

1.8 Arthropod Pest Management

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Introduction: Arthropod Pest Management

UNIT OVERVIEW

Although organic growers work to prevent or minimize pest damage, more direct treatment measures are sometimes required to prevent economic loss. This unit introduces students to the principles, practices, and skills used to manage beneficial and problem arthropods within the standards set for certified organic production systems. The first lecture introduces the role of pest management in organic farming systems and how specific practices used in sustainable production serve to prevent the growth of pest populations beyond economic thresholds. In lecture 2 and through field and laboratory exercises, students will be introduced to the basic biology and ecology of arthropods as they relate to identification for management purposes. The principles and practices of field monitoring, determining thresholds at which various management options would be exercised, and the treatment options that are available for certified organic farms are then discussed. The design principles and practices used to enhance biological control through the use of non-crop vegetation will also be introduced. Students will be encouraged to address arthropod pest problems in a manner that makes best use of local resources, and is compatible with certified organic production standards and an ecological approach to the design and management of agricultural ecosystems.

MODES OF INSTRUCTION

- > LECTURES (2 LECTURES, 1.5 HOURS EACH)
Lecture 1 covers the role of pest management in organic farming systems, the farming practices that aim to prevent the unchecked growth of pest populations, the components of a pest management program, and the common procedures used in arthropod monitoring. Lecture 2 introduces the basic biology and ecology of arthropods as they relate to identification and management
- > DEMONSTRATION 1: PEST MONITORING, SAMPLING, AND IDENTIFICATION (2 HOURS)
Demonstration 1 introduces the practices of field monitoring. Students practice systematic monitoring techniques for sampling arthropods and crop damage, then identify the samples, and research and discuss the economic thresholds for control action intervention and control action options.
- > DEMONSTRATION 2: FIELD OBSERVATIONS (2 HOURS)
In this demonstration, students and instructor visit a working farm and review the pest management program growers have developed for their certified organic farming operation.
- > ASSESSMENT (0.5 HOUR)
Assessment questions reinforce key unit concepts and skills.

LEARNING OBJECTIVES

CONCEPTS

- The role of pest management in organic farming systems
- Farming and gardening practices that serve to prevent unchecked growth of pest populations
- Essential components of a sound pest management program for certified organic farming systems
- Basic arthropod biology and ecology as they relate to management
- Simple and practical methods for monitoring and identifying arthropods, classifying them by functional group, and classifying their damage
- Commonly available active control treatments suitable for use on certified organic farms and gardens
- An ecosystem approach to enhancing biological control through the use of non-crop vegetation

SKILLS

- How to sample for arthropods
- How to identify insects to order, common name, genus and species using printed and on-line resources
- How to classify insects by functional grouping
- How to recognize key pest groups and their damage symptoms
- How to recognize the basic groups of beneficial arthropods
- How to use IPM printed and on-line resources to determine control action thresholds
- How to evaluate a range of control measures available and their relative strengths and weaknesses

Lecture 1 Outline: Arthropod Pest Management

for the instructor

A. Pre-Assessment Questions

1. Why is the management of arthropods so important in crop production?
2. Why are pesticides ineffective in controlling insect pests?
3. What are some of the things insects and other arthropods do to enhance agricultural and environmental quality?
4. Which agricultural practices can you describe that serve to prevent the growth of pest populations beyond economic thresholds?
5. What would be some of the components of a sound pest management program for a certified organic farm or garden?
6. What would be the best ways to monitor for pests in the garden and small farm?
7. How would you go about determining if an insect is a “pest” or a “beneficial”?
8. What are several different organically acceptable ways to actively control pests?

