1.9

Managing Plant Pathogens

Introduction: Managing Plant Pathogens

UNIT OVERVIEW

Prevention and early diagnosis are critical to limiting damage by plant pathogens. This unit introduces students to the fundamental concepts and basic skills needed to identify and manage plant pathogens in certified organic production systems. Topics include the economic importance of plant pathogen management and the basic biology (especially life cycles) of bacteria, fungi, viruses, nematodes, phytoplasmas, and parasitic higher plants that are common plant pathogens and vectors in agricultural systems. Abiotic diseases such as nutrient deficiencies and air pollution are presented, along with the interactions among environment, pathogen, and crop plant. Management techniques for each pathogen and vector are also discussed.

MODES OF INSTRUCTION

> LECTURE (1 LECTURE, 3.0 HOURS)

The class lecture covers the basics of plant pathology: History and causes of disease, biology of causal organisms, disease diagnosis, ecological management, climatic factors. Note: as you begin the lecture, pass around 5 samples of ubiquitous plant diseases, including (at least 1) fungal, oomycete, bacterial, and viral on both herbaceous and woody plants. Choose plants and diseases the students are likely to have seen; powdery mildew and Botrytris are particularly helpful. After the discussion of the Evolutionary Ecology of Plant Diseases (point D in the lecture) is a good place to take a break.

> DEMONSTRATION 1: DISEASE IDENTIFICATION (1.5 HOURS)

During the disease identification demonstration, students will collect and diagnose diseases and disease-like samples they gather. Management techniques for each disease will be discussed.

> ASSESSMENT QUESTIONS: (0.5–1 HOUR)

Assessment questions reinforce key unit concepts and skills.

> POWERPOINT

See *casfs.ucsc.edu/about/publications* and click on Teaching Organic Farming & Gardening.

LEARNING OBJECTIVES

CONCEPTS

- The economic importance of plant pathogen management
- Basic biology (especially life cycles) of bacteria, fungi, viruses, nematodes, phytoplasmas, parasitic higher plants
- Abiotic diseases: Nutrient deficiencies and air pollution
- The disease triangle: Interactions among environment, pathogen, and plant
- Disease management from an ecological perspective

SKILLS

- How to collect samples of diseased plants and use diagnostic resources

Lecture 1: Managing Plant Pathogens

Pre-Assessment Questions

1. What is plant disease?
2. What are the steps involved in diagnosing plant diseases?
3. Why are plant diseases rare in natural systems, yet common in agriculture?
4. What are the main causal organisms for plant diseases?
5. What is the disease triangle, and how do we use it in ecological disease management?

A. Description, Economic Importance of Plant Disease

1. What is plant disease?

   A disruption in normal physiology—usually with some kind of negative effect on survival or fitness of the individual. For most plant pathologists, this includes infectious agents, nutrition, and air pollution. They also include nematodes as causing disease, but not insects, mites, or genetic abnormalities, unless infectious agents cause them. In practice, most plant pathologists work with infectious agents: The three most important, by far, are fungi, bacteria and viruses.

2. Economic importance of plant disease

   Diseases are important to humans because they cause damage to plants and plant products, commonly with an associated economic effect, either positive or negative. Negative economic effects include crop failure, incremental loss from lower quality or failure to meet market standards, elimination of crop options because of disease propagule buildup, or the costs of control methods. A positive effect is the creation of new endeavors to manage diseases.

B. Disease Diagnosis

Accurately diagnosing the cause of a disease is key to management. Unfortunately, professional help is frequently necessary. Fortunately, anyone can learn to collect a good sample (see Demonstration 1, Practical Plant Disease Diagnosis, Biology and Management).

1. Symptoms should exist on several individual plants and not have an obvious non-pathogen cause
2. Observe the pattern of symptoms or signs in the field, and don't forget to look at the roots if the symptoms include wilting. A symptom is an observation of the host response to infection by the pathogen. A sign is a visible structure of the pathogen itself, and is much more diagnostic.
3. Whenever possible, collect a sample that includes the border between healthy and diseased tissue (this is likely where the pathogen is most active, making the observation of signs, and pathogen isolation in the lab, more probable)
4. Collect a range of symptoms from light to heavy. Bring as much of each diseased plant as possible, including roots; bring samples from more than one plant and note the distribution of symptoms in the field.
5. Resources to help diagnose plant diseases include Cooperative Extension services, other professionals, and pictorial disease guides (see Resources section for print and web-based diagnostic resources). It is easy to misdiagnose a disease. Be cautious diagnosing and treating diseases on your own until you have experience.

C. Evolutionary Ecology of Plant Disease

Plant disease has an essential role in plant evolution and ecosystems. Understanding this role helps us design more resilient farm systems.

