Principles of Plant Disease Management

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Preface

This book presents the technology of disease management according to epidemiological principles. My intention is to provide a useful, substantive treatment of plant disease management for graduate and undergraduate students who have had an introductory course in plant pathology.

The major goal was to combine theoretical and practical elements into the solid background that practitioners and researchers in plant disease management need. The book was not meant to be a collation of specific control recommendations for specific crops. Instead, I have used specific diseases and control practices to illustrate basic principles or strategies.

I have initially illustrated how one derives principles of plant disease management from knowledge of plant disease epidemiology. Subsequently, one must consider diverse strategies to implement these principles. Then, we evaluate technologies for accomplishing the various strategies by using data in the research literature. This treatment of principles, strategies, and technologies should provide students with sufficient theory and detail that they can evaluate whether or not a given disease management approach is likely to be effective.

The book is designed to be adaptable to specific regions. I have limited the detail so that teachers can add examples typical of a region without overburdening students and can also illustrate similarities between their region-specific examples and the classical examples used in the text.

The book has been organized into three major sections. The introductory part (Chapters 1 and 2) includes a brief discussion of diagnosis. The second section (Chapters 3–6) analyzes disease epidemiology as the basis for disease management, and the third section (Chapters 7–14) includes strategies for implementing the two major principles of disease management. One group of strategies is designed to reduce the amount or efficacy of initial inoculum (Chapters 7–9); another group of strategies is designed to reduce the rate of epidemic development (Chapters 12–14). Two chapters (10 and 11) on plant disease resistance serve as transition between the major groups of strategies. The final chapter (15) illustrates the practical application of disease management principles in five diverse agroecosystems. Each section of that chapter was written by an expert knowledgeable about that agroecosystem.

In addition to college students, several other groups of readers should find this book of value. These include county extension agents, private consultants, professional plant pathologists, entomologists, plant protectionists, and environmentalists.

Completion of this book depended on the activities of many people. Students in the plant disease control courses and colleagues at Cornell University were instrumental in causing me to refine principles and to identify clear examples of the principles. R. V. James, W. A. Sinclair, P. A. Arneson, and V. J. Spadafora made many helpful suggestions. H. H. Lyon made photographs for almost every figure. Many of those figures were constructed by A. E. Apple. B. J. Mosher, who typed the manuscript, maintained her cheerful attitude throughout the many tedious revisions. I am grateful to each of these persons. T. Kosuge and the Plant Pathology Department, University of California at Davis, provided facilities and helpful conversations for the initiation of this book during my sabbatical there. My special thanks go to my wife, Barbara, who was supportive of my entire effort and was quietly tolerant during the hectic time-consuming periods.

William E. Fry

Contents

4 Epidemiology: Influence of the Biotic Environment

5 Effect of the Physical Environment

6 Disease Forecasting: Epidemiological Considerations

7 Exclusion to Reduce the Amount of Initial Inoculum

1

Introduction to Disease Management

The purpose of this book is to identify and integrate logical approaches to plant disease management. Modern disease management is based on knowledge and understanding of economic, environmental, cultural, genetic, and microbiological factors that determine crop development and crop use. Techniques discussed in Chapters 6–14 are derived from this understanding. In this chapter we identify the need for disease management, and show that disease management is an integral component of crop production, and that there are logical principles, strategies, and approaches to disease management.

Plant diseases have influenced human welfare since before recorded history. Books of the Bible which are well over 2000 years old refer to blights, blasts, and mildews (see, for example, I Kings 8:37). Ancient Greeks such as Theophrastus (374–288 B.C.) and ancient Romans such as Pliny (23–79 A.D.) were aware of plant disease (Orlob, 1964). Romans attempted to pacify Rubigo, their god of rusts, as early as 700 B.C. (Orlob, 1964). Prior to the nineteenth century, understanding of plant disease was a matter of superstition, and efforts to suppress disease were generally unsuccessful.

