which thermal equilibration is a function of altitude among neutral atoms and molecules, ions, and electrons is one of the important areas of ionospheric geophysics in which no direct experimental measurements are as yet available.

A third direction is the "calibration" of less direct but ground-based measurements, which accumulate statistically large quantities of not-always-clear data. For example, movements within ionospheric layers are inferred from ground-based radio-frequency interferometers. Whether these are gross mass motions (winds) or the phase velocities of wave motions is now being investigated by means of simultaneous measurements of wind profiles by chemical release. If the motions are in fact those of winds, their study can reduce the need for the more costly rocket-borne profiles which will always be limited to statistically small samples. As another example, upper-atmosphere motions of electron irregularities are observed (at 200 to 500 km) by the large backscatter radar of the Arecibo Ionospheric Observatory in Puerto Rico. These motions will be compared with direction and velocity of neutral winds up to 250 km determined by chemical releases, to find whether the two motions are similar or generated by a common energy source.

Other chemical releases are still emerging from the stage of testing techniques rather than atmospheric properties and will be incorporated into the tool kit of the upper-atmosphere scientists as they are brought to the status of proven measurements. Both the techniques of controlled release and of ground-based observations of the releases, spectrally and spatially resolved, need continued improvement. In some areas, this requires increased sophistication in experimental design. Paradoxically, in other areas, simplification of measurement techniques to the most routine level possible is more important, to make feasible the collection of a sufficiently large number of observations for an understanding of the "meteorology" of the ionosphere. What is certain is that imaginative investigators will continue to come forward with novel experimental approaches and interpretations in this fertile field.