1. Viruses are special

   There is a debate as to whether viruses are living organisms or not. In many ways they straddle the line between biotic and abiotic. Viruses replicate and evolve at an extraordinary rate but they cannot make their own proteins, have no nutritional requirements, and most are composed of only nucleic acids and protein. How viruses evolved is unclear but many think that viruses are remnants of the earliest forms of "life." Viruses may lead to evolutionary changes in their hosts through transfer of genetic materials. Viruses hop in and out of different hosts and may occasionally bring along bits of host DNA with them and transfer it to a new host; they are the original genetic engineers.

2. Probable evolutionary history of non-virus pathogens

   A range of nutritional strategies exist for plant pathogens. The majority of fungi and bacteria exist as saprophytes (decomposers) indicating that this is likely the ancestral nutritional strategy. Early life forms died and saprophytes evolved to "clean up" and recycle their bodies. Gradually, saprophytes gained the ability to "feed" on live plants and became pathogens. Some evolved further, losing all saprophytic ability and became obligate pathogens (must have a living host). Fossil records of plant symbionts indicate that some pathogens, such as oomycetes, evolved from photosynthetic algae.

3. Obligate (must have a host) and non-obligate pathogens

   Non-virus plant pathogens range on a scale from completely obligate (eg powdery mildews) to almost completely non-obligate (e.g., Botrytis rots). Both types of pathogens are essential for ecosystem diversity and overall health.

   a) Obligate pathogens have evolved such that they can only live on the plant species within their narrow host range and have no saprophytic ability (i.e., cannot live on dead tissue). They cannot exist in an active form without a live host. An obligate pathogen that is extremely virulent (able to attack and kill all individuals of its host range) would result in extinction of its host, followed quickly by extinction of the pathogen itself. Thus, survival for both host and obligate pathogen depends on a dynamic, genetic relationship between host resistance and pathogen virulence, in which neither organism can gain complete domination over the other. Plants and pathogens have genetic flexibility such that sexual reproduction produces diverse individuals containing a variety of resistance and virulence genes (gene-for-gene interactions). In natural (undisturbed) ecosystems, obligate pathogens are common but do not inflict much damage on their hosts, except to the few plants that arise without resistance.

   b) Non-obligate pathogens don't have or need the same close genetic relationship with their plant hosts, because they can live on organic matter and/or a wide range of host plants. In these interactions host genetics are less important than environmental factors (e.g., humidity) in determining plant susceptibility. In undisturbed ecosystems, micro-environments vary widely, preventing non-obligate pathogens from doing much damage, but also helping to ensure no one plant species or genotype excludes all others. If a particular plant genotype dominates a natural system, plant disease will act as a "reset button" to restore diversity. Even the mighty redwoods will not dominate forever!

4. Why agriculture increases the incidence of plant disease

   Agriculture, and in particular the use of hybrid crop varieties and monocultures, circumvents natural checks and balances. For high yields, plants are grown close together and given abundant water: Ideal environments for obligate and non-obligate plant pathogens. Continuous, large quantities of genetically similar hosts skew natural selection to accelerate the appearance of highly virulent obligate pathogens. The associated high risk of widespread catastrophic disease can only be tolerated with effective pesticides and/or a strong plant breeding program. In contrast, ecological plant pathology attempts to decelerate the evolution and success of virulent pathogens by reducing the pathogens' access to these hosts, and improving the micro-environment. It isn't easy to control agricultural plant diseases ecologically because agriculture, by definition, is an unnatural environment, where we artificially favor specific plant genes and high plant density. However, we can use our knowledge of ecology and evolution to design the whole growing system to slow down, reduce, or avoid disease on plants. "Pesticide-based" agriculture has often ignored ecological principles in designing cropping systems.

5. Nutritional strategies of pathogens

   Bacteria and fungi do not ingest their host, but use absorptive nutrition (enzymatic degradation outside the pathogen). Nematodes use alimentary nutrition (enzymatic- and bacterial-mediated degradation inside the pathogen). Viruses are obligate intracellular molecular parasites: They do not acquire nutrition from their host, rather they use the host's molecular machinery to make new viruses.

D. How Pathogens Cause Disease

1. Enzymatic degradation

   Pathogens secrete enzymes, which catalyze the breakdown of host tissues, similar to the digestion of food in mammals. Symptom: Rotting.

2. Toxins

   Pathogens often benefit by producing toxins, which kill the tissue in advance of enzymatic degradation. In many pathogens, particularly non-obligate pathogens, toxins cause the majority of damage to the host. Symptom: Yellowing. Some pathogen products damage or plug up the plant's plumbing (xylem or phloem). Symptom: Wilting and stunting.

3. Growth regulators

   Pathogens often find it advantageous to produce growth regulators (or cause the host to produce them). The most common are those that cause translocation of nutrients to host cells and/or cause host cells to enlarge or divide in the vicinity of the pathogen, thus providing an increase in food for the pathogen. This allows the host to go on living while providing ample food for the pathogen. Symptoms: Tumors and stunting.

4. Genetic manipulation

   All viruses, plus a few bacteria, are able to force the plant to produce pathogen proteins (gene products) from pathogen genetic material. This severely decreases the amount of plant protein available for normal cell function, resulting in dysfunctional cells. Symptoms: Tumors, stunting, twisting, yellowing, mosaic patterns.

E. Causal Organisms

1. Bacteria

   Bacteria are single celled, have no nucleus, and one chromosome. They have a limited overall size, but unlimited reproduction by fission (no chromosomal segregation). This allows bacteria to reproduce faster than fungi and may result in quick epidemics. They use absorptive nutrition, and most in nature are saprophytic. Pathogens cause blights (rapid, toxic killing of plant tissue), rots (mushy breakdown), wilts (plugging of vasculature), and galls (growth regulator-mediated enlarged areas on plants). Bacteria are very sensitive to the environment. Individual actively replicating bacteria don't have much protection from sunlight and drying; however, in nature bacteria often exist as a biofilm, which consists of a mixture of different bacteria inside a matrix of protective slimy material (dental plaque is a biofilm of mouth bacteria). When not actively replicating or within biofilms, plant pathogenic bacteria have found ways to survive unfavorable conditions such as living inside seed coats. They spread by wind, water, seeds, people and insect vectors. Examples: Fire blight on pear, crown gall on many woody plants, citrus greening disease of citrus (huanglongbing), Pierces disease of grape, soft rot on many herbaceous plants.

2. Fungi

   Fungi are connected cells with nuclei, multiple chromosomes, mitochondria, and chitin for strength. Their overall size is unlimited, but without a vascular system they don't have good connections/ "communication" among segments and easily fragment into multiple bodies. Most are able to form differentiated structures used in reproduction and dispersal, e.g., mushrooms, spores. Like bacteria, most are saprophytic. Plants infected with fungi exhibit many symptoms, including rot, blight, leaf spots, and wilts. Fungi are fairly sensitive to light and dry conditions when growing, but can make very resistant structures to survive. They spread by wind, water, seed, and vectors. Examples: Apple scab, powdery mildews, peach leaf curl.

3. Oomycetes

   Oomycetes are like fungi in many ways, but have a different evolutionary history, perhaps arising from photosynthetic algae that lost the ability to photosynthesize. They produce zoospores (mobile spores) and oospores (survival spores). Most are water or soil inhabitants, and favored by free water or a film of water in which zoospores can swim. Oomycetes are spread by wind, water, seed, and vectors. Examples: Downy mildew, Pythium (damping-off), Phytopthora root rots.

4. Viruses

   Viruses are pieces of nucleic acid (RNA or DNA) inside a protective coating usually made only of protein. Viroids are even smaller than viruses and are just small pieces of naked RNA. They are always a parasite, although not necessarily a pathogen. The nucleic acid in a virus only codes for a few proteins that the virus needs to replicate and move through the plant. Viruses are molecular parasites meaning that they take over the molecular machinery of the host cell and cause it to produce virus proteins instead of host proteins. Symptoms mimic genetic abnormalities and nutritional deficiencies and include mosaics, yellows, distortions, and death. Viruses spread by mechanical means, seed, or vectors, which is an important consideration when choosing a control method. Most plant viruses are able to cause disease on several different hosts and some viruses can infect over 1,000 different species of plant. Examples: Tobacco mosaic virus, Cucumber mosaic virus, Tomato spotted wilt virus, Beet curly top virus.

5. Nematodes

   Nematodes are microscopic worms; the presence of a stylet (a needle-like mouthpart that is stabbed into the host) differentiates plant parasitic nematodes from saprophytes. They occur as ecto-nematodes (all but the head is outside the plant) and endo-nematodes (the entire nematode is inside the plant), and can be sedentary or migratory. Injection of the nematode's saliva upsets plant metabolism, causing an excess or shortage of nutrients or hormones. Symptoms include tumors and death of affected parts. Nematodes spread slowly unless carried by water or humans and occur most often in sandier soils and warmer climates. Examples: Rootknot nematode on many plants, beet cyst nematode on vegetables.

6. Phytoplasmas

   "Bacteria without a cell wall," phytoplasmas are fastidious (very fussy eaters) obligate pathogens that are only able to survive inside the plant vascular system (xylem and phloem). Because phytoplasmas cannot survive outside of the plant vascular system they are only spread to new plants through grafting and insect vectors. Examples: Pear decline, aster yellows.

7. Parasitic higher plants

   Parasitic vascular plants rely on a host for water and minerals (green-colored leaves) and sometimes carbohydrates as well (non-green-colored leaves). Deleterious effects are usually from hormonal upset of the host rather than nutrient or water loss. These parasites occur primarily in forestry, perennials, and poorly managed annual crops. Examples: Mistletoe on trees, dodder on vegetables.

8. Abiotic

   Nutrient toxicities (too much) and deficiencies (too little) in a plant occur as a result of nutrient toxicities or deficiencies in the rock from which the soil formed, or from poor management. Examples: Iron, nitrogen, potassium, zinc, copper, boron toxicities or deficiencies. Air pollution: Lead, NO_2, CO, HF, Ozone, SO_2.

F. Ecological Disease Management

1. Disease triangle (Host / Environmental Growing Conditions / Pathogen)

   In general, disease results from a susceptible host, a virulent pathogen, and a favorable environment. Together, these three factors make up the disease triangle. All three must occur at the same time for disease to occur. Pesticide-based agriculture concentrates on reducing the disease after it is first seen, or on a spray schedule using a calendar or forecaster that examines environmental conditions. Ecological disease management concentrates on avoiding conditions that predispose plants to disease. Note that this is quite unlike arthropod management, where a range of natural enemies can be encouraged or deployed. Organic farmers often make the mistake of assuming that the methods for disease and arthropod management are the same.

   Theoretically, approaches that avoid disease make more sense than those that try to fix things afterwards. Chemical fixes may have unintended effects, including plant toxicity and removal of natural enemies that were controlling other pest problems. In general, strongly growing, healthy plants are most able to resist disease, although exceptions occur. Plant susceptibility to a particular disease usually changes depending on the amount and type of physiological stress. To some extent, growers can manipulate the Disease Triangle (above)—the host, the pathogen, or environmental conditions—as outlined below.

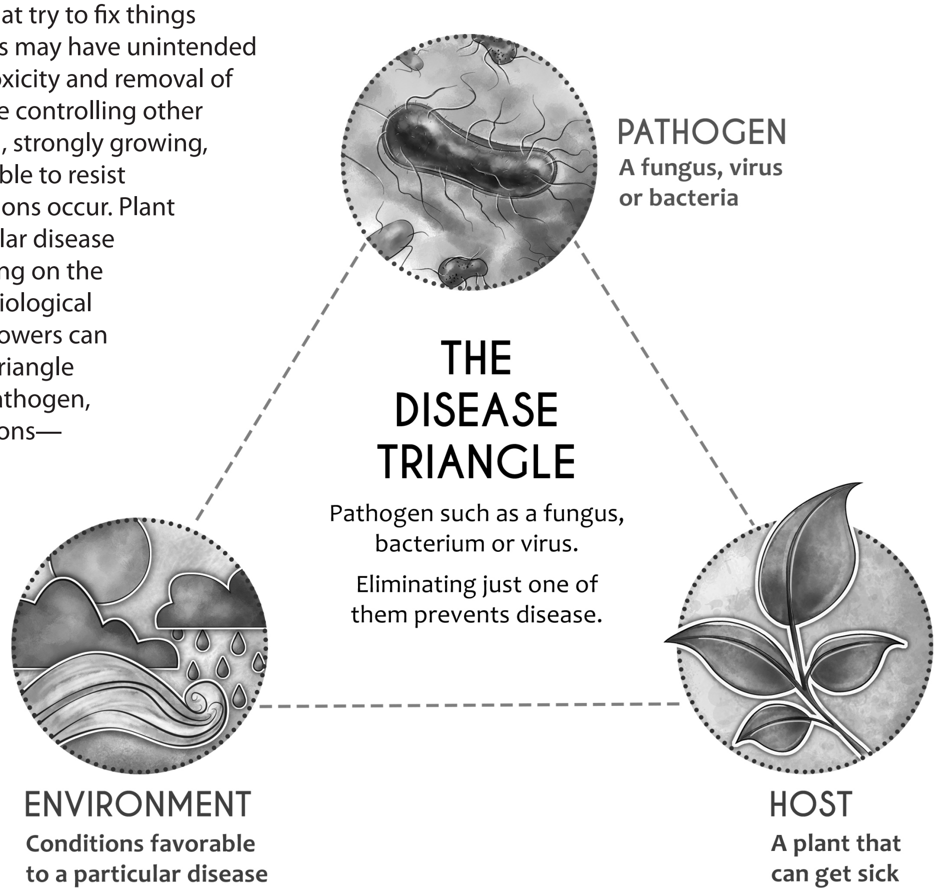

Illustration by José Miguel Mayo

2. Environmental manipulations

   The grower usually has most control over the cropping environment; examples include increasing plant spacing (to reduce humidity and decrease infection), regulating the amount of irrigation and drainage, choosing where the crop is grown (climate, soil, nutrition, landscape diversity, soil biodiversity), etc.

3. Host manipulation

   We often have less control of the host, since we have already chosen it in the crops we are growing. We can look for resistant cultivars, use pathogen-free planting materials (through quarantine or eradicative techniques such as hot-water seed treatment), and practice crop rotation (both temporal and spatial, such as intercropping).

4. Pathogen manipulations

   We try to keep the pathogen out of the field, or get rid of it when it is seen (either manually by removing affected host tissue, or by using chemical controls). Unlike industrial agriculture, few highly effective chemical controls are available to organic growers besides sulfur and copper. Commercial use of non-pathogenic microbes to compete with, kill, eat, and induce resistance to pathogens is far behind arthropod systems. Ecological agriculture, with its goal of both high numbers and diversity of microbes in soil and on leaves, may increase its reliance on non-pathogens for disease control in the future.

5. Climate and weather patterns that encourage the rate of growth, development, and distribution of certain plant pathogens

   In general, most plant pathogens like wet, warm weather with an abundance of free moisture on plant surfaces. However, some pathogens, such as powdery mildew, will be inhibited by rainfall, and overhead irrigation is sometimes used to control this disease. Weather that is too hot or too cold for the plant to grow properly can make the host susceptible to disease. Some pathogens, such as many of the anthracnose diseases, need rain to spread their spores; others need wind (such as the powdery and downy mildews), and some need both wind and rain (some bacterial diseases). A critical pest management step is to insure the compatibility of one's crop and crop varieties with the regional growing climate where production will take place.

Demonstration 1: Practical Plant Disease Diagnosis, Biology & Management

for the instructor

OVERVIEW

Through this hands-on field exercise and discussion, students will learn how to collect representative samples of diseased plant tissues from their own farm and garden, observe the instructor's methods for diagnosis, and learn management techniques for each pathogen and vector.

PREPARATION AND MATERIALS

1. If possible, students should have received the lecture portion of this unit covering disease diagnosis. If not, present this material.
2. Divide the class into groups of four or fewer students and give them a half hour to collect suitable samples of plants that they think may have disease and that they are most interested in.
3. Give the students a small break and sort the samples setting aside the ones that will best illustrate important plant disease concepts.

PREPARATION TIME

5 minutes

DEMONSTRATION TIME

1.5 hours

DEMONSTRATION OUTLINE

Proceed through as many samples as you have time for. Encourage student questions.

A. Diagnosis

1. Host
2. Type and extent of symptoms
3. How relatively useful the symptoms are for diagnosis
4. The importance of professional help, and lab analysis in accurate diagnosis
5. Discuss the danger of guessing

B. Provide illustrations of Pathogens or Characteristic Symptoms

C. Give a Synopsis of the Disease and Management Practices

1. The relative importance of actively managing the pathogen (i.e., potential agricultural and economic consequences of unchecked growth)
2. Biology: Life cycle and timing for intervention
3. Review of ecological disease management practices accepted under certified organic farming standards, using the disease triangle
   a) Environmental manipulations
   b) Host manipulations
   c) Pathogen manipulations

Demonstration 1: Practical Plant Disease Diagnosis, Biology & Management

step-by-step instructions for the students

OVERVIEW

The key to successful disease management is accurate diagnosis, an understanding of the biology of the causal agent, and use of the disease triangle to design a management system. These step-by-step instructions will assist you in collecting suitable samples of affected plants and allow the instructor to illustrate these concepts.

PROCEDURE

Collect suitable samples from plants that you think have disease and that you find interesting.

- Symptoms should exist on several individual plants and not have an obvious non-pathogen cause.
- Observe the pattern of symptoms or signs in the field (they can provide information about how the disease spreads) and don't forget to look at the roots whenever possible.
- Whenever possible, collect a sample that includes the border between healthy and diseased tissue.
- Collect a range of symptoms from light to heavy. Bring as much of the plant as possible, including roots. Bring samples from more than one plant.

Assessment Questions

1) List five different plant diseases, including the pathogen, plant host, and how each one interferes with normal plant physiology.

2) What are three environmental conditions that often encourage the growth, development, and distribution of bacterial and fungal blights?

3) Describe three specific environmental manipulations that farmers/gardeners may use to manage or prevent plant pathogens ecologically.

4) What are the four techniques that should always be included when taking a suitable sample for disease diagnosis?

5) Describe three specific plant host manipulations that farmers/gardeners may use to manage or prevent plant pathogens ecologically.

Assessment Questions Key

1) List five different plant diseases, including the pathogen, plant host, and how each one interferes with normal plant physiology.
   - *Bacteria*
   - *Fungi*
   - *Viruses*
   - *Nematodes*
   - *Mycoplasma-like organisms*
   - *Parasitic higher plants*
   - *Nutrient deficiencies*
   - *Air pollutants*
2) What are three environmental conditions that often encourage the growth, development, and distribution of bacterial and fungal blights?
   - *High relative humidity*
   - *Warm (temperatures 55°F or higher)*
   - *Free moisture on plant surfaces*
3) Describe three specific environmental manipulations that farmers/gardeners may use to manage or prevent plant pathogens ecologically.
   - *Increase crop spacing (to reduce humidity)*
   - *Regulate amount or timing of irrigation (to reduce humidity, moisture on foliage, or soil moisture levels)*
   - *Regulate drainage (to influence soil moisture levels)*
   - *Changes to crop and soil type*
   - *Changes to soil nutrient levels*
   - *Changes to crop location relative to climate and microclimate*
4) What are the four techniques that should always be included when taking a suitable sample for disease diagnosis?
   - *Symptoms existing on several individual plants*
   - *Make observations of patterns of symptoms*
   - *Make observations of both foliage and roots*
   - *Collect samples from the border between healthy and potentially diseased plant tissues*
   - *Collect a range of samples exhibiting symptoms including heavily and lightly affected*
5) Describe three specific plant host manipulations that farmers/gardeners may use to manage or prevent plant pathogens ecologically.
   - *Select disease-resistant cultivars*
   - *Use only certified disease-free plant materials*
   - *Crop rotations in both space and time*