The influences of plant diseases have ranged from major catastrophes to minor annoyances. Two diseases that had calamitous effects are late blight of potato, caused by *Phytophthora infestans*, and brown spot of rice, caused by *Helminthosporium oryzae*. Late blight was directly responsible for the Irish potato famine of the 1840s. Irish peasants depended on potatoes as their major source of food. When late blight suppressed yields and rotted tubers in storage, the resulting food shortage created a famine which led to about a million deaths and caused about 1.5 million people to emigrate from Ireland (Large, 1940). Brown spot of rice caused human suffering of similar magnitude in Bengal during the 1940s. In 1942 weather favorable to *H. oryzae* enabled brown spot to suppress rice yields severely. Subsequently, rice prices rose so high that many people could not buy it. People from rural areas migrated to cities in the hope of finding work and rice. "Finding neither, they slowly died of starvation" (Padmanabhan, 1973). About two million people died as direct result of the rice brown spot epidemic.

Fortunately, severe plant disease does not always lead to severe human suffering. For example, two severe epidemics recently in the United States caused economic hardship and reduced the quality of life but did not lead to famine. In 1970, southern corn leaf blight, induced by *Helminthosporium maydis*, destroyed about 15% of the U.S. corn crop, causing a loss of about $1 billion (Ullstrup, 1972). From the 1930s through the 1970s, Dutch elm disease, induced by *Ceratocystis ulmi* (= *Ophiostoma ulmi*), destroyed elm trees in residential neighborhoods and in forests in the eastern two-thirds of the United States. The disease caused economic hardship to individuals and municipalities and lowered the quality of their environment (Sinclair and Campana, 1978).

Most plant diseases have smaller impacts than the four just mentioned. Epidemics are usually restricted to discrete geographic areas, even to single farms, fields, or gardens. However, regardless of their extent, if plant diseases suppress quantity or quality of food and fiber crops or if they reduce the esthetic value of landscapes or ornamental crops, growers will attempt control (suppression) by using various management strategies and tactics.

I. THE NEED FOR DISEASE MANAGEMENT

The epidemics of potato late blight, rice brown spot, southern corn leaf blight, and Dutch elm disease illustrate that diseases can be devastating on a large scale. Consequently, growers attempt to suppress most plant diseases. These efforts are not always successful. It is extremely difficult to quantify losses due to disease over a large region, but some authorities estimate losses due to pathogens, weeds, and insects to be about 30% of the total worldwide food production (Ennis *et al.*, 1975). In developed countries yield losses due to disease reduce income of some growers, elevate the price of the affected commodity, and thereby place an economic burden on producer and consumer alike. In developing countries, yield losses reduce an already insufficient food supply.

In this section we identify that "modern" agriculture and the world population explosion necessitate an increased efficacy of disease management in crop production.

A. Modern Agriculture

Several practices of modern agriculture have enhanced the destructive potential of diseases. Two of the most important are use of genetically similar crop plants in continuous monoculture and use of plants susceptible to pathogens.

Continuous monoculture of genetically similar plants selects efficiently for biotic pathogens that are well adapted to the genotype of the crop. Continuous monoculture provides the pathogen with a substrate that is continuous in both area and time. Rubber trees (*Hevea brasiliensis*) and a fungal pathogen (*Microcyclus ulei*) illustrate the result of growing similar plants in a monoculture instead of a mixed population. Both rubber trees and *M. ulei*, which induces South American Leaf Blight, are indigenous to the Amazon basin. Prior to the early twentieth century, latex was gathered from wild rubber trees in the jungle, and South American Leaf Blight was a common but nondestructive disease. In an effort to increase production amount and efficiency, rubber trees were planted in extensive plantations in the Amazon Basin during the early part of the twentieth century. In these monocultures, leaf blight became very destructive and contributed to failure of the plantations (Thurston, 1973). Thus, a disease that was not especially destructive on plants growing in a diverse ecosystem (several rubber trees per hectare) was very destructive on plants growing in an intensive monoculture.

Continuous monoculture of an annual crop in a given field will also select soil-bone pathogens well adapted to that crop. For example, continuous monoculture of cotton has enabled *Phymatotrichum omnivorum* to develop to large populations in soils of cotton fields. The consequence is that this fungus then induces severe root rot.

Modern agriculture increases the potential for severe plant disease when crop cultivars are developed without regard to their susceptibility to pathogens.

The 1970 southern corn leaf blight epidemic in the United States is a dramatic example. In 1970 more than 85% of all the corn in the United States had Texas male sterile (Tms) cytoplasm, which caused it to be particularly susceptible to *H. maydis* race T. This cytoplasm was widely used because it was helpful in constructing hybrids. Cytoplasmic inheritance of male sterility eliminated the need for manual detasseling of the female inbred parent. Southern corn leaf blight had not been a big problem before 1970, so the few reports indicating the greater susceptibility to *H. maydis* of hybrids with Tms cytoplasm (Mercado and Lantican, 1961) were not fully appreciated. Widespread planting of the susceptible genotype was the most important factor leading to the devastating 1970 epidemic.

Rice cultivar IR-8, one of the dwarf varieties developed as part of the "Green Revolution," is susceptible to rice tungro virus, and leafhopper vectors acquire the virus from infected plants readily (Rao and Anjaneyulu, 1979). Other dwarf or semidwarf cultivars (e.g., IR-20) are more resistant and tungro is less devastating on these crops.

In developing susceptible plants, modern agriculture has made a natural problem more severe. Whether plants evolve naturally or through plant breeding, evolution in the absence of a pathogen may result in a plant population particularly susceptible to the pathogen. The ease and speed of intercontinental travel create a great potential for pathogens to be introduced into regions where they have not previously existed. In most cases, introduced pathogens do not find suitable hosts or environments and do not survive. But where they do, introduced pathogens may devastate populations of native plants that evolved without selection for resistance. Extreme susceptibility of North American elms to the introduced *Ceratocystis ulmi* is the primary reason that Dutch elm disease has been so destructive in the United States.

Modern agriculture may permit some agents to be more destructive than they would be in natural ecosystems. Pathogens that eliminate their hosts in nature do not long predominate in the pathogen population because they lose the selective advantage of a susceptible host genotype. Susceptible plants are replaced by resistant individuals. In locations where pathogens and hosts have coevolved without human influence, resistant plants predominate in the host population (Leppik, 1970). Modern agriculture prevents the natural demise of a plant genotype because it uses various technologies to enable seed production in the absence of pathogens. By assuring a supply of susceptible plants, modern agriculture enhances the destructive potential of some pathogens.

In summary, agricultural practice aggravates the destructive potential of biotic pathogens by crowding hosts together in continuous monoculture, and by exposing susceptible plants to pathogens. In spite of strong efforts to develop resistant plants, the problem will continue because of the practical need to cultivate large areas of similar plants. Therefore, disease management is necessary.

B. World Population

The world's human population as of 1981 is greater than four billion and is projected to double again in fewer than 40 years. Some important resources are already in short supply. In many locations, food supplies have been inadequate. Whether shortages were caused by war (Southeast Asia), changes in the environment (Sahel), or plant disease (Bengal), the growing human population creates such a strong demand for food that even temporary shortages lead to massive human misery. Indeed, Mayer (1976) estimates that one billion people are undernourished and about 400 million live on the brink of starvation. Of all resources necessary to support human life, food is most critical. As the world population increases, the need for food will become more acute.

The global solution is to slow population growth. However, the task is very complex. Child bearing is influenced by religious, social, political, and economic factors. Populations are growing at different rates in different countries. Annual growth rates of developed countries are about 0.9% whereas those of less developed countries (LDC's) are about 2.4% (UN, Concise Report). About two-thirds of the world's population lives in LDC's. Even if the number of births dropped to the replacement rate, population of LDC's would more than double within the next 30 years, because about half of the people in LDC's are just now becoming of child-bearing age.

Although we do not yet have an adequate solution to population pressure, one component of any solution must include an effort to increase world food supplies. Suppression of plant disease and reduction of yield losses due to disease are a necessary part of increasing the food supply. The principles, strategies, and tactics of plant disease management are important to preventing yield losses.

Increase of human populations not only necessitates more effective disease management, but also constrains the technologies that can be applied. Large numbers of people burden the environment with waste and are in turn affected by it. In order not to overburden the environment with waste, human activities in general and disease management technologies specifically must have only limited detrimental impact on the environment. Some important agriculture resources (i.e., soil, fertilizer nutrients, and pesticides) become pollutants when removed from agricultural fields. Disease management in a crowded world must strive to contain these resources and to decrease their pollutant effects.

These paragraphs have illustrated that the burgeoning world population increases the need for disease management, but also constrains technologies that are acceptable. We next investigate some general characteristics of disease management.

II. DISEASE MANAGEMENT IN PERSPECTIVE

Disease suppression will be most efficient if a practitioner or researcher maintains at least three perspectives: disease management is an integral component of crop production; it employs a logical system of technologies; and it requires accurate understanding of the destructive potential of diseases.

A. Disease Management as an Integral Component of Crop Production

Most crop production practices influence disease development, some intentionally, others unintentionally. We have already observed that in modern agriculture we manage ecosystems to favor growth of a single plant. The resulting simplified ecosystems (=agroecosystems) that are unstable persist only because of management efforts by growers. Decisions such as choice of crop, crop cultivar, planting date, planting method, fertilization rates, pesticides, tillage type and frequency, irrigation method and frequency, harvesting method, and crop storage all influence diseases (Fig. 1.1).

Two important precepts result from the integral relation between crop production and disease development. The first is that disease management will be most successful if it is considered during all phases of crop production. Effective disease management may require several approaches, at several times during a crop cycle. For example, if a practitioner relies exclusively on weekly applications of fungicide to suppress potato late blight, the resulting disease suppression may be inefficient or inadequate. If irrigation practices, microenvironment of the field, and plant susceptibility all favor disease development and if there is a large pathogen population (infections in seed tubers or infections in neighboring potato fields, gardens, or in discarded potatoes) even weekly fungicide applications may not suppress disease adequately. Conversely, if these factors do not favor disease development, weekly fungicide applications will be unnecessary. Disease management will be most successful if it is integrated into the crop production system and if it employs diverse approaches.

The second precept is that changes in crop production will affect disease management. For example, replacement of tillage by herbicide

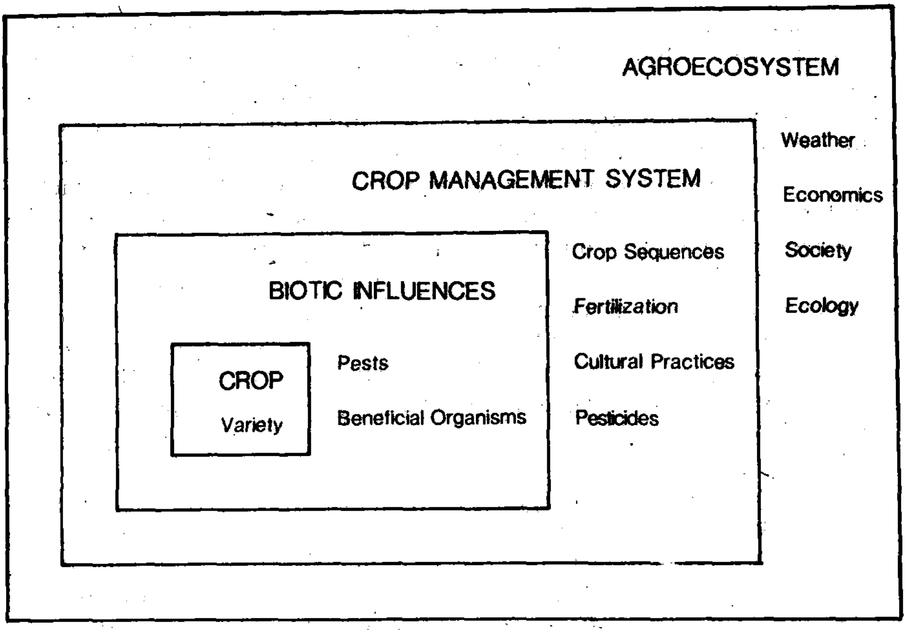

Fig. 1.1. Interrelationships of crop, biotic influences, crop management system, and agroecosystem.

application (conservation tillage) is likely to alter the activities of several pathogens; some may become more prevalent, others less so. Disease management must adjust to these changes. A second example concerns the availability and costs of fossil fuels. Modern agriculture in the United States depends intensively on oil. Oil and capital replaced human energy and work animals during the 30 years following 1945. During that time 30 million people emigrated from rural to urban areas of the United States (Edens and Koenig, 1980). Real prices of agricultural commodities declined by factors of 2 to 4 (Edens and Koenig, 1980). Mechanical and chemical crop production changed rapidly. Growers adopted widescale use of agricultural chemicals, in part to replace expensive human labor. Chemicals could be used, for example, to control weeds in lieu of cultivation, or to eradicate orchard pathogens in lieu of pruning diseased branches. As agriculture adjusts to increased energy prices and erratic supplies, disease management practices are likely to change.

B. Disease Management as a Logical Integration of Technologies

Disease management is the selection and use of appropriate techniques to suppress disease to a tolerable level. The appropriateness of a technique depends on several types of information: the pathogen involved (see Chapter 2), epidemiological characteristics of the agroecosystem (Chapters 3–6), and efficacy of the specific technique (see Chapters 7–14). Diseases may develop to intolerable levels if any part of this information is lacking. Definition of a "tolerable" level of disease is complex. Disease dynamics, economics, and social and health factors contribute to defining a tolerable level of disease. For example, consider the tolerable level of white mold, induced by *Sclerotinia sclerotiorum*, on snap beans for processing. During years in which there was a large supply of healthy snap beans, processers rejected lots of beans in which more than 1% were affected by white mold because it was expensive to remove moldy beans. When the supply of healthy beans was low, however, processers accepted lots in which up to 5% of the beans were affected. The "tolerable level" of white mold was influenced by supply of healthy beans.

Successful disease management may involve one or several techniques. Efforts that involve several techniques are more likely to be stable than are efforts relying on only a single technique. Changes in a pathogen population that allow it to overcome plant resistance and also to overcome the toxic effects of a pesticide are less likely in combination than singly. If both techniques are combined with cultural manipulations, which reduce initial pathogen populations and which do not favor pathogen growth, disease management should be both effective and stable.

C. Disease Management as the Result of Accurate Understanding of the Destructive Potential of Diseases

It is critically important that a grower or his/her advisor understand the destructive potential of a disease. Without this understanding some growers will waste effort and resources by suppressing even those diseases of little destructive potential. In contrast, other growers may allow some destructive diseases to develop to intolerable levels before attempting to suppress them. Errors of both types, wasted effort and destruction by unhindered disease, occur repeatedly. Growers who tolerate little risk are risk averse, and those who tolerate more risk are risk takers.

Disease forecasts and action thresholds are tools designed to enable growers to enhance the efficiency and adequacy of their disease management efforts. Forecasts are methods to predict whether or not disease is likely to occur in an important amount, and action thresholds are levels of disease or pathogen populations at which disease management