United States rose 240 percent, the energy required to produce them rose 310 percent. Now, when energy supplies have become more costly, and fertilizer almost unavailable in some developing countries, the cry has arisen that the Green Revolution was just a sham, an excuse to export American technology without regard to possible consequences. And what, ask other critics, was actually gained? Population has grown apace so that now tens of millions of people depend on the new crops. They will die if drought and lack of energy combine to cause a famine (SN: 5/11/74, p. 306).

Borlaug replies that the first Green Revolution merely "bought time" in which to solve the problems of economic imbalance and burgeoning population. That time, he concludes, has now been largely wasted. Only full cooperation among the industrialized nations, he told Science News, can prevent chaos in world food supplies. "The stage is set for real trouble."

Part of that effort includes expanded agricultural research to overcome some of the weaknesses of the original Green Revolution plant strains and to apply newly discovered techniques toward the production of even more versatile and productive kinds of crops. Already the international, foundation-sponsored research centers are incorporating drought and disease resistance into their high-yield varieties of wheat and rice, national laboratories are adapting the crops to local conditions, and the best characteristics of diverse plants are being combined through broad crossing.

At the International Rice Research Institute (IRRI) in the Philippines, a new strain of rice called "IR-26" has been produced. It is resistant to five major insect, disease and soil-condition problems and moderately resistant to eight others—by far the best record of any strain ever produced. The new variety also seems the most resistant of any to drought, an ability especially important to upland rice farmers, who are among the poorest in the world. To help farmers in lowland areas plagued by frequent floods, institute scientists are experimenting with "floating rice," plants that will grow up to 15 feet tall so that their tops will remain above water.

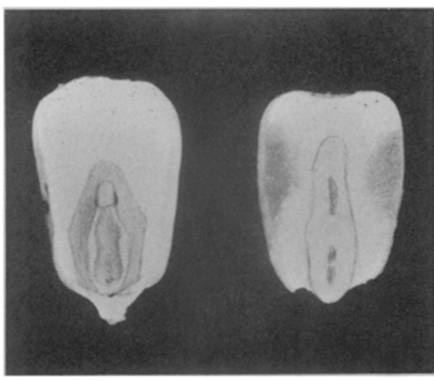
Since one third of the world's people depend on rice for over half their entire food intake, one of the great challenges for the future is to increase the protein content of this staple. (Rice is particularly lacking in the amino acids lysine and tryptophan.) At IRRI, some strains have been developed that are as much as 40 percent higher in their protein content than others. But plant breeders are still faced with a dilemma. For any given strain, varying environmental conditions to increase protein content, beyond a given point, simultaneously decreases the total grain yield.

In some cases, the major problem with a new crop strain has been its lack of acceptability in a particular culture. Changes made in wheat and rice did not greatly affect the taste or appearance of the resulting grain, but when corn was bred to increase its protein content, the resulting kernels were white and opaque rather than yellow and translucent. The new variety, called "opaque-2" had a lysine content more than half again as large as regular corn, and because the body's utilization of other amino acids depends on the presence of lysine, the effective protein content of the corn was as much as doubled for peasants who use the grain as a staple.

But they didn't like it. The kernels had a soft texture that produced a fine flour when ground so that traditional corn breads did not turn out right. Also, the low density of the kernels caused harvested crops to weigh less by as much as 10 percent. Rather than change their cooking habits, most people rejected the new hybrid, which is now grown only in three limited areas and used largely for hog feed. The International Wheat and Maize Center (CIMMYT) of Mexico has now undertaken the task of producing a further modification of opaque-2 that will still possess a good amino acid balance but taste and appear more acceptable for human users.

The scarcity of fertilizer and its rapidly increasing price have stimulated attempts to extend and improve the self-fertilizing ability of some plants. The

Borlaug: Stage set for "real trouble."



Opaque-2 and regular corn (right).

