The Southern Corn Leaf Blight Epidemic

A new race of the fungus *Helminthosporium maydis* threatens domestic prices and corn reserves for export.

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The southern corn leaf blight, a disease caused by *Helminthosporium maydis* Nisikado & Miyake, has been in the news recently because of its impact on corn growers, the commodities market, and other activities dependent on grain. It has important implications for agricultural science, especially for plant breeding and plant pathology, and for the dependability of food production.

Magnitude of the Problem

The December 1970 estimate of the U.S. corn crop was 4.11 billion bushels, a reduction of 710 million bushels below the July estimate (*1*). At current market prices of about $1.50 per bushel the loss amounts to approximately a billion dollars, attributable primarily to a new race of the fungus that is highly virulent on corn with T-type cytoplasm, which is extensively used in hybrid seed production. The most direct effects, of course, are on the many individual farmers whose corn crop was damaged and on the communities and regions where losses were especially heavy. As the blight was developing in July and August the commodities market reacted strongly. Although our grain stocks are substantial and are thought to be adequate for almost any contingency, losses of the magnitude being experienced are expected to reduce reserves critically. Corn carried over from previous crops totaled about 999 million bushels. The 1970 corn crop has been estimated to fall about 800 million short of the amount of consumption anticipated before the blight struck and the price rose. Higher corn prices are expected to attract reserve stocks of sorghum, barley, oats, and wheat to help make up the feed deficit. The export market has been uneasy about the 600 million bushels of corn that had been anticipated for that outlet. Such estimates are tentative but serve to emphasize the point that normal reserves are not large in relation to the hazards of weather and pests. Shortages can have an important impact on domestic food prices and on exports.

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Implications for High-Yield Grain Programs

Much concern has been expressed in recent years regarding the problem of food production and prospects of avoiding large-scale famine in the years ahead. Increases in production associated with new grain varieties and improved cultural practices have been termed a "Green Revolution." The benefits and hope afforded by these developments are significant, but we should not lose sight of inherent hazards. Some of the so-called second-generation problems in the social and economic area have been alluded to frequently. Those closely associated with the developments are aware of the threat posed by crop pests which may mutate or evolve to forms that are virulent against previously resistant varieties. The corn blight epidemic is a dramatic demonstration that gains in crop production, especially from high-yield varieties, may be short-lived unless supported by constant alertness and an aggressive research program. The lesson really is not a new one for we have observed many times the "running out" of varieties, often abruptly, as a new biotype of a pathogen or insect pest became prevalent. Changes in the pathogen population sometimes make new varieties susceptible and obsolete even before seed multiplication is completed. In other instances a virulent form of a pathogen is present in the population in trace amounts for several years but is detected only occasionally. Such was the case with race 15B of wheat stem rust which was found with low frequency in surveys in the United States for a period of 11 years before it accumulated the genetic traits enabling it to multiply and become a major component of the population (*2*). We recall that race 15B destroyed 65 percent of the durum wheat crop in 1953; 75 percent of it in 1954; and 25 percent of the bread wheat in the United States in those years. The present corn leaf blight situation in many respects is reminiscent of that story on wheat.

In nature an uneasy equilibrium exists among the many biotypes or strains of a pathogen. The frequency of the individual components within the pathogen population depends on the genotype of the host crop and on the virulence and reproductive rates of the individual components. When a new crop variety is introduced, diseases to which it is resistant are suppressed—those to which it is susceptible will thrive and multiply. Likewise, as variants of the pathogen arise by mutation or other genetic means, those that encounter a susceptible host increase whereas those that are not virulent on the prevalent host plants do not survive, or else persist in limited numbers. These evolutionary processes mean that a new crop variety resistant to a particular strain of a disease inevitably will become susceptible. If a new variety has substantial agronomic or horticultural merit it is likely to occupy a large proportion of the acreage of the crop. This favors rapid buildup of a biotype virulent on the new variety and provides a situation conducive to a severe epidemic.