References

1. *U.S. Standard Atmosphere, 1962* (Superintendant of Documents, Washington, D.C. 1963).
2. D. R. Bates, *J. Geophys. Res.* **55**, 347 (1950).
3. H. D. Edwards, J. F. Bedinger, E. R. Manring, C. D. Cooper, in *Aurora and Airglow*, E. B. Armstrong and A. Delgarno, Eds. (Pergamon, New York, 1955), p. 122.
4. M. Dubin, NASA Headquarters, Washington, D.C., private communication; C. Henry, thesis, Univ. of Paris (19 June 1964); A. Kochanski, *J. Geophys. Res.* **69**, 3651 (1964); E. Manring, J. Bedinger, H. Knaflich, D. Layzer, *U.S. Nat. Aeronaut. Space Admin.* NASA CR-36 (Washington, D.C., 1964); G. V. Groves, *Space Res.* **5**, 1012 (1964).
5. E. R. Manring, J. F. Bedinger, H. Knaflich, *Space Res.* **2**, 1107 (1961); J. E. Blamont and C. de Jager, *J. Geophys. Res.* **61**, 3113 (1962); E. R. Johnson and K. H. Lloyd, *Australian J. Phys.* **16**, 490 (1963); S. P. Zimmerman and K. W. Champion, *J. Geophys. Res.* **68**, 3049 (1963).
6. J. Blamont, M. L. Lory, G. Courtes, *Ann. Geophys.* **17**, 116 (1961).
7. I. S. Shklovskii *Iskusstv. Sputniki Zemli Akad. Nauk SSSR* **4**, 195 (1960).
8. D. Golomb, N. W. Rosenberg, *et al.*, *J. Geophys. Res.* **70**, 1155 (1965).
9. M. Dubin and J. F. Bedinger, *International Quiet Sun Year Instruction Manual 9, Sounding Rocket Research Techniques* (IQSY Secretariat, London, 1964), p. 42.
10. C. O. Hines, *Can. J. Phys.* **38**, 1441 (1960); *Quart. J. Roy. Meteor. Soc.* **89**, No. 379 (1963); *J. Geophys. Res.* **70**, 177 (1965).
11. H. Föppl *et al.*, *Planetary Space Sci.* **13**, 95 (1965).
12. B. Authier, J. Blamont, G. Carpentier, M. Hersé, *Compt. Rend.* **256**, 3280 (1963).
13. N. W. Rosenberg, D. Golomb, E. F. Allen, *J. Geophys. Res.* **69**, 1451 (1964).
14. B. Rosen, *Rev. Franc. Astronaut.* **1965**, 18 (1965); H. Bredohl, I. Dubois, L. Gausset, *Bull. Soc. Roy. Sci. Liege* **12**, 820 (1964).
15. N. W. Rosenberg, *J. Geophys. Res.* **68**, 3057 (1963).
16. H. P. Broida, H. I. Schiff, T. M. Sugden, *Trans. Faraday Soc.* **458**, 259 (1961).
17. J. Pressman, L. M. Aschenbrand, F. F. Marmo, *et al.*, *J. Chem. Phys.* **25**, 187 (1956).
18. M. Zelikoff, F. F. Marmo, *et al.*, *J. Geophys. Res.* **63**, 31 (1958).
19. C. D. Cooper, in *U.S. Air Force Cambridge Res. Lab. Environ. Res. Paper* No. 15, Project Firefly 1962 (1964), p. 122 (available from CFSTI, Springfield, Va. 22151).
20. N. Jonathan and P. Doherty, *ibid.*, p. 393.
21. E. R. Johnson and K. H. Lloyd, *Australian J. Phys.* **16**, 490 (1963).
22. N. W. Rosenberg, D. Golomb, E. F. Allen, *J. Geophys. Res.* **68**, 3328 (1963).
23. ———, *ibid.*, p. 5895.
24. N. W. Rosenberg and H. D. Edwards, **69**, 2819 (1964).
25. "Symposium Sporadic E," *Radio Science* (Feb. 1966).
26. F. F. Marmo, L. M. Aschenbrand, J. Pressman, *J. Am. Rocket Soc.* **30**, 523 (1963); P. B. Gallagher and R. A. Barnes, *J. Geophys. Res.* **68**, 2987 (1963); J. W. Wright, *ibid.*, p. 3011; N. W. Rosenberg and D. Golomb, *Progr. Astronaut. Aeronaut.* **12**, 395 (1963).
27. D. Golomb, N. W. Rosenberg, J. W. Wright, R. A. Barnes, *Space Res.* **4**, 389 (1963); M. A. MacLeod and D. Golomb, *U.S. Air Force Cambridge Res. Lab. Environ. Res. Paper* No. 101 AFCRL-65-287 (available from CFSTI, Springfield, Va. 22151).
28. W. Nordberg, *Aeronaut. Astronaut.* **2**, 48 (1964); in *International Quiet Sun Year Instruction Manual 9, Sounding Rocket Research Techniques* (IQSY Secretariat, London, 1964).
29. G. V. Groves, *J. Geophys. Res.* **68**, 3033 (1963).
30. N. W. Rosenberg, *ibid.* **69**, 2323 (1964).

Plant Pathology and Human Welfare

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Diseased plants have always been with us and influenced our well-being. The history of mankind through the ages has been the story of hungry men in search of food. Tribes that tended sheep or cattle for their own food needed forage for their animals as well. The desire for food and forage has brought on many conflicts, small and large, from the beginning of time.

Diseases of plants have causes similar to those among animals and man. In early times, physicians using medical terms wrote about plant diseases—even though plants do not feel ease or disease as men do. But plants with disease may be so impaired that their usefulness to themselves or to mankind is seriously reduced. With the dawn of history we find reports of famine resulting from mildew and rust, induced by fungi. Certainly, plant diseases were troublesome even in the earliest historic times. Doubtless they were present in evolutionary times, as fossils show. Many of the extinct plants probably had diseases that hastened their disappearance.

How plant diseases developed is not definitely known. Probably when weakened plants died, various microorga-

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isms assisted in decomposing them and in returning the materials to the soil to enrich it. Presumably most of these microorganisms worked only on dead plants and animals, clearing away debris and building humus. However, some microorganisms apparently were able to cause decay while the plants were still alive. This was a parasitic mode of life. By further adaptation, other microorganisms, such as certain rust and mildew fungi, were able to attack and grow on living tissue only.