B. Why Managing Arthropods Is Important in Crop Production

1. Reduced productivity/yield
2. Spread of plant pathogens
3. Reduced visual aesthetics and thus marketability of crop (cosmetic damage)
4. Crop loss
5. Build up of pest populations in subsequent years

C. A Sketch of Arthropod Natural History

1. Insects
 - a) The number of insect species
 - b) Example: The diversity and abundance of Coleoptera (beetles)
 - c) Estimates on the number of species of insects yet to be described: 2 and 100 million species
 - d) Tropical diversity: At least 6 million to 9 million species
2. Why have insects been so successful throughout natural history?
 - a) Insects have been around for more than 350 million years
 - b) Except for marine habitats, insects have adapted to almost every environment possible
 - c) The reasons for their success include the following factors:
 - i. Short generation times and high numbers of offspring
 - ii. A highly efficient body plan and construction
 - iii. The ability to fly, aiding dispersal to new and potentially favorable environments
 - iv. The development of “complete” metamorphosis
3. Ecosystem “services” provided by arthropods in agroecosystems: The good stuff bugs do
 - a) Pollination
 - b) Organic matter decomposition
 - c) Natural or intrinsic levels of pest suppression
 - d) Summary

4. Crop losses attributed to arthropods
 - a) Much more attention is given to insects as “pests” than is often warranted by evidence
 - b) The influence of multi-national chemical companies over the adoption of synthetic pest control strategies
 - c) Example: Tropical rice production
5. Ineffectiveness of attempts to control pests with agricultural chemicals
 - a) Insecticide resistance
 - b) Leads to the need for increased application rates of insecticides, development of genetic resistance, and loss of effectiveness
 - c) Insecticide-induced resurgence due to disproportionate mortality of predaceous natural enemies

D. Sustainable Agricultural and Preventive Pest Management: Preventing the Growth of Pest Populations Beyond Economic Thresholds

1. Crop rotation
2. Cover cropping
3. Polyculture cropping patterns
4. Sound soil fertility management
 - a) Soil organic matter management
 - b) Nutrient budgeting, soil amending, and supplemental fertilizing: Balancing nutrient inputs with outputs
 - c) Sound irrigation and tillage practices
5. Native plant associations, farmscaping, and the use of non-crop vegetation (see Bugg 1998)
 - a) Farmscaping defined
 - b) Insectary plantings
 - c) Trap crops
 - d) Companion planting
6. The use of resistant crop varieties

E. Components of a Pest Management Program for Certified Organic Farming Systems

1. Prevention of pests (see above)
2. Identifying pests and understanding the ecology of agronomically important arthropods
 - a) Accurate identification (see Demonstration 1)
 - b) Understanding of how environmental conditions affect populations of both pest and beneficial arthropods
 - i. Example: Degree days and the emergence of codling moth (*Cydia pomonella*)
3. Monitoring for presence and abundance of arthropod populations and/or damage
4. Establishment of thresholds for pest control intervention (see Flint 1998)
 - a) “Control action thresholds”
 - b) Quantitative control action thresholds exist for some but not all crops and pests (see www.ipm.ucdavis.edu/; Flint 1998)
 - c) General rule: Any time you find a lot of one type of pest insect (more than 5 on 2–3 plants in a row with no predators found in that same area) the pest/beneficial ratio is out of balance and some outside control will be necessary
 - d) For those crops without control action thresholds, growers must determine thresholds themselves through observation, trial and error
 - e) Control action guidelines do not include monitoring of beneficial arthropods

5. Active (non-preventive) control methods (see Flint 1998; www.ipm.ucdavis.edu/)
 - a) Biological control
 - b) Chemical controls
 - c) Cultural control
 - d) Physical controls