Protecting the Crops

The evolution of crop pests and deterioration of crop varieties have been observed many times. Agricultural scientists are aware that genetic homogeneity in a crop means vulnerability to pests. Breeding programs attempt to have a flow of superior new varieties so that no single genotype predominates, and so that a substitute will be available when an old variety becomes susceptible. A helpful procedure in developing resistant varieties is having an extensive network of cooperative experiments and exchange of information among nations. Breeders thus become aware of new forms of virulence in the population of a pathogen and of sources of resistance before the virulent strain is present in their country. Breeding selections are tested for resistance by sending them to the virulent pathogen. By this means, development of resistant varieties can be well on the way by the time the new form of virulence evolves or is introduced. It would not be safe, of course, to bring an exotic form of virulence into the country to identify sources of resistance. These procedures are helpful, as illustrated with rusts of small grains (*3*), but obviously they represent only a single approach toward pest control. My objective is not to describe in detail what an adequate research program would consist of but to emphasize the vulnerability to pests of our major crops.

Corn usually has been considered to be less vulnerable to diseases than such crops as wheat and oats. This is as expected because corn is cross-pollinated with much genetic heterozygosity and heterogeneity, and thus not uniformly susceptible to any strain of a disease. The development of hybrid corn greatly altered the situation as open-pollinated varieties were replaced by uniform hybrids and the overall genetic structure of our corn crop was radically altered. With this shift came greater resistance to many diseases as selection for resistance was more effectively practiced. Loss of buffering against pests is part of the price paid for narrowing the germ plasm base and achieving greater uniformity of the crop. An early demonstration of the possible consequences was the northern corn leaf blight *Helminthosporium turcicum* Pass. epidemic in the north central states in the late 1940's and subsequent years until resistant lines were put into production. More recently the corn stunt and maize dwarf mosaic groups of viruses have come into prominence. As current reminders we have southern corn leaf blight and yellow corn blight. In terms of the genetics of host-parasite interactions the corn crop, as it has become modernized, has taken on some of the characteristics of small grains such as wheat and their historic vulnerability to rusts.

History of Southern Corn Leaf Blight

Southern corn leaf blight underwent a dramatic transformation from a disease of quite minor status to one of almost catastrophic dimensions in a single season. It was grouped with other leaf blights caused by *Helminthosporium*, which were responsible for an average aggregate loss of about 2.3 percent (*4*). The hybrids at that time were relatively resistant to the races of the pathogen prevalent in the United States.

In 1961, Mercado and Lantican (*5*) reported susceptibility of lines with "T" cytoplasmic male sterility. Villareal and Lantican (*6*) confirmed the earlier observations and presented conclusive evidence of the association of extreme susceptibility to *Helminthosporium maydis* of corn with T cytoplasm. The few people in the United States who may have been aware of the Philippine experience evidently did not recognize its significance to the U.S. corn crop.

The loss in 1968 of 200,000 pounds of seed, because of ear rot incited by *Helminthosporium maydis*, is now presumed to have been caused by the new race (*7*). In 1969, greater-than-normal susceptibility to *Helminthosporium maydis* was noted (*8*) in seed fields and in hybrid test fields. An association between susceptibility and the presence of T cytoplasm was observed. Hooker *et al.* (*9*) made similar observations in the field and conducted greenhouse trials during the winter with inoculum collected in September 1969 from heavily blighted fields. The specific association of extreme susceptibility with the presence of T cytoplasm was confirmed. During the 1969–70 winter season in Florida several seedsmen observed the extreme susceptibility of corn with T cytoplasm to *Helminthosporium maydis.*

The 1970 Epidemic

During the spring and summer of 1970 the disease moved into the main crop of Florida, Georgia, Alabama, and Mississippi. In June the situation was recognized as a serious epidemic of *Helminthosporium maydis* specifically virulent on corn with T cytoplasm. Losses of 50 percent or more were common in fields throughout the Gulf region. The potential magnitude and seriousness became evident when it was realized that probably considerably more than 80 percent of the U.S. corn crop was highly susceptible. The weather pattern that developed was favorable to movement of spores from the Gulf states up into Kentucky, Ohio, Indiana, Illinois, and other midwestern states where infections became widespread during July. During August there were reports of secondary spread and intensification and movement into Wisconsin, Minnesota, and Canada.

Anxiety developed along several lines. Would the supply of corn be adequate for domestic feed and processing needs? What about the 600 million bushels needed for export? Is a similar or even more severe epidemic likely in 1971 and subsequent years? What can be done to control the disease this year and in future years? If genetic resistance can be found how long will be required to breed it into productive hybrids and increase the seed for planting? Will there be enough seed for planting in 1971, and what proportion of it will be of resistant types? At the same time these and other questions were being asked, rumors began to circulate that the 1970 plants and grain were highly toxic to animals and men. Fortunately some of the states in which the epidemic developed early promptly initiated feeding trials with farm and laboratory animals. These showed clearly that fears of acute toxicity were groundless but left a few lingering doubts about longer range effects and the problem of possible invasion of the grain by secondary organisms which might be toxin producers. Impact of the disease and associated costs are far-reaching. Farmers whose primary enterprise is corn growing are especially hard hit by the high losses sustained. Seedsmen with large investments in production for 1971 planting may find that blight has destroyed viability of the seed, or that there is no market for a large part of the production involving T cytoplasm. Livestock feeders with an inventory of animals may have problems obtaining grain, or at least will pay higher-than-normal prices. Consumers of meat and other products derived directly and indirectly from corn will pay higher prices. Secondary effects will extend to such things as the barley seed business in England where, due to rising prices for feed grains, seedsmen find themselves in a squeeze between the prices at which they can obtain seed from farmers and the prices at which they had contracted to furnish seed for the coming planting season.

Outlook for 1971

The crisis should be relatively short-lived because plant pathologists and geneticists have already provided a considerable body of related information and breeding stocks and because of the high technical competence in the U.S. seed industry. Seedsmen have been quick to understand the nature of the problem and have responded vigorously. On the strength of the previously recognized association between T cytoplasm and the less serious yellow leaf blight (*10*), some 1970 seed production had been shifted to corn with other than T cytoplasm and to manual detasseling. Seed thus produced will be resistant also to the T race of southern corn leaf blight and will help alleviate the shortage of resistant seed for 1971 planting. Winter plantings are being grown to increase stocks of resistant parent seed for 1971 seed fields and also, to some extent, to produce resistant seed for general farm use. In some areas of very high probability of an epidemic in 1971, there will be an acute shortage of resistant seed. Some growers will resort to using advanced generation seed despite the known loss of hybrid vigor. The 20 to 30 percent loss of yield from this source will be preferable to the high risk of much larger losses from growing susceptible hybrids. Some farmers will switch to alternative crops such as grain sorghum or soybeans. Almost all of the seed produced in 1971 is expected to be without use of the male sterility and T cytoplasm, so the T race of *Helminthosporium maydis* is not expected to be a serious threat to the 1972 crop. There will remain the danger that still another race of *Helminthosporium maydis* may appear or that one of the other corn diseases will become critical. Manual detasseling will increase the labor requirement and seed cost but the additional cost will be slight relative to the added value of resistant seed.

Longer-Range Considerations

The benefits of using male sterility rather than detasseling in hybrid seed production are substantial. At least as important as the cost of labor required are the problems of recruiting dependable crews for a very seasonal operation. Bad weather sometimes so interferes with the detasseling operation that some pollen is shed by the seed parent resulting in a corresponding amount of inbreeding and reduced yield potential of the seed. Intensive study during the 1970 epidemic has identified several strains of corn that confer resistance to the T race of *Helminthosporium maydis* even in the presence of T cytoplasm. The genes responsible presumably can be bred into the parents of superior hybrids by appropriate crossing and backcrossing but the process will require at least 3 or 4 years. Another possibility would be to use one of the other 25 or 30 known cytoplasms that induce male sterility. The effectiveness of most of these is distinctly inferior to the T type for prevention of pollen production in seed parents and as to reliability of fertility restoration regulated by genes from pollen parents. Either restoration of male fertility or blending with nonsterile seed is necessary to assure pollen production and, subsequently, pollination and seed set in the farmers' fields. If one of the cytoplasms now being tested appears to be satisfactory, it will take several years to substitute parental genomes through backcrossing before hybrids can be made. The U.S. Agricultural Research Service and the state agricultural experiment stations are cooperating in evaluating the alternative sources of germ plasm. Promising materials and information are supplied promptly to the seed industry for incorporation into commercial hybrids. The full cooperation of all interests is contributing to minimizing losses to the blight and shortening the duration of the crisis.

Now that it is known that susceptibility to yellow corn leaf blight (*Phyllosticta* sp.) and to southern corn leaf blight are inherited through the cytoplasm, much more consideration will be given to the cytoplasm as the vehicle for inheritance of important characters. There has been a consciousness of the hazards associated with a narrow germ plasm base in a crop. That concept will have to be extended to include the cytoplasm as well as the chromosomes. It seems unlikely that in the future there will be such widespread reliance on a particular cytoplasm. In addition to diversification of cytoplasms, a considerable amount of seed may be produced by detasseling. Other genetic mechanisms of producing male sterile plants are also likely to be studied more intensively in the search for a long-range solution. Apomixis, a nonsexual mechanism of reproduction, has never been reported in corn but has been found in several grass species including sorghum (*11*). A more efficient screening mechanism and a more thorough search for apomixis seem justified.

Cytoplasmically controlled male sterility is used in producing seed of several crops in addition to corn. Among these are grain sorghum and sugar beets. Programs for its use in wheat are well along. The experience with southern corn leaf blight emphasizes that the hazards of growing the same genotype of a crop on extensive acreage applies to characters inherited through the cytoplasm as well as to those inherited through the nucleus. The appearance of two important diseases of corn, for which susceptibility resides in a particular type of cytoplasm, dramatically emphasizes our need of knowledge of cytoplasmic genetics, and especially its role in host-parasite interactions.

Summary

A dramatic shift in the genetics of host-parasite interaction and balance occurred in the U.S. corn crop in the 1970 growing season. Southern corn leaf blight incited by *Helminthosporium maydis* Nisikado & Miyake evolved from a minor disease that causes an average annual loss of less than 1 percent, to one that caused more than the 12 percent average expected from all diseases of corn in the United States. In 1970 the losses to corn leaf blight approaches 710 million bushels. Reserves of corn and other grains ease the impact on the economy and food supplies but there are important domestic and foreign effects of the loss. The epidemic illustrates the vulnerability of our food crops to pests. Sources of genetic resistance to the new race of *Helminthosporium maydis* are available. The seed industry estimates that for 1971 enough resistant and partially resistant seed to plant about one-half of the crop may be available. Adequate supplies are ex-

pected in 1972. Sustained research programs are essential in protecting our food supplies from potential losses of catastrophe magnitude.

Several professional groups, including the American Phytopathological Society and the Entomological Society of America, have urged that a program and facilities be established for the study of exotic pests that threaten our agriculture so that controls may be found before the pests are here. Such a program would be desirable but covers only one aspect of the problem. What is really needed is an overall strengthening of research on crop pests.