Certain common names for plant diseases came easily enough. The rust fungi often had the color of iron rust. Terms like soft rot, dry rot, wilt, and leaf spot are descriptive.

Cause of Disease

Diseases are not always caused by microorganisms. Injuries that occur because of accidents, poisons, or defects in the environment often result in diseased tissue. Fire, flood, frost, higher animals, insects, and machinery, as well as poor agricultural techniques, may also produce damage. Many chemicals are beneficial, but when improperly used they too can cause losses.

Important environmental factors may be damaging; for example, the weather can be too hot or too cold, too wet or too dry. The light can be too intense or too weak; or the length of daylight may be too short or too long. There can be too little or too much fertilizer. In addition to the common mineral elements, such as potassium, phosphorus, and nitrogen, many plants require traces of boron, zinc, copper, manganese, or other nutrients.

Between the nonparasitic diseases and those caused by pathogens (literally, disease-causers) is a large additional group caused by viruses. There is no agreement about whether or not viruses are living. But this depends on what we regard as life, rather than on our ignorance about these viruses. Much of our basic information about the viruses that cause serious diseases of animals and men has come from the study of plant viruses, especially tobacco mosaic virus.

Most groups of living microorganisms include some that may be pathogenic. The concept of pathogenicity was established by Prevost in 1807 but went unrecognized until the middle of the last century. The research was done with covered smut, a disease in which the grains of wheat were replaced by fungus growth, looking mostly like black dust but being in reality a black powdery mass of spores. The disease was always present, but was not epidemic. Sometimes it caused heavy loss in one field and little in another. When Prevost put some of the black dust in water and watched it under a microscope, the black dustlike bodies grew. He also observed that traces (about 1 part per million) of soluble copper from a dirty copper kettle would prevent growth. These two keys were basically important. However, they were not turned in the lock to open the way for the control of bunt until later in the century.

The idea that specific living microorganisms could cause disease was accepted quite slowly. Many received such ideas only with chuckles of amusement—whether disease of plant, animal, or man made no difference. Many preferred to generalize about disease as a principle. It was to be overcome by another principle, health and natural good. Comparable ideas persist today.

But the means of securing adequate evidence was soon at hand. For plants we use the rules of proof for pathogenicity, known as Koch's postulates, adopted from medicine. Briefly, the pathogen must be consistently associated with the diseased tissue, it must repeatedly be isolated and characterized in culture, it must reproduce the disease symptoms when inoculated onto or into the host plant, and it must again be isolated and proved to be identical with the first isolate. Most of the pathogens causing plant diseases are bacteria or fungi. One has only to mention a few examples, such as those causing blight of potatoes (fungus), fire blight of apples and pears (bacterium), chestnut blight (fungus), and Dutch elm disease (fungus). Such major crops as wheat, corn, rice, potato, apple, and tomato are subject to 50 or more diseases. In addition, certain flowering plants prey on other plants and cause disease. Examples are mistletoe, dodder, and witchweed. By common consent, the eelworms (nematodes) appear among the plant pathogens. Only in recent years have we recognized their great importance.

On the other hand, some microorganisms are beneficial. Certain bacteria induce the root nodules of legumes, such as alfalfa, clover, and peas, and thus make possible the fixation of atmospheric nitrogen. Various fungi aid germination of seed and normal growth of plants such as orchids, heaths, and trees by association with the roots.

Fortunately, the pathogens of plants rarely produce diseases in animals or man. However, some of the fungi are poisonous when eaten. Ergot of rye has been notorious. This fungus grows as long, hard, purple masses replacing some of the grains in a maturing head of rye. It was often included in low-cost bread until its poisonous nature was discovered. A toxic alkaloid in the fungus induced abortion and gangrene. Epidemics of ergot poisoning swept over France nine times in the 17th century and eight times in the 18th century, and thousands died. Various other fungi, including certain mushrooms, are poisonous when eaten.

Some Historic Losses

Enormous losses of food, history-making losses, have been frequent in the story of mankind. Before epidemics were understood, they were considered as special kinds of plagues. Many factors have combined for the final result—the plant pathogens often need suitable weather, especially warm temperature and high moisture. Sometimes insect vectors, in addition to the damage they themselves do, add further injury by spreading or injecting disease-inducing microorganisms or viruses. But the importance of microorganisms was slow to be recognized. All could see the devastations of swarms of locusts—they descended on fields, ate every green leaf or twig, and left fields bare—but the stealthy work of fungi seemed obscure to the farmers.

Various famines, and even the outcomes of wars, have been influenced by the shortage of food caused by plant disease microorganisms. Speculation about the supernatural was common. After the Irish Famine, or potato murrain, which began in 1845–46, the real cause was worked out. Potatoes had originated in the Andes in America and, no doubt, the blight fungus did too. However, blight in Europe corresponds in time to the advent of steamships. Men have argued the possibility that diseased potatoes, which decayed on slow sailing vessels, could have landed from fast steamships and started the potato murrain. In any case, this is doubtless an early example of a way in which growers have moved dangerous microorganisms from one country to another.

The potato famine continued for several years. Starvation occurred in Ireland and in western Europe. Rebellions, looting of landowners' property, even murders, took place. During this time, America benefited by the immigration of many of the western European people. They were a select group. A few were criminals, but usually only those with initiative and an adventurous spirit would say "good-by" to relatives and tradition for a try in the New World.

The proof that the potato famine was caused by a fungus helped explain the riddle of the common barberry bushes and rust. Stem rust on wheat was proved to be caused by a fungus that appeared first red, then black, and had the barberry as an alternate host. The rust was worse near barberries, and laws had been passed against growing them.

Rusts on stems or leaves of wheat had been a plague since the dawn of history. The Romans had a God called Robigus whom they tried to appease for a good harvest. During the 1st century, annually on 25 April, they held a procession to his sacred grove, poured red wine over the altar, and sacrificed a red dog. This was also the time that rust first appeared generally, and that the dog star was thought to be malign. Robigus was thus cajoled into accepting a cheap red substitute for the red on the wheat, into calling off the dog star, into saving the wheat, and thus into letting his mortal followers have their bread.

Rusts of stems and leaves probably prevented wheat from becoming a major food crop in the southeast of the United States—hence the wide use of corn products there. Rust was serious during World War I in both Europe and North America; in the single year 1916, it was estimated that 300 million bushels of wheat were lost in the United States and Canada. Such slogans as "Food will win the war" were common. The food losses from potato blight and other diseases in Germany doubtless helped to shorten World War I.

Wheat rusts, wheat smut, and potato blight have been carried all over the world, but they are only several examples of the many diseases on all our crops. The world's important food crops include bananas, beans, cassava, corn, peanuts, potatoes, rice, soybeans, sugar beets, sugar cane, wheat, and many others. Plants yielding fiber, lumber, drugs, and so on, are valuable in our daily lives. We must not forget rubber and tobacco. Each has many diseases. Merely to list the plants and diseases by name occupies a large book. Ignorance about them often causes hardship in developing countries. Let us consider two examples.

Coffee rust put an end to a thriving coffee industry in Ceylon. In 1879 the Ceylon government sent an appeal for help to the botanical institution at Kew in England. It was a decade too late. The rust took the leaves off the trees, and after several defoliations the trees died. After much economic hardship, Englishmen planted tea and the English became confirmed tea drinkers. Coffee rust has spread widely; it occurs in Malaya, India, Java, Sumatra, the Philippines, and the east and west coast of Africa. Big growers doubtless can handle it, but the small growers cannot afford control measures. With planes going so fast and frequently, how long will it take the rust to reach South and Central America, where over 99 percent of the coffee trees are susceptible? And how much more in aid money will be needed to help coffee-growing countries? A seldom-considered Damocles' sword is hanging over American coffee growers.

But American fungi also present some threats to the Far East. Rubber trees growing there were native to South America. But in America, a fungus causes a defoliating leaf spot, making rubber-growing expensive. By lucky circumstances, the fungus was left behind when Englishmen took the rubber trees to Malaya, and rubber plantations have spread in the Far East. Here again, how long will it be before the leaf spot moves to and attacks the eastern rubber trees?

These are only two diseases. Many more could be discussed. Their control or prevention is in the hands of a relatively few scientists throughout the world. Their chief means of operating is mentioned very briefly.

Control

The control of plant pathogens is ordinarily based upon an understanding of the pathogens' points of vulnerability. Since, with occasional exceptions, individual plants are of relatively small value, the plant pathologist is concerned with the control of epidemics. An epidemic occurs when there is a rapid repetition of the cycle whereby the pathogen enters the plant, becomes established and reproduces, comes to the surface again, produces spores and so forth, and is carried somehow to another host. Under favorable conditions a new generation can occur in from 8 to 14 days. Each infection produces hundreds, sometimes many thousands, of spores. These phenomenal "population explosions" can cause devastation of a crop. Plant pathologists secured the ideas of cycles from medical workers. Control measures can be applied at various points in this cycle where weak links occur in the chain of events. For example, the use of quarantines, inhibiting agents, special cultural practices, repulsion of disseminating insects, and the development of disease-resistant plant varieties, all have successful applications.

Most of the other control measures, in the minds of some people, are merely stopgap procedures to be employed until disease-resistant varieties can be developed. However, the development of new varieties must be more or less continuous. For as smart men breed a variety that resists disease, the microorganisms may have or evolve a different race or strain of the pathogen or even a different pathogen to attack it. So the plant breeder has a problem to keep one jump ahead.

For breeding, undisturbed or natural areas are most important. Here the breeder searches for native plants having desirable characteristics. When natural areas are destroyed, his problem becomes serious. Every effort must be made to preserve a suitable number of natural areas over the world. Every year of delay means that potentially important plants, bearing genes for resistance or other valuable characteristics, become extinct.

In Europe and North America, research has made possible the reduction of plant diseases so that in some cases we have an abundance or a surplus in storage of products such as wheat, corn, or cotton. (Fungi also may attack food in storage.) This supply is possible only as a result of continued research of the pathologists, along with their colleagues in agronomy, horticulture, entomology, soils, genetics, engineering, and so forth. After the War Between the States, research stations and substations were established frequently in the areas to be served, because what was suitable for one place might not be right for another. The large supply of crops was produced by the applications of many years of research.

Although this supply in North America may cause problems, one should not overlook the enormous asset it provides in case of armed conflict. Better still, it serves as a strong deterrent for men in any nation who might try to overcome any country in North America. At the same time, it may provide food for developing countries while they work on their own problems.

Developing Countries

Many people in Europe and North America do not realize that much of the world's population goes to bed hungry every night. Also, it has often been erroneously thought that if some of the South American, African, and Asian countries would use our seed and our methods, there would be plenty of food to go around. Unfortunately, the procedures that work in Europe and North America are quite apt to fail in other places. For that matter, procedures that are suitable for southern Wisconsin may not be suitable for northern Wisconsin. Research has been necessary in order to learn the application of basic knowledge for particular localities. Consequently, these questions are raised: Without research by plant scientists, including pathologists and their colleagues, can the developing countries be wholly or partly self-sustaining? Likewise, can they be encouraged to produce much of their own food rather than depend upon purchases or gifts? Do they need a philosophy of responsibility and activity along lines that would make them largely or entirely self-sustaining? The 2-year assignments of experts to developing countries too often have proved inadequate. What is needed mostly is long-term research, comparable to that sustaining North America and western Europe. This cannot be emphasized too strongly.

Among the primary problems are these: What can we do with the arid lands? They occupy about one-third of the world's land area. What can we do with fertilizers? This is important almost everywhere, including the apparently fertile wet tropics, because many such areas are badly leached. What can we do about weeds? Can chemicals wisely replace cultivation?

Some have argued that an increase in food production is self-defeating, especially when the products of arable land are consumed by the exploding populations. However, populations must be fed until the explosion can be controlled. Meantime, the prevention of plant diseases holds great promise. But, the measurement of losses points up the magnitude of the problem.

Disease Losses in Modern Times

Plant disease losses in developing countries are difficult to determine at present. Vallega and Chiarappa (*1*) have given a few examples. In 1947–48 in New South Wales, Australia, stem rust caused a loss of wheat estimated at 270,000 tons. This represented food for about 3 million people for 1 year. In South Africa, disease losses in sorghum have recently averaged about 1 million tons. This is enough food for 5.5 million people for 1 year. A small "Irish Famine" occurred during 1951 in Chiloe, southern Chile. The mean loss there of potatoes from the late blight area was 40 percent, with 23 percent for the entire country. Ghana and Nigeria have suffered severe losses in cocoa. Coffee has never come back as a crop after the coffee-rust epidemic in Ceylon in 1880–90. In South India, the loss from coffee rust sometimes may run to 70 percent; in East Africa, 30-percent loss from coffee rust is frequent. In the Philippines, of an original population of 250,000 coconut trees on San Miguel Island prior to the appearance of cadang-cadang in 1961, only 80 trees were still bearing fruit in 1965. In the state of São Paulo, Brazil, 75 percent of the 6 million citrus trees were infected and killed by tristesa in 1949. And so goes the story of disease. Many times, in a single-crop area, great economic disturbances occur that result in much suffering because of crop losses.

In the United States, the figures on losses are much more accurate. LeClerg (*2*) has given many details, some of which are summarized in Table 1. Here the average annual loss from pathogens for 1951–60 was $3,251,114,000. To this total must be added the average annual loss from nematodes of $372,335,000, and the average annual expenditures of $2,255,000 for suppression of plant diseases and nematodes. In round figures, this is an annual loss caused by plant disease in the United States, held down from an unknown very large sum, to just over $3½ billion.

There is an excellent report by Ogawa (*3*) of losses in California, and this serves as an example of the situation in a leading agricultural state. A summary appears as Table 2, which shows losses in landscape plantings, apparently omitted by LeClerg.

After total destruction no loss appears on the record. The foregoing discussions and tables of losses do not take into account the losses from crops that have already been wiped out. For example, nothing is noted about the loss from fire blight on commercial Bartlett pears in central or eastern United States. Fire blight killed the trees. Nothing is said about losses from chestnut blight. The chestnut trees were killed by the blight fungus. So it goes with Vicland oats, stone fruits in the Salt River Valley, Arizona, hops for beer near Milwaukee, certain varieties of corn, citrus, cotton, flax, and many other crops. This is a continuing process. In some places the Dutch elm disease alone, or together with phloem necrosis, is now destroying the American elms.

Without the use of control measures, the crop losses from plant diseases would be really serious. Doubtless harvests would often be reduced greatly and some crops would be completely destroyed. Prices would be enormously increased, and for some things we would go hungry, even in the United States. And our souls would miss much of nature's beauty.

Pattern for Control

To control plant diseases, the time-honored means is as follows. Basic research is done on the host, on the pathogen, and on their interaction, as well as on the environment. The most promising control measures are tried in fields that represent the extremes of environment likely to be encountered by the plant in question. After successful control measures are found, they are imparted to the agricultural workers via the extension procedures. They are also given to students. The success achieved in the United States has often followed this pattern.

This is a procedure that is promising for developing countries as well. But it takes years of trial and error in each new location to insure success. Although the basic principles may be known, their application must be modified in most cases for a new location and usually for a new environment.

To make such environmental studies, crude facilities were built years ago. Now, some institutions provide batteries of growth chambers with excellent control of temperature, moisture, light, and nutrition, suitable for growing small plants. For larger plants, many possibilities are provided by mountains having warm bases and a cool top, wet and dry sides, ridges and valleys for variations in light, and so on. But suitable precautions are necessary to prevent dangerous pathogens from spreading.

The introduction of foreign disease organisms is one of the major problems for all countries, but especially for developing countries. Few of them have adequate quarantine laws and services. Still fewer have enough competent men and facilities for the operation of such services. Thus, when men import promising crops, at the same time they too often import disease organisms and injurious insects that make their plant growth difficult or impossible. Quarantine officials complain particularly against diplomats and their wives, who claim diplomatic immunity against examination of their luggage as they move about.

The Outlook

No gift of prophecy is needed to say we shall always need food. We eat plants and certain animals, but these animals also eat plants. Wherever crop plants can grow there are diseases that need control.

Dedicated men will take the basic work already done, will try it on the land, and will pass on to the growers the results of successful trials. Likewise, these or other men will educate the students.

This is particularly important for developing countries. But here the basic information developed elsewhere must be tried under local conditions (*4*). Since planting, growing, and harvesting usually occur only once a year, a competent man usually needs a year in an area new to him to learn what problems are important. Then the second year he can make experiments. Many times, his first experiments fail because of some unanticipated circumstance. So several years of undisturbed continuity are necessary—as any Agricultural Experiment Station can testify. Then taking the results of successful experiments to growers requires much skill. In developing countries, this is often best done by dedicated natives. For best results, they should devote their lifetimes to plant pathology.

One can hardly overemphasize the importance of taking tried and true successful local results to the growers. Neither can one overemphasize the importance of educating the native students who face the challenges of the future.

Further progress depends on many factors. They are similar oftentimes to the needs in sister sciences. For example, we need a better means of classifying knowledge so that we can go to the libraries and find what is known about a given subject. Also, in the United States and, to a lesser extent, in Europe, the subjects plant pathology, entomology, soils, genetics, and so on are separated for convenience in administration and teaching. But in nature, they are seldom separated—all work together. Correspondingly, men who are trained in these subjects often have a better chance of success if they work together as a team. A team should be able to continue its function, however, with or without a substitute, if for some reason a member drops out.

Additional basic information also will foster progress. An indication of some of the numerous fundamental problems is given in various recent publications (see *5*). Among the subjects needing further research are: improved control with chemicals (including chemotherapy); effect of temperature, moisture, and other environmental factors on the host and the pathogen (and their interaction); genetics of the pathogens; genetic development of the host plant to increase resistance; chemicals in the host or parasite that influence either resistance or pathogenicity, and chemicals (phytoalexins) produced by the interaction of host and parasite that affect resistance; ecology, especially concerning the effects of crop rotations on soil-borne diseases; biological control; hidden disease agents and inhibiting agents that reduce crop yields; nematodes and their direct damage, as well as their introduction of other pathogens; tissue culture, the comparison of the metabolism of host and of pathogen; microscopic observation of the responses of host cells to parasitic attack under various conditions; mycorrhiza and pathogens near the roots; and so on and on. These are merely a dozen among many possible examples. The order in which they appear and the omission of others have no significance. The field is so broad that a plant pathologist must be able to work with other colleagues who understand related subjects from agronomy through to zoology.

No doubt future crops will be protected by future dedicated plant pathologists, who will find great personal satisfaction in recognizing and accepting the great challenge and opportunity for service. They, along with other colleagues, will be helping provide mankind with some of the basic needs—including food, clothing, and shelter which we, in the United States, too often take for granted.

Table 1. Average annual loss in crop groups due to disease (from *2*).

Commodity	Average annual loss 1951–60 inclusive ($1000)
Field crops	1,890,836
Forage crops and pastures and ranges	808,701
Fruit and nut crops	223,505
Ornamental plants and shade trees	14,099
Forage seed crops	23,584
Vegetable crops	290,389
Total	3,251,114

Table 2. Summary of crop group losses and disease-control costs for 1963 in California (from *3*).

Commodity	Losses and control costs for 1963 ($1000)
Citrus and subtropicals	23,088
Field crops	79,749
Forest crops and products	18,015
Fruit and nut crops*	105,467
Ornamental crops†	136,339
Small fruit crops	9,564
Vegetable crops	68,424
Total	440,646

* Mostly grapes, peaches, plums, and prunes.
† Mostly landscape plantings.

Summary

Diseases have always been present in plants and have caused many changes in the lives of men. They have influenced what men ate, what they wore, the shelter they used, and so on. Industries have flourished and have disappeared. Famines have occurred; populations have moved; even the outcomes of wars have been influenced. Important plants are frequently attacked. Losses each year in the United States are held down from unknown enormous sums by various control measures. The control of disease is one of the promising means by which developing countries can maintain and advance themselves. Dedicated scientific men, no doubt, will continue serving mankind by their research, extension, and teaching about plant diseases, if given the opportunity. They will need to cooperate with colleagues in related fields.

References and Notes

1. J. Vallega and L. Chiarappa, *Phytopathology* **54**, 1305 (1964).
2. E. LeClerg, *ibid.* **54**, 1309 (1964); "Losses in Agriculture," *U.S. Dept. Agr. Agr. Handbook No. 291* (1965).
3. J. Ogawa, *Estimates of Crop Losses and Disease-Control Costs in California, 1963* (Dept. of Plant Pathology, Univ. of California, Davis, 1965).
4. W. Paddock and P. Paddock, *Hungry Nations* (Little, Brown, Boston, Mass., 1965), 344 pp.
5. K. Baker and W. Snyder, Eds., *Ecology of Soil-Borne Plant Pathogens. Prelude to Biological Control* (Univ. of Calif. Press, Berkeley, 1965); C. Holton, Ed., *Plant Pathology. Problems and Progress* (Univ. of Wisconsin Press, Madison, 1959); J. Horsfall and A. Dimond, Eds., *Plant Pathology–An Advanced Treatise* (Academic Press, New York, 1959–60); A. J. Riker, *Am. Inst. Biol. Sci. Bull.* **12** (2), 30 (1962). See also *Ann. Rev. Phytopathol.*, beginning with **1** (1963).
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Plans for Project Intrex

M.I.T. proposes to establish an experimental basis for the design of future information services.

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Project Intrex is a program of *in*formation *tr*ansfer *ex*periments directed toward the functional design of new library services that might become operational at the Massachusetts Institute of Technology and elsewhere by 1970. This project has been established with the twofold objective of finding long-term solutions for the operational problems of large libraries and of developing competence in the emerging field of information-transfer engineering. The project will be carried out in the School of Engineering in close concert with the M.I.T. libraries.

In the university of the future, as it is visualized at M.I.T., the library will be the central facility of an information-transfer network that will extend throughout the academic community. Students and scholars will use this network to gain access to the university's total information resources, through Touch-Tone telephones, teletypewriter keyboards, television-like displays, and quickly made copies. The users of the system will communicate with each other as well as with the library; data just obtained in the laboratory and comments made by observers will be as easily available as the texts of books in the library or documents in the departmental files. The information traffic will be controlled by means of the university's time-shared computer utility, much as today's verbal communications are handled by the campus telephone exchange. Long-distance service will connect the university's information-transfer network with sources and users elsewhere. Figure 1 presents a schematic view of this concept.

Today we do not know how to specify the exact nature and scope of future information-transfer services. We believe that their design must be derived from experimentation in a working environment of students, faculty, and research staff. A favorable situation for such experimentation exists at M.I.T. at the present time. There are library users in all academic categories who are accustomed to the experimental approach and who will cooperate in meaningful tests of new services. In Project MAC, M.I.T. is already carrying forward a broad study of machine-aided cognition that will greatly stimulate the rise of new concepts in information transfer.

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Planning the Project

The experimental plan for Project Intrex was formulated in August 1965 at a conference sponsored by the Independence Foundation. The membership, from both inside and outside M.I.T., was divided among librarians and documentalists, scientists and engineers, and some representatives of architecture, linguistics, mathematics, philosophy, psychology, and publishing. The report of the Intrex Planning Conference has been published (*1*). The purpose of this article is to present a brief overview of the experimental program recommended by the conference. This article borrows extensively from the language of the report, and thereby attempts to capture the consensus of the participants in the conference rather than present exclusively my own viewpoint.

Three mainstreams of progress in the field of information transfer were intensively discussed: (i) The modernization of current library procedures through the application of technical advances in data processing, textual storage, and reproduction; (ii) the growth, largely under federal sponsorship, of a national network of libraries and other