Cross-breeding rice in Philippines.

process can proceed in two ways. In legumes, *Rhizobium* bacteria infect the plant's roots, sending threads into special cells whose growth is seen as the characteristic nodules along the roots of soybeans and similar plants. Here the bacteria form nitrogenase, an enzyme that catalyzes the "fixing" reaction that incorporates atmospheric nitrogen into compounds the plant can use. In some "tropical grasses" (a generic term covering such plants as sugar cane) "free living" bacteria such as *Klebsiella* and *Azotobacter* thrive in the soil environment around a plant's root system, and fix nitrogen there. Research now centers on how to optimize these naturally occurring processes and how to extend this symbiotic relationship between plants and bacteria to crops that lack the ability to support it.

Legumes have long frustrated plant scientists. They do not respond well to fertilizer and can grow only in temperate climates. Two schools of thought have arisen on how best to proceed. One maintains that research should concentrate on how the bacteria make nitrogenase. Scientists of this view argue that adding fertilizer to the soil doesn't work because this just shuts off the production of nitrogenase by the bacteria, and the legume takes up the artificial fertilizer rather than the nitrogen compounds made in its own root system.

The other school of thought contends that the real problem is a wasteful chemical reaction that takes place in legumes (as well as other plants). The reaction is called "photorespiration." Waste occurs because the reaction can either use a carbon atom to make useful carbohydrates or it can take an oxygen atom and produce nothing at all useful—while wasting energy, time and another carbon atom. If photorespiration could be controlled, this school argues, one would find there is no reason to worry about nitrogenase production, in order to get higher yields. These scientists have illustrated their point by raising soybeans in an artificial atmosphere rich in carbon dioxide and poor in oxygen, to minimize the effect of photorespiration. The result, they report, was a doubling of the bean crop.

Tropical grasses do not have photorespiration. Their distinctive method of photosynthesis allows them to use as much sunlight as they can get, unlike most plants, whose photosynthesis mechanism can accept only just so much sunlight before it saturates.

As new croplands are opened up in the tropics, agriculturists are taking a second look at tropical grasses and seeking ways to stimulate the growth of the nitrogen fixing bacteria that inhabit their root systems. Little is known about this loose type of "associated symbiosis," but it appears that the root environment is an ideal niche for the growth of the bacteria. Some scientists talk of breeding plants for their ability to optimize this environment, others have tried to improve it artificially. At IRRI, for example, sprinkling some phosphorus or potassium over a rice paddy increased nitrogen fixation by bacteria so much that further artificial fertilization was not necessary.

Agricultural geneticists, however, have an even bigger dream—the transfer of this nitrogen-fixing ability to new crops through broad crossing. Within members of the same species, cross fertilization is not difficult (though the physical work involved is exceptionally tedious). The pollen-producing anthers of a flower are clipped off and pollen from the flower of another plant is dusted on the first flower's pistil, or seed-producing part. When this procedure is tried between flowers of different species, however, usually nothing happens. Several new procedures promise ways of overcoming this difficulty.

First, the mechanism that prevents genetic material from the pollen of one plant from being accepted into the ova of another plant appears to have some similarities to the immunological response by which the human body rejects a transplanted organ. Following up on this idea, some scientists have successfully used drugs similar to those that repress the human immune response to allow cross-fertilization between different species. By tediously nurturing the resulting embryo and chemically causing its chromosomes to duplicate themselves, they have succeeded in producing fertile plants bearing the characteristics of both parents. One of these, *Triticale*, was produced in Mexico at CIMMYT by crossing wheat with rye, gaining the high yield of the former and the disease and drought resistance of the latter.

Another technique, not yet perfected, involves taking individual cells of two plants, stripping off the outer wall of cellulose and then fusing the two resulting "protoplasts." The genetic material of the two cells mix, and by careful manipulation with hormones, a new plant can be persuaded to grow. Using this technique, Peter S. Carlson of Michigan State University has succeeded in producing a fertile tobacco hybrid with the desirable characteristics of both parents. Protoplast fusion has also been successfully accomplished between soybean and barley plants, but Carlson says the technology to bring such a broadly crossed hybrid to maturity does not yet exist.

Scientific research and the development of new plant strains will not be sufficient to feed the starving world, as the limited success of the first Green Revolution demonstrated. Better crops require better handling, including fertilization, irrigation and storage. The transportation and marketing systems of most developing countries are not equal to the task of distributing increasing yields to an increasing population. These problems, together with the potential of applying the genetic manipulation techniques of the Green Revolution to livestock, will be reported in forthcoming articles. □