Resources

PRINT RESOURCES

BOOKS

Agrios, George N. 2005. *Plant Pathology, Fifth Edition*. Amsterdam: Elsevier Academic.

A textbook of plant pathology from general to specific topics.

Compendium of Diseases. St. Paul, MN: APS Press.

A series of publications covering diseases of many common crops, published by the American Phyotopathological Society's APS Press.

Flint, Mary Louise. 1998. *Pests of the Garden and Small Farm: A Grower's Guide to Using Less Pesticide, Second Edition*. Publications 3332. Oakland, CA: University of California Division of Agriculture and Natural Resources.

Covers insects, mites, plant diseases, nematodes, and weeds of fruit and nut trees and vegetables. Individual sections describe the biology, identification, and control of common pests and pathogens; includes symptom-identification tables organized by crop. Recommended methods rely primarily on organically acceptable alternatives.

Flint, Mary Louise. 2012. *IPM in Practice: Principles and Methods of Integrated Pest Management, Second Edition*. Publications 3418. Oakland, CA: University of California Division of Agriculture and Natural Resources.

Great introduction to understanding and implementing integrated pest management of plant pathogens, weeks, and insects.

Flint, Mary Louise, and Steve Dreistadt. 1998. *Natural Enemies Handbook: The Illustrated Guide to Biological Pest Control*. Publication 3386. Oakland, CA: University of California Division of Agriculture and Natural Resources.

How-to book describes ways to combine cultural, physical, and chemical methods with biological control; to minimize pesticide impacts on natural enemies; release natural enemies and enhance their activity; and identify and use natural enemies to control pests.

Koike, Steve. 2006. *Vegetable Diseases: a Color Handbook*. Manson Publishing Ltd.: London.

Extensive, excellent photos of many common vegetable diseases.

Koike, Steve, Mark Gaskell, Calvin Fouche, Richard Smith, and Jeff Mitchell. 2000. *Plant Disease Management for Organic Crops*. Publication 7252. Oakland, CA: University of California Division of Agriculture and Natural Resources.

Describes various techniques for managing diseases in organic crops, including use of resistant plants, site selection, pest exclusion, and compost use.

Pscheidt, Jay W., and Cynthia M. Ocamb (eds.). 2015. *Pacific Northwest Plant Disease Management Handbook*. Corvallis, OR: Oregon State University. pnwhandbooks.org/plantdisease/node/1788/print

A ready reference guide to the control and management tactics for the more important plant diseases in the Pacific Northwest.

Schumann, Gail L., and Cleora J. D'Arcy. 2012. *Hungry Planet: Stories of Plant Diseases*. St. Paul, MN: The American Phytopathological Society.

Describes the impact of several different plant diseases and illustrates basic biological and plant pathology concepts in an easy-to-understand way.

University of California IPM Program. *Integrated Pest Management Manual Series*. Oakland, CA: University of California Division of Agriculture and Natural Resources.

Comprehensive IPM manuals for growers and pest control advisors offer detailed information on numerous agricultural crops, landscape trees and shrubs, and home gardens.

PERIODICALS

Annual Review of Phytopathology

Excellent summaries of major topics.

Biocontrol Science and Technology

Presents original research and reviews in the fields of biological pest, disease and weed control.

IPM Practitioner

Focuses on management alternatives for pests such as insects, mites, ticks, vertebrates, weeds and plant pathogens.

Journal of Sustainable Agriculture

Basic research on social and agronomic aspects of sustainable agriculture.

Microbial Ecology

International forum for the presentation of high-quality scientific investigations of how microorganisms interact with their environment, with each other and with their hosts.

Organic Farming Research Foundation Reports

Summarizes research projects (many by growers) on practical organic farming topics, including pest and disease control.

Phytopathology

Primary research journal.

Plant Disease

Primary practical research journal.

WEB-BASED RESOURCES

Agriculture Research Service Biological Control of Plant Diseases

www.ars.usda.gov/research/programs.htm

See the Crop Production and Protection programs for descriptions and reports of USDA-funded research on pests and disease control.

American Phytopathological Society

apsnet.org

The Education section covers many specific plant pathogens and overall concepts. Includes a reference list of books, websites, videos, etc. The Illustrated Glossary provides definitions and illustrations of many technical terms used in plant pathology. The article on the Plant Disease Doughnut (http://www.apsnet.org/edcenter/instcomm/TeachingArticles/Pages/PlantDiseaseDoughnut.aspx) provides a useful graphic to describe the difference between a disease and a pathogen.

California Pest Management Guidelines

www.ipm.ucdavis.edu/IPMPROJECT/pubsmenu.htmll

Official guidelines for pest monitoring techniques, pesticides, and nonpesticide alternatives for managing insect, mite, nematode, weed, and disease pests in agricultural crops, floriculture and ornamental nurseries, commercial turf, and in homes and landscapes.

Consortium for International Crop Protection, IPMnet

www.ipmnet.org

New research, links, bulletin board, newsletter, based out of Oregon State University.

New York State/Cornell IPM Program

www.nysipm.cornell.edu

Valuable resource covering many fruit and vegetable crops, including identification information, cultural practices and inputs to manage pests and diseases.

North Carolina State University Center for Integrated Pest Management

www.cipm.info/

Database of resources on pest management in North Carolina.

Pacific Northwest Plant Disease Management Handbook

pnwhandbooks.org/plantdisease

This handbook is intended as a ready reference guide to the control and management tactics for the more important plant diseases in the Pacific Northwest.

UC Sustainable Agriculture Research and Education Program

www.sarep.ucdavis.edu

Includes reports and resources on organic farming and on SAREP-funded research projects, including Biologically Integrated Farming Systems (BIFS). See the SAREP-funded Projects Database.

SUPPLEMENT 1

The Importance of Farmer-to-Farmer Social Networks

The three key factors that interact to determine plant pathogen activity in crops are susceptible host, virulent pathogen, and environmental conditions. As described in the lecture, the goal of an organic farming system is to slow down, reduce, or avoid disease problems by designing the system to be resilient and unfavorable to pathogens. Knowledge of local disease pressures and prevention practices shared amongst farmers can be an important element in developing a disease-resistant farming system.

Of the three factors illustrated by the disease triangle, organic systems have influence over, and sometimes focus on, environmental and growing conditions. By contrast, conventional systems often focus on trying to eliminate individual pathogens through chemical control. Because certified organic growers have few options for approved chemical controls (e.g., copper, sulfur, neem), synergistic environmental and host controls are implemented to reduce or avoid the potential for an outbreak in the first place.

The techniques and methods one implements in an ecological system to deter plant diseases from causing significant damage vary based on several factors, including: geography, climate, soil type, and baseline presence of the pathogen. Strong, healthy plants in microbiologically active soils provide farmers with a helpful ecological defense to disease. Selecting crops well suited to local soil and climatic conditions is thus important to building a resilient system. Season by season, farmers who select and save seeds from their most disease-resistant individual plants actively build a stronger defense against pathogen pressures. Similarly, building soil health with regular additions of compost and cover crops helps support high levels of microbial activity in soils, which may act as a deterrent and competitive force against disease-causing bacteria and fungi. Local conditions also dictate the likely presence of a disease. For example, places where cool nights and morning dew persist (e.g., coastal California) provide more favorable conditions to downy mildew than a dry, warm climate (e.g., Texas). Being informed by place is both a part of the agroecological philosophy as well as a practical skill that farmers need to continually develop in order to effectively manage pests and diseases.

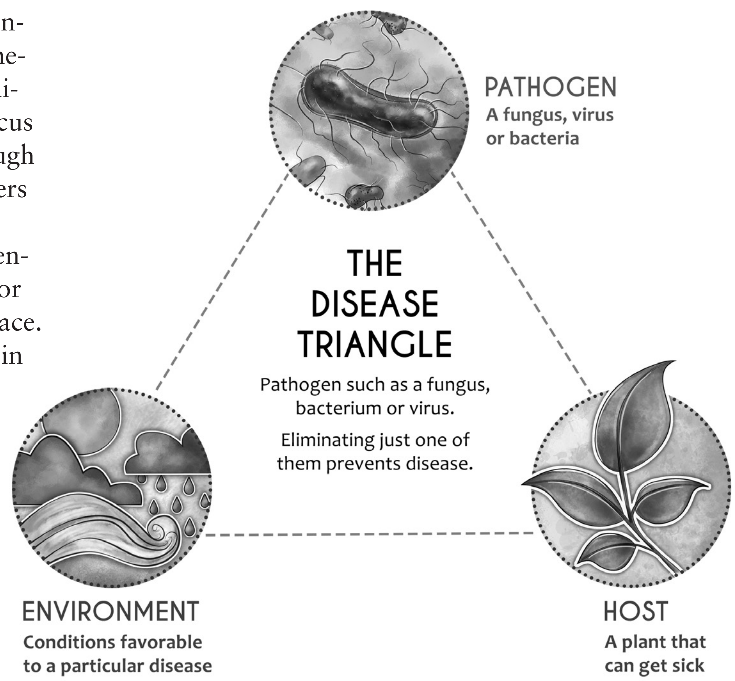

Illustration by José Miguel Mayo

For new farmers, and those who move to new climates, acquiring this knowledge may be challenging. Previously learned techniques and methods from farming experiences in other locations may not always be applicable. Counties may have university-supported agricultural extension offices that offer publications on pest and pathogen management, although these resources are often geared toward a handful of commodity crops. Local cooperative extension offices mostly offer resources for conventional agriculture throughout the country, and may not be able to provide information specifically for organic systems. Federal research funding is often inadequate to support research and development for pest and pathogen management in these systems, so extension staff members may not be able to prioritize this kind of research. The location-specific nature of agroecological pathogen management and the limited availability of extension services in some areas means that established local farmers are often the best resources for new farmers on information about diseases in the area and locally adapted management techniques.

Benefits of Experiential Learning

Farmers, more so than most, benefit greatly from experiential learning. Climate, precipitation, soil nutrient availability, and seed viability are just a handful of important variables that affect crop growth and disease presence and are subject to change each season. The collective experience of a local community of farmers with these variables will always dwarf any individual's experience in the same season. For this reason, sharing experiential knowledge with other farmers, new and old, is an important aspect of the practice of agroecology and organic farming.

From this perspective, each farmer's season growing a particular crop, say beets, is a "field trial" from which that farmer learns about his or her successes and failures in controlling pests and diseases. Taken together, a local community of beet farmers offers a wealth of knowledge on beet pest and disease management that stands to benefit all. Even in a competitive economy, sharing best practices for disease management creates mutual benefits for neighboring farmers because disease pressure on one plot (especially highly mobile bacteria and fungi) threatens every plot within that pathogen's range of mobility. Since organic systems rely more on prevention than treatment, maintaining the integrity of the system is paramount for effective disease management.

In addition to the disease management benefits of farmer-to-farmer networks, there is another important reason for these connections—empowerment. The budding Farmers' Guild network in California (www.farmersguild.org) is one example of this type of self-supporting, farmer-helping-farmer movement, although often these networks include mostly beginning farmers and it is important to access the knowledge of long-time farmers to be most effective. Internationally, the Movimiento Campesino a Campesino (MCaC), which started in Guatemala, provides an example of the sociopolitical importance of a strong network of small, sustainable farmers and their allies.

The MCaC began as an attempt to improve rural, smallholder farmers' livelihoods through farmer-led, sustainable agricultural development, long before the term was coined in international discourse. As a result of the Green Revolution, increasing national debt, and reduced government support for traditional agriculture, campesinos (or peasant farmers) turned to each other for support and development assistance. Through loosely organized networks, farmers who learned successful cultivation, fertility, and irrigation techniques taught others the same methods. These farmers freely chose to adopt or ignore the techniques, depending on their local conditions. If adopted and successful, the second group would pass the techniques on to another set of farmers, and so on. After thirty years, the MCaC has transitioned from a practical training network into an international social movement for equity and the rights of smallholder farmers and against destruction of soil, water, and genetic diversity.

The significance of knowledge discovered and shared locally cannot be overestimated. After years of marginalization by colonizers, government actors, private firms, or large landowners, campesino communities often exhibit distrust of outsiders, even those with good intentions. The MCaC, and others like it, formed and carried on by campesinos themselves, is self-empowering and provides a path towards independence and self-sustainability.

Still, sustainable agriculture is the alternative, not the dominant system that guides resource distribution, and trade and environmental policy. Beyond spreading the practice of sustainable agricultural development, the MCaC must cultivate social, economic, and political power to change the institutions that shape agriculture. This will require new knowledge to be disseminated through the same farmer-to-farmer exchanges that brought sustainable practices to so many smallholder farmers in developing countries at the outset.

There will also have to be much more education of citizens in developed countries, where much of the national debt of developing countries is held and significantly impacts agricultural policy of debtor nations (see Lecture 2 in Unit 3.1, Development of

U.S. Agriculture). As one campesino puts it, "I think we should not fall in the trap of seeing the development of agroecology by just looking at the physical aspects of the farm or just at the economics. Agroecology is not just a collection of practices. [It] is a way of life."

More information on farmer-to-farmer networks–

Holt-Gimenez, Eric. 2006. *Campesino a Campesino: Voices for Latin America's Farmer to Farmer Movement for Sustainable Agriculture*. Oakland, CA: Food First Books.

Holt-Gimenez, Eric. 2001. Scaling up sustainable agriculture: Lessons from the Campesino a Campesino movement. *LEISA Magazine*, Vol. 17 No. 3.

www.agriculturesnetwork.org/magazines/global/lessons-in-scaling-up/scaling-up-sustainable-agriculture