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, mycoplasma-like organisms, 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.

> DEMONSTRATION: 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.

LEARNING OBJECTIVES

CONCEPTS

- The economic importance of plant pathogen management
- Basic biology (especially life cycles) of bacteria, fungi, viruses, nematodes, mycoplasma-like organisms, 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 diagnose diseases and use diagnostic resources

Lecture Outline: Managing Plant Pathogens

for the instructor

A. Pre-assessment Questions

1. What is plant disease?
2. How do pathogens cause disease symptoms?
3. What are the main causal organisms?
4. What is the disease triangle, and how do we use it in ecological disease management?
5. How do you diagnose plant diseases?

B. Description and History of Plant Disease

1. What is plant disease?
2. Economic importance of plant disease
3. Evolution of hosts and pathogens
   a) Probable evolutionary history
   b) Nutritional strategies of pathogens
   c) Obligate and non-obligate pathogens
   d) Co-evolution of plants and pathogens

C. How Pathogens Cause Disease

1. Enzymatic degradation
2. Toxins
3. Growth regulators
4. Genetic manipulations

D. Causal Organisms

1. Bacteria
2. Fungi
3. Oomycetes
4. Viruses
5. Nematodes
6. Phytoplasmas
7. Parasitic higher plants
8. Abiotic

E. Disease Diagnosis

1. Field-scale patterns of disease
2. Symptoms and signs
3. Koch's Postulates
4. Resources for disease diagnosis

F. Ecological Disease Management

1. Disease triangle
2. Environment manipulations
3. Host manipulations
4. Pathogen manipulations
5. Climate and weather patterns that encourage the rate of growth, development, and distribution of certain plant pathogens

Detailed Lecture Outline: Managing Plant Pathogens

for students

A. Pre-assessment Questions

1. What is plant disease?
2. How do pathogens cause disease symptoms?
3. What are the main causal organisms?
4. What is the disease triangle, and how do we use it in ecological disease management?
5. How do you diagnose plant diseases?

B. Description and History 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 but not insects, mites, or genetic abnormalities, unless infectious agents cause them. In practice, most plant pathologists work with infectious agents.

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. Plant diseases are also responsible for the creation of new industries to develop control methods.

3. Evolution of hosts and pathogens

   a) Probable evolutionary history

      Early life forms died and saprophytes evolved to "clean up" and recycle their bodies—the only way to have life in the earth's closed system. Gradually, saprophytes gained the ability to "feed" on early life forms while still alive, and became pathogens. Ancient fossil records of plant symbionts indicate that some pathogens such as oomycetes are more closely related to photosynthetic algae.

   b) 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 skip the nutrition phase and take over the genetic and protein-synthesizing processes of the cell and force it to produce new viruses. Viruses have no role in "cleaning up" the dead, but may lead to evolutionary change in their hosts through transfer of genetic materials. Viruses hop in and out of different hosts and by accident, bring along bits of DNA with them—the original genetic engineers.

c) Obligate and non-obligate pathogens

Obligate pathogens can only live on the plants within their host range and have no saprophytic ability. They cannot exist in an active form without a live host. Non-obligate pathogens have saprophytic ability, which ranges from survival only on their dead host to survival and growth on a wide range of organic materials. The implications of obligate vs. non-obligate survival on disease management will be discussed below.

d) Co-evolution of plants and pathogens

A completely successful obligate pathogen (able to attack and kill all individuals of its host range) would result first in extinction of its host, followed quickly by extinction of the pathogen itself. Thus, survival for both host and 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 reproduction produces diverse individuals containing a variety of resistance and virulence genes. In undisturbed systems, natural selection prevents a plant or pathogen from being completely resistant or virulent.

Agriculture, and in particular the use of hybrids, provides continuous, large quantities of genetically similar hosts, thus skewing natural selection to accelerate the evolution of highly virulent pathogens, leading to highly damaging, uncontrollable diseases. Ecological plant pathology attempts to decelerate the evolution of virulent pathogens by reducing the pathogens' access to these hosts. 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. 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 during system design.

C. How Pathogens Cause Disease

1. Enzymatic degradation

   In their most basic form, pathogens secrete enzymes, which catalyze the breakdown of host tissues, similar to the digestion of food in mammals.

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.

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. Obligate pathogens are very good at this technique because it allows the host to go on living, but still provides extra food for the pathogen.

4. Genetic manipulations

   All viruses plus a few bacteria are able to force the plant to produce pathogen gene products from pathogen genetic material. This starves plant cells and disrupts their function.

D. 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 have quick epidemics. They exhibit 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—when active, they don't have much protection from sunlight and drying. When not active, they have found ways to survive unfavorable conditions such as living inside seed coats. They spread by wind, water, seeds, and vectors (such as insects, people). Examples: fire blight on pear, crown gall on many woody plants, 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, 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. 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)—those with a protein coat are viruses, those without are viroids. They are always a parasite, although not necessarily a pathogen. The nucleic acid in a virus or viroid codes for a few proteins and takes over a cell, upsetting normal metabolism and causing an excess or shortage of molecules used to make new cell components. Symptoms mimic genetic abnormalities and include mosaics, yellows, distortions, and death. Viruses spread by mechanical means, seeds, or vectors (very important when choosing a control method). Examples: squash mosaic on zucchini, yellow viruses on many plants, tobacco mosaic on tomato.

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 only found in plant sap. They spread by grafting or insects. Examples: pear decline, Pierce's disease on grapes.

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 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 and deficiencies occur as a result of nutrient toxicities or deficiencies in the rock from which the soil formed, or from poor management. Examples: zinc, copper, boron toxicities and deficiencies. Air pollution: lead, NO_2, CO, HF, Ozone, SO_2.

E. Disease Diagnosis

1. Field scale patterns of disease

   Identify the host. Look for patterns of damage—circular, down rows, or across rows can provide clues of how the disease spreads. Focus on borders between healthy and diseased; this is likely where the pathogen is most active making the observation of signs, and pathogen isolation in the lab, more probable.

2. Symptoms and signs

   Be clear on whether you are looking at a symptom or a sign. 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. Observe the full range of symptoms; compare symptoms to pictures. Find out what diseases are common locally. Don't be surprised if you aren't sure: Many diseases need to be identified with laboratory techniques. Don't guess.

3. Koch's Postulates

   Koch's Postulate is a method for proving that a particular organism causes disease. The organism is removed from the plant, grown in pure culture,and inoculated to healthy plants. If disease results and the same organism is re-isolated, the pathogenicity is confirmed.

4. Resources for disease diagnosis

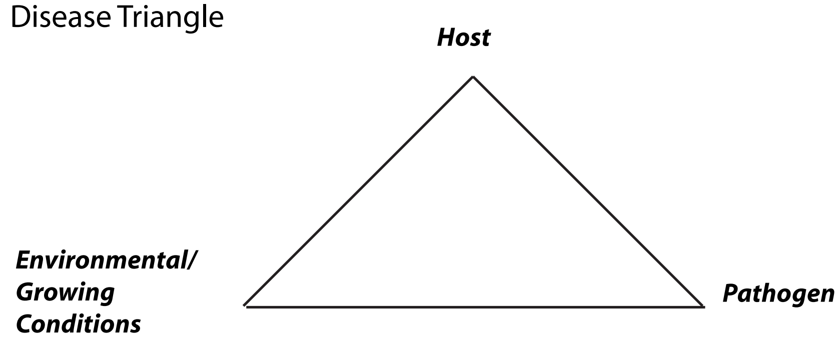
   Resources to help diagnose plant diseases include Cooperative Extension services, other professionals, and pictorial disease guides (see Resources section for print and web-based diagnostic resources).

F. Ecological Disease Management

1. Disease triangle

   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. Ecological disease management concentrates on avoiding conditions that predispose plants to disease.

Disease Triangle



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.

2. Environment 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 manipulations

   We often have less control of the host, since we have already chosen it in the crops one is 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). Copper, sulfur, Neem, and potassium bicarbonate are the primary disease-controlling chemicals allowed in certified organic production. A newer technique that still needs a lot of understanding is the role non-pathogenic microbes have in competing, killing, eating, and inducing resistance to pathogens. 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: Disease Identification

for the instructor

OVERVIEW

Through this hands-on field exercise and discussion, students will learn how to collect representative samples of diseased plant tissues and practice identifying plant pathogns using printed and web-based diagnostic resources. The instructor should also discuss 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. Gather good samples of 8 different diseases from as many different hosts and plant pathogen groups as possible. Arrange the samples in 8 well-separated stations.
3. At each station, place an appropriate reference book* that covers that particular host (or provide a computer with online access), a 2–10x hand lens or dissecting scope, and a small knife. (*Web-based resources may be used as substitute where available. See Resources section.)
4. Divide the students into eight groups
5. Each group moves through each of the stations (with a four-minute time limit) and attempts to identify each host and diagnose each disease. The instructor should be on-hand to provide guidance. When all groups have finished all the stations, the entire group meets to compare notes. The instructor should explain the elements of both correct and incorrect diagnoses, as well as management options for each pathogen and vector identified.

PREPARATION TIME

1 hour

DEMONSTRATION TIME

1.5 hours

DEMONSTRATION OUTLINE

A. Review/Discuss Collection of a Suitable Sample

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
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.

B. Review/Discuss Considerations in Disease Diagnosis

1. Field-scale patterns of disease
2. Symptoms and signs
3. Koch's Postulates
4. Resources for disease diagnosis

C. At Each Station, Have Each Group Present Their Diagnosis

D. Discuss Each of the Following

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

E. Provide Illustrations of Pathogens or Characteristic Symptoms

F. When Possible, 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
   a) Environment manipulations
   b) Host manipulations
   c) Pathogen manipulations

Demonstration: Disease Identification

step-by-step instructions for students

OVERVIEW

The key to successful disease diagnosis is the collection of a suitable sample. These step-by-step instructions will assist you in collecting suitable samples of affected plants and accurately diagnosing the cause of the disease.

PROCEDURE

1. Collect a suitable sample
   - 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.
2. Attempt diagnosis
   - Observe under magnification
   - Use reference books and pictorial disease guides; good pictures of most diseases can be obtained on the worldwide web
   - Ask professionals
   - Submit a sample to local farm advisor, or nursery professional

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, G.N. 1988. *Plant Pathology, Fourth Edition*. New York: Academic Press.

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, 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, 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.

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

Canadian Journal of Plant Pathology

IPM Practitioner

Journal of Sustainable Agriculture

Basic research on social and agronomic aspects of sustainable agriculture.

Microbial Ecology

Phytopathology

Primary research journal.

Organic Farming Research Foundation Reports

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

Plant Disease

Primary practical research journal.

WEB RESOURCES

Agriculture Research Service Biological Control of Plant Diseases

www.barc.usda.gov/psi

Information on biological control of pests and diseases.

California Pest Management Guidelines

www.ipm.ucdavis.edu/PMG/crops-agriculture.html

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.

IPM Resources-Vegetables

www.ippc.orst.edu/cicp/Vegetable/veg.htm

Database of resources on vegetable pest management

Northwest Plant disease guidelines.

www.bcc.orst.edu/bpp/

Disease guidelines for Oregon and Washington.

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).