References and Notes

1. Anonymous, *Crop Production* [U.S. Department of Agriculture, Statistical Reporting Service, CrPr 2-2 (12-70) (1970)].
2. Anonymous, *Race 15B Stem Rust of Wheat* [U.S. Department of Agriculture, Agricultural Research Service (ARS 22-10) (1954)].
3. W. Q. Loegering and N. E. Borlaug, *Contribution of International Spring Wheat Rust Nursery to Human Progress and International Good Will* [U.S. Department of Agriculture, Agricultural Research Service (ARS 34-46) (1963)].
4. *U.S. Department of Agriculture Handbook No. 291* (1965).
5. A. C. Mercado, Jr., and R. M. Lantican, *Philippine Agr.* **45**, 235 (1961).
6. R. L. Villareal and R. M. Lantican, *ibid.* **49**, 294 (1965).
7. A. J. Ullstrup, "Cytoplasmic male sterility and susceptibility to diseases in corn," in the minutes of the meeting of the North Central Corn Breeding Research Committee (CR-35-70).
8. G. L. Scheifele, W. Whitehead, C. Rowe, *Plant Dis. Rep.* **54**, 501 (1970).
9. A. L. Hooker *et al.*, *ibid.*, p. 708.
10. G. L. Scheifele, R. R. Nelson, C. Koons, *ibid.* **53**, 656 (1969); J. E. Ayers, R. R. Nelson, C. Koons, G. L. Scheifele, *ibid.* **54**, 277 (1970); D. C. Arny, G. L. Worf, R. W. Ahrens, M. F. Lindsey, *ibid.*, p. 281.
11. W. W. Hanna, K. F. Schertz, E. C. Bashaw, *Science* **170**, 338 (1970).

Bone Marrow Transplantation

Research in marrow grafting has generated extensive new information for the hematologist.

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The diseases acquired by man and animals during postnatal life are frequently irreversible and sometimes lead to total destruction of organs and organ systems. Because a size-function relationship exists for biological structures, an essential organ (for example, the bone marrow) can be reduced by disease to such a point that its level of function will no longer support life, and death occurs. Inadequate development of an organ, brought about by congenital disease, can have a similar effect, with death occurring when a critical level in the size-function relationship is reached. An example of this is the category of birth defects known as immune deficiency disorders. These are characterized by a failure to develop adequate amounts of lymphatic tissue, the structure that is essential for the immune response that helps prevent viruses and other microorganisms from invading and destroying vertebrate organisms.

It is primarily because of these organismal disasters that the transplantation of bone marrow represents an exciting chapter in the history of biomedical investigations on organ grafting for the treatment of pathological processes. However, the seemingly miraculous things done with organ grafting in very healthy, expendable laboratory animals lead us to imagine that such techniques will soon be applicable in the relief of some human disease. The history of progress in clinical organ transplantation shows that this mode of therapy is slow and difficult, with occasional brillant successes against a background of many futile attempts to do something for desperately ill patients (*1*).

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Technique of Bone Marrow Transplantation

Bone marrow and its ancillary lymphatic tissues are usually procured and transplanted in ways quite different from those used in other organ transplants. Needles and syringes are used to aspirate the normal red bone marrow from the cavities inside bones. Suspensions of the living cells are then made in an appropriate vehicle, so that the cells can be injected directly into the bloodstream of the recipient. Once inside the blood, the stem cells of the marrow lodge in the recipient's bones in the spaces that normally contain red marrow; there they grow and replace the destroyed organ.

This procedure is not as artificial as it seems, because the stem cells of bone marrow normally circulate in small numbers in the blood of mammals. They are present along with the other blood cells that were originally produced by division and differentiation of stem cells of the same type as those residing in the marrow (*2*). A schematic representation of these patterns is given in Fig. 1. Small numbers of bone marrow stem cells are also found among the free cells in the peritoneal cavity (*3*), and larger numbers occur in the spleen red pulp and the fetal liver in mice.

A major achievement in bone marrow transplantation and related areas of research has been a new understanding of the complicated patterns of cell migration through the bone marrow, peripheral blood, lymphatic tissues, and thymus. This field of investigation, which some of us call experimental hematology, is now a major activity of many laboratories throughout the world.

Recent advances in experimental hematology which exploit knowledge gained in marrow and lymphatic tissue transplantation in laboratory animals are reported in *Experimental Hematology* and in many other publications (*4*). Much of the material in *Experimental Hematology* deals with new directions in hematology that were not anticipated when marrow grafting was first used as therapy for radiation injury. The review by Petrov and Zaretskaya (*5*) is an extensive account of experimental hematology.