F. Arthropod Monitoring and Management Procedures

1. Monitoring methods commonly used
 - a) Visual inspection/observation
 - b) Pest-specific monitoring and sampling procedures (see Flint 1998)
 - c) Larger-scale monitoring and sampling (see ucanr.org/)
 - d) Arthropod sampling techniques for the garden and small farm
 - i. Traps
 - Pheromone traps
 - Sticky traps
 - Light traps
 - Pit fall traps
 - ii. Catching
 - Sweep nets
 - Aspirators
 - Shaking plants
 - iii. Degree-day monitoring
2. Monitoring protocol for in-field visual inspections
 - a) Survey crops systematically and on regular basis
 - i. Frequency: 1x/week; 2x/week during peak growing season
 - ii. Vegetable crops
 - Walk furrows, check both sides of leaves on every few plants
 - Remove wilted plants and examine root system
 - Root crops: Check the soil before you plant from the soil level to 4 inches down by running your fingers through the soil looking for small insects. Collect and identify samples.
 - iii. Orchards
 - Check trunk for injury
 - Check fruit for scars or points of entry
 - Check interior of grounded fruit for pest presence
 - Examine both sides of leaves on each side of the tree
 - b) Assess and record the following
 - i. Date, time, crop, and weather conditions
 - ii. Is proper cultural care being delivered?
 - iii. Number of pests observed
 - iv. Amount and type of damage
 - v. Presence and numbers of beneficials/natural enemies
 - vi. Evidence of parasitism or predation
 - vii. Stage of crop development

3. Management procedures
 - a) Determine if control action threshold has been exceeded
 - b) Research control action options
 - c) Implement control actions
 - d) Document control actions taken and responses to treatment

G. Select Examples of Commonly Used Forms of NOP-Certified Control Strategies

1. Biological control methods
 - a) Classical biocontrol
 - b) Inoculative biocontrol
 - c) Inundative biocontrol
 - i. Microbial biocontrol
 - *Bacillus thuringiensis*—Bt
 - Naturalis
 - Predatory nematodes
 - Your own collections
 - ii. Selected beneficial insects
 - Aphytis
 - Encarsia
 - Lacewings
 - Ladybugs
 - Geocoris
 - Praying mantids
 - Predatory mites
 - Trichogramma wasps
 - Anaphes
2. Chemical control methods
 - a) Powders, soaps, and oils
 - i. Diatomaceous earth
 - ii. Drax
 - iii. Soaps
 - iv. Oils and neem oil
 - b) Botanicals
 - i. Garlic barrier
 - ii. Hot pepper wax
 - iii. Neem extracts
 - iv. Pyrethrins
 - v. Rotenones
3. Cultural control methods
 - a) Changes in frequency or timing of irrigation
 - b) Pruning to increase air circulation or prevent contact with soil
 - c) Field sanitation between cropping

4. Physical control methods

- a) Row covers
- b) Solarization
- c) Vacuums
- d) Traps
- e) Flooding
- f) Tillage
- g) Field sanitation
- h) Netting
- i) Hand picking
- j) Reflective mulches
- k) Petroleum oil barriers

5. Pheromones

- a) Pheromones defined
- b) Trapping out
- c) Mating disruption

Detailed Lecture 1 Outline: Arthropod Pest Management

for students

A. Pre-assessment Questions

1. Why is the management of arthropods so important in crop production?
2. Why are pesticides ineffective in controlling insect pests?
3. What are some of the things insects and other arthropods do that enhance agricultural and environmental quality?
4. Which agricultural practices can you describe that serve to prevent the growth of pest populations beyond economic thresholds?
5. What would be some of the components of a sound pest management program for a certified organic farm or garden?
6. What would be the best ways to monitor for pests in the garden and small farm?
7. How would you go about determining if an insect is a “pest” or a “beneficial”?
8. What are several different organically acceptable ways to actively control pests?

B. Why Management of Arthropods Is Important in Crop Production

1. Reduced productivity/yield: Unchecked growth of pest populations of plant-juice-sucking insects may lead to reductions in crop vigor, size, visual aesthetics, and overall yield
2. Spread of plant pathogens: Arthropods may create points of injury in plant tissues that allow fungal, bacterial, and viral diseases to successfully attack the plant. This is particularly important in perennial fruits and vegetables (e.g., Pierce’s disease).
3. Reduced visual aesthetics of crop: Directly feeding on the crop (fruits, vegetables, or flowers) reduces the visual aesthetics thereby rendering the crop unmarketable
4. Death of crop plants: Certain arthropods that feed on root systems of crops can cause death of the plants
5. Build up of pest populations: The absence of management may lead to the build up of pest populations, eventually causing increased crop losses in subsequent years

C. A Sketch of Arthropod Natural History

1. Insects
 - a) The number of insect species is greater than the number of all other species of organisms combined (excluding prokaryotic organisms)
 - b) The number of taxonomically described beetles (only one of 31 orders of insects) is more than 250,000 species—more than all the species of flowering plants
 - c) Estimates on the number of species of insects yet to be described range from between 2 and 100 million species
 - d) At least 6 million to 9 million species of arthropods are now thought to live in the tropics, with only a small fraction currently described
2. Why have insects been so successful throughout natural history?
 - a) Insects have been around for more than 350 million years
 - b) Except for marine habitats, insects have adapted to almost every environment possible

- c) The reasons for their success include the following factors:
 - i. Short generation times and high numbers of offspring result in populations that are highly adaptable under the stress of environmental changes (rapid adaptation/evolution)
 - ii. A highly efficient body plan and construction: The insect “exoskeleton” is a light-weight, but incredibly strong “suit of armor” whose external waxy coating protects against moisture loss. Outwardly directed ridges and spines serve to protect or hide the insect from enemies, or are colored and modified to attract mates, while inward protruding ridges and spines serve as points of attachment for muscles.
 - iii. The ability to fly: Active flight was first to evolve in the insects, aiding dispersal to new and potentially favorable environments
 - iv. The development of “complete metamorphosis” in some orders, allowing the juvenile stages to no longer compete with the adults for space or resources. Body forms could be solely adapted to a specific and independent role or function.
3. Ecosystem “services” provided by arthropods in agroecosystems: The good stuff bugs do
- a) Pollination: Many species of native bees and flies pollinate crops
 - b) Organic matter decomposition: Mold mites, springtails, wolf spiders, centipedes, sow bugs, ground beetles exist at different trophic levels and serve to break down organic matter into its constituent parts. They feed directly on organic matter or prey on those that do.
 - c) Natural or intrinsic levels of pest suppression: The great diversity of insects includes predaceous, parasitic and parasitoid adaptive strategies (see descriptions below) and are “natural enemies” of agricultural pests. These “beneficial insects” may serve to effectively suppress the development of pest populations if habitat for these species is effectively managed.
 - d) Summary: Organic growers and researchers have an important role to play in this regard as they are attempting to manage agroecosystems without the use of synthetic chemicals. Their task requires that they adopt a “whole-systems approach”—replacing externally derived synthetic inputs with an understanding of how the biological resources of the system can be optimized to provide a full range of services, including insect pest and disease suppression.
4. Crop losses attributed to arthropods
- a) While there is no doubt that insects can and do cause significant losses to farms and gardens, it is also increasingly clear that much more attention is given to insects as “pests” than is often warranted by the evidence.
 - b) This is in large measure due to the fact that multi-national chemical companies have enjoyed decades of profits from chemical insecticides on the order of \$35 billion per year, and in order to justify their continued profit taking—at the expense of the health of ecosystems and millions of people—insect pests need to be sold as “serious threats,” even when they might not be so
 - c) Example: Research on tropical rice shows that the current \$3 billion/year industry in rice insecticides could conservatively be reduced by more than 95% without any increase in losses (Bill Settle, pers. comm.). In fact, the evidence shows insecticides cause pest outbreaks more than they prevent them (Bill Settle, pers. comm.).
5. Ineffectiveness of attempts to control pests with agricultural chemicals
- a) Due to the highly adaptable nature of insect populations, repeated exposure to insecticides often leads to insecticide resistance—an inherited increase in the physiological range of tolerance to synthetic chemical controls
 - b) This often leads to the need for increased application rates of insecticides to achieve similar degrees of control, leading to further resistance and eventual loss of effectiveness of insecticide
 - c) Insecticide-induced resurgence: The rapid expansion of pest populations following a pesticide application resulting from pest populations being “released” from the population-control mechanism of predation by beneficial insects and spiders killed by pesticide exposure

D. Sustainable Agricultural and Preventive Pest Management: Preventing the Growth of Pest Populations Beyond Economic Thresholds

1. Crop rotation: Changing on an annual basis the place in the garden or field where crops are grown interrupts the host/pest cycle and thereby reduