MANAGING PLANT DISEASES-AN OVERVIEW[1]

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World figures on exploding populations and the problem of food for these populations are well-known; nevertheless, seldom in history has mankind been more dependent on the success or failure of agriculture than at the present time. A rapidly increasing percentage of the world's population live in urban centers, producing no crops themselves, and thus completely dependent on others for their food. With increasing efficiency in agriculture and a move to industrialize foremost goals of many emerging nations, the trend towards urbanization will continue with millions of people vulnerable to food shortages.

The recent spectuacular successes in Asia and Latin America in increasing rice and wheat production have brought renewed hope for a better life for millions. This "green revolution" plus the intensified efforts of peoples throughout the world to improve their agriculture bring with them serious dangers, but dangers which can be overcome if they are recognized, anticipated, and planned for in advance. The increased yields of the green revolution are based on the widespread use of a small core of germplasm, larger plant populations per acre, increased use of fertilizer, increased pressure to obtain two -three crops per year from the same land, more widespread use of irrigation, and improved cultural methods. It is paradoxical and unfortunate that often these practices can increase the chances of serious attacks by pests and pathogens.

Although plant diseases are caused by both abiotic and biotic factors, the majority are caused by a diverse group of biotic agents; fungi, nematodes, viruses, and bacteria. Some major crop plants are known to be attacked by from 50 up to 200 pathogens, and a single pathogen may attack one plant species or up to 1,200 or more hosts (2). Plant disease losses from 1951-1960 in the U.S.A. were estimated at $4.25 billion, not including $0.25 billion spent on disease control. This is about 10 percent of the annual agricultural production (8). Although reliable figures are difficult to obtain, plant disease losses in the tropics are at least double those of temperate zones; probably 20-30 percent. The above figures do not include losses from disease in storage, the market, or in the hands of the consumer.

Plant diseases have caused well known disasters in the past; the potato famine in Ireland, due to *Phytophthora infestans* (late blight), the Bengal famine of 1943 in which *Helminthosporium oryzae* (brown spot of rice) was a major factor, and the almost virtual elimination of coffee in Southeast Asia in the late 1800's by *Hemileia vastatrix* (coffee rust). In 1970 coffee rust caused serious losses after its introduction into Brazil, and *Helminthosporium maydis* caused a 10% loss of the corn crop in the U.S.A. Many other examples could be cited, but these serve to illustrate the potential cost that complacency about hard won gains in agricultural productivity may bring if a constant effort is not made to manage plant diseases with all available methods.

The methods and principles of plant disease control or management are the same throughout the world. However, the practical application and adaptive research necessary to apply these principles may vary greatly, depending on many factors such as the crops involved, climate, soil, altitude, cultural practices, government, econo-

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mic resources, and the social system of a specific country or region.

A single control method is rarely successful over a long period of time, thus an integration of many principles and methods is essential for continued success. For the successful management of plant diseases it is essential to have a clear concept of the cycles of diseases and host development, and the effect of the environment on these cycles and host-parasite interactions. Without this information disease management becomes risky and often fails.

Plant disease control cannot focus only on the pathogen or the damage it causes. It has to be integrated with the entire package of management practices in agriculture, especially those related to insect and weed control. The object of these practices is the production of maximum yields consistent with sound ecological principles which maintain or result in a wholesome environment. Plant disease control is an integral part of crop protection or pest management.

The principles and methods of plant disease control have been classified and reclassified many times in order to clarify thinking and transmit knowledge in an orderly fashion.

Probably the first set of principles was developed by H. H. Whetzel (6) who listed exclusion, eradication, protection and immunization. Subsequent authors have expanded this list with added knowledge and for greater clarification. R. A. Young et al (8) recentlyl isted avoidance, exclusion, eradication, protection, development of resistant hosts, and therapy as principles. G. C. Kent (personal communication, 1971) uses the same list except that he uses the term elimination rather than eradication.

A brief definition of principles in the order in which they would be expected to be applied in a growing season is as follows:

1. **Exclusion** - preventing the introduction of a pathogen into a presently uncolonized area.
2. **Elimination** - the elimination or eradication of the pathogen at its source (which could be a region or an individual plant).
3. **Avoidance** - avoiding disease by manipulation of planting time or planting in areas where the pathogen is rare or absent.
4. **Protection** - protection of a susceptible host by placing a barrier (usually a chemical one) between the host and the pathogen before it has entered a plant.
5. **Breeding for resistance** - changing the host in such a way that a pathogen causes less injury. Genetic manipulations of the host plant are implied for this method of obtaining resistance.
6. **Therapy** - restricting the growth of a pathogen once it has entered the host.

Managing plant diseases is the successful application of the above principles. To expand the definitions of these principles and adequately explain all of the methods of accomplishing them is impossible in this paper. Nevertheless, emphasis can be given on how these principles can be used in an integrated program of pest management with some examples of how they might be used in a tropical area such as Southeast Asia.

Exclusion and Elimination

Exclusion is undoubtedly the best and cheapest method of plant disease control and if it fails elimination (eradication) is the next best method. Pathogens can be excluded from a given area (from a farmer's field to a continent) by many means such as treatment by heat, gases, or chemicals of seed or vegetative planting materials in order to kill any pathogens or pests they may harbor. They may also be excluded by inspections and quarantines. Many countries have reliable inspection and certification services which enable growers to obtain pathogen free planting material. Quarantines are often considered to be a bothersome formality, expensive, and in actual practice are often not very efficient, but they may often delay or indefinitely prevent the introduction of important pathogens.

Almost all of the above methods depend on a well-informed and cooperative public, but perhaps even more important, well-informed government officials. It is of utmost importance and a duty and responsibility of scientists to educate the public, administrators, and politicians on the importance of efficient use of exclusion methods.

Plant pathologists in tropical countries are generally aware of diseases in their own countries or even on their own continent, but often are not cognizant of serious problems on other continents. For example, the recent introduction of *Hemileia vastatrix* (coffee rust) into Brazil was a tragic event and perhaps might not have occurred had the public and government officials been educated to prepare for its possible introduction. It now appears that it had been in Brazil for several years before its discovery. On the other hand scientists in the rubber growing areas of Southeast Asia were aware some years ago of the danger from *Dothidella ulei* (South American leaf blight of rubber). Growers were educated to identify the disease if introduced, defoliants were tested and stockpiled, and a plan for rapid eradication was made in case the disease should ever appear (7). All plant pathologists working in the tropics should be concerned that every precaution is taken to prevent extending the range of dangerous diseases such as the following: hoja blanca virus of rice (the Americas), downy mildew of corn caused by *Sclerospora philippinensis* (India and the Philippines), the Moko disease of bananas caused by the insect transmitted strain of *Pseudomonas solanacearum*, Monilia pod rot of cacao (South America), the swollen shoot virus of cacao (Africa), and the coffee berry disease (Africa). The Food and Agricultural Organization of the United Nations is active in promoting and coordinating plant quarantine activities in Southeast Asia through the Plant Protection Committee for the Southeast Asia and Pacific region.

There are many means of eliminating (eradicating) pathogens once they have been introduced. This may mean complete eradication of an introduced pathogen, eliminating it as a destructive entity for a single crop season, or reducing it's population so it causes little or no damage. Some of the methods used to eliminate pathogens are biological control, crop rotations, removal or destruction of susceptible plants or plant parts which harbor pathogens, and heat, chemical or other treatments of plants or soil. There are a few outstanding examples of complete eradication from a country of an introduced pathogen, (such as the eradication of *Xanthomonas citri* (Citrus canker) from the U.S.A.), but this is often difficult and expensive.

If we define biological control as the control or suppression of disease by living microorganisms, there are few success stories to cite. The most success has occurred in biological control of pathogens in the soil through competition, parasitism, and antibiosis. Research in this area (5) may produce additional practical application in the future and such research should be strongly supported as biological control is inexpensive and would have little if any deleterious effect on the environment. Many of our present control methods such as crop rotation, paddy culture of rice, the plowing under of green manure, and fallowing are undoubtedly effective because of biological control, but scientists seldom understand the complex interactions of microorganisms within the soil that result in control.

Crop rotations, perhaps the oldest method of disease control, are widely used in plant disease control, but their effectiveness vary widely. The object of crop rotation is to reduce the severity of attack by soil borne pathogens by reducing their numbers or eliminating them. Since this is usually an inexpensive method of control, much more research should be done under tropical conditions to add usable information applicable to tropical crops.

Removal of diseased plants, elimination of weed hosts and alternate hosts for certain rust fungi, and sanitation (elimination or removal of overseasoning plant parts and cleaning up plant debris) are all methods of elimination. These cultural methods are used widely for the control of many tropical diseases, and much more emphasis should be given to their study, as they often require little capital, and with proper education growers who cannot afford chemicals can use these methods.

Many heat and chemical treatments have been devised to eliminate pathogens in plant parts or soil. These may be highly effective and economic for small areas (such as seedbeds), but often, because of their expense, cannot be used by small growers. Flooding land for long periods (flood fallow) to control pathogens was a method developed in the American tropics primarily to control Fusarium wilt of bananas. Clean fallowing is successful in controlling some pathogens. Long term rotation and fallowing experiments, especially with tropical subsistance crops, would be of great value in evaluating the effectiveness of these cultural methods of control.

Avoidance

To use avoidance a good understanding of the life cycle of the pathogen and stages in the development of the host when it is most susceptible are necessary. It is perhaps the least desir able of the principles of control, because its use is often risky and subject to chance. However, with sound information on which to base recommendations it is a very inexpensive control method.

Choice of a geographic area to avoid disease (as a dry irrigated area versus a humid area) may be highly effective with many diseases. Even within fields some areas (well drained versus poorly drained) may help to avoid diseases. The use of disease free seed produced in a dry area to escape infection is a very effective means of disease control. For example, most of the bean seed in the U.S.A. is produced in the dry, irrigated areas of the west to avoid seed borne diseases.

Planting dates are often manipulated to avoid disease, and in tropical areas where distinct wet and dry seasons occur proper choice of planting dates may enable growers to escape or reduce disease incidence. However, unusual weather conditions such as an early monsoon can make such practices risky. Proper spacing of plants, pruning, and weed control (for better air circulation) are practices which can also help to avoid severe disease losses.

In the tropics planting at different altitudes is a method of avoiding certain plant diseases. For example in the Philippines tomatoes with resistance to *Pseudomonas solanacearum* (bacterial wilt) are susceptible below an elevation of about 2,000 feet because of high temperatures, but at higher elevations the same tomato lines may be grown successfully. The use of shade is widespread with certain crops in the tropics and the severity of some diseases (American coffee leaf spot and Cercospora leaf blight of bananas) can be reduced when these crops are planted in the shade. Unfortunately, yields are usually lower from shade grown crops.

Protection

Protection is used when exclusion, elimination, or avoidance have been ineffective. Protection consists of those practices where a chemical barrier is placed between the susceptible host and the pathogen. Spraying, dusting, and seed treatment are common protection methods. The use of insecticides to control insect vectors of plant diseases is also considered protection.

Chemical control has been most successful when used on the foliage and seed of plants. The root rots, caused by many fungi and bacteria and diseases caused by nematodes have not been so successfully controlled economically by chemicals, perhaps due to costs of $50 to $400/acre for treating soil with chemicals (3).

Rapid progress has been made in the last few decades in the discovery of new and safer compounds to control plant diseases. The inorganic copper, zinc, sulfur and mercury compounds have largely been replaced by a wide variety of organic compounds such as the dithiocarbamates, the quinones, and others. With the exception of the mercury compounds widely used for seed treatment until recently, fungicides have been far less toxic to man or animals than the insecticides and less public pressure has been exerted to reduce their use. Nevertheless, the high cost of their development has discouraged chemical companies from developing more and better compounds.

In general, except for high value cash crops such as bananas, rubber seedlings, coffee, cacao, and tomatoes, chemicals are not widely used in the tropics for plant disease protection. The primary reason for this is economic. Efficient application equipment is expensive, and since the chemicals often have to be imported this adds to their cost. Too often, information on rates of application, timing, methods of application, and the best product to use is not available. Fungicides must be tested under tropical conditions, as the patterns of rainfall, temperature, and humidity can alter recommendations for their most efficient use. Each country will have to work out its own problems on its own crops, although excellent and abundant information can be found as a starting point for almost any crop. The epidemiology of tropical plant pathogens is seldom well understood. Epidemiology and forecasting plant diseases would be an additional worthwhile area for research which would reduce the use of chemicals.

Resistance

The outstanding success story of agriculture in the U.S.A. has been told many times. One of the major reasons for its success has been the development of disease resistant crops. According to Young et al (8)

> "Prior to 1900 only a few thousand acres were planted with crop varieties developed through research directed to the development of resistance. Currently, approximately 75 percent of the total acreage in agricultural production in the United States utilizes resistant varieties developed by plant breeders and plant pathologists since the early 1900's. For certain crops, such as alfalfa and small grains, 95 to 98 percent of the vast acreage grown is planted with varieties that are resistant to one or more diseases."

Resistance as a principle implies changing the host in such a way that pathogens cause less injury. If one considers the number of species of plants grown and the relatively few diseases they have, plant resistance is a common characteristic and most plants are resistant to most pathogens. As man has developed agriculture, however, plant populations have become more uniform, and thus more susceptible, especially to introduced pathogens. The story of rubber illustrates in recent history what can happen when a formerly wild plant is grown in a monoculture. In the native Amazon jungle habitat of *Hevea*, there are about 6 *Hevea* trees per acre. Each tree is screened from other rubber trees by the foliage of trees of other genera which serve as barriers to windborne spores. South American leaf blight (caused by *Dothidella ulei*) was an obscure disease which did little damage during the time when rubber was collected in the jungle from wild *Hevea* trees as the main source for world markets (1). When *Havea* was established as a cultivated crop on large plantations *D. ulei* became a serious problem and wiped out thousands of acres of plantings in Latin America. This observation emphasizes the importance of maintaining diversity in plant breeding schemes.

The inheritance of disease resistance is essentially the same as the inheritance of other characters. Disease resistance may be inherited in a simple or extremely complex manner. Unfortunately it is the complex inheritance (which confers genetic diversity and thus greater stability) which is more difficult to obtain. Simply or qualitatively inherited resistance (due to one or a few genes) seldom lasts for more than a few years, although an exception is monogenic resistance to certain soilborne fungal and bacterial pathogens which has lasted many decades. This is maybe due to the slow spread of soilborne pathogens in nature. The frequent rapid loss of monogenic resistance to *Puccinia graminis* (stem rust of wheat) and *Phytophthora infestans* (late blight of potatoes) illustrate the ability of air-borne fungal pathogens to produce new races rapidly which can break down simply inherited resistance.

The use of resistant varieties in controlling plant diseases in the tropics varies widely. Some crops, such as cassava or coconuts, have received little attention, while other crops, such as sugar-cane, without the discovery and development of resistant varieties, might have disappeared from culture due to diseases. Sugarcane breeders have had to change varieties once every six years in Hawaii due to diseases. The primary basis for the control of many diseases of tropical crops is the use of resistant varieties. Examples are sugar-cane mosaic, Panama disease of banana, hoja blanca of rice, and Dothidella leaf spot of rubber.

There is a great diversity in disease resistance in most plants of the tropics such as corn, rice, cassava, beans, cocoa, vegetables, fruits, and forest trees. The same diversity is found in respect to many other characters. This diversity is undoubtedly one of the reason that diseases seldom cause catastrophes when farmers use poor cultural practices, little or no fertilization, sources of seed and propagating material that have never had the approval of a government or certifying agency, and no fungicides, herbicides, or nematocides. The diversity within crops and the growing together of a diversity of crops undoubtedly reduces pathogen activities and diseases that may cause disaster in a monoculture but which are relatively innocuous when many crops are grown together. Every effort should be made in the tropics to make intelligent use of diversity in the agro-ecosystem, especially in breeding programs.

The use of simply inherited or monogenic resistance (qualitative inheritance) that can be overcome by the appearance of new physiologic races should be avoided where sources of quantitatively inherited resistance are available. The utilization of simply inherited resistance should not be discarded, as sufficient examples are known where it has held up for many years to make its use worth-while, but quantitatively inherited or complex resistance (also known as "minor gene" resistance, partial resistance, field resistance, etc.) has not been conclusively shown to break down rapidly when new races appear. Much more information is needed on a wide range of tropical plants on the nature, value, and utilization of this type of resistance. It should be a high priority research area in the tropics. Quantitatively inherited resistance is being studied at the International Rice Research Institute in order to obtain more stable resistance to *Pyricularia oryzae* which causes rice blast (4).

The tropics have advantages over temperate areas in plant breeding for disease resistance. It is often possible in the tropics to get two, and even three generations in a year. This can speed -up breeding and testing procedures and reduce the time between the original cross and giving seed to the growers. In addition disease testing can frequently be done in the field under optimal conditions in the tropics, thus reducing the need for costly laboratory and greenhouse facilities.

Therapy

Therapy consists of restricting the activities of the pathogen once it has entered the host. Therapy is produced by chemicals (injected or absorbed into the plant) and heat. The recent introduction of systemic fungicides and nematocides have added a new approach for plant disease control. As some of these compounds can be applied in granular form, there is no need for expensive application equipment, and almost any grower can use them.

In addition, plants may be made more resistant by manipulation of cutural practices, especially plant nutrition. This resistance is not heritable and nutritional manipulations often reduces yield in the absence of disease. For example, rice is more susceptible to *Pyricularia oryzae* (rice blast) when plants receive high levels of nitrogen.

SUMMARY

The foregoing is a necessarily superficial overview of the principles and methods used in managing plant diseases. Several points emerging from this discussion are worth emphasizing. First, there are many weapons in the arsenal of the plant pathologist and they all must be considered in designing disease control systems. One method by itself seldom gives lasting control and a multiple integrated approach to control is necessary. Plant pathology presently uses integrated control as every conceivable method is used to escape, inhibit, inactivate, or kill the pathogen and permit growers to produce a healthy crop. We hear a great deal about over use of chemicals, but their use is only one of the weapons of plant disease management which has been integrated with long established cultural and biological methods. These principals and methods must be reduced to a practical methodology which the farmer can understand and use with economic results. The best scientific research is useless in plant disease management unless it reaches this point.

Plant pathologists must educate the public, governmental officials, and administrators on the importance of plant disease management. Unfortunately, each agricultural discipline tends to give his specialty top priority. Realistic figures on losses due to pests with reliable data to back them up must be presented to administrators if support is to be obtained.

Probably twice the number of plants are grown for food and fiber in the tropics that are grown in temperate zones. The research needs in plant disease management are many and pressing. Nevertheless, we should never lose sight of the fact that training the young scientists of developing nations to do the job of increasing food production themselves is the best and most efficient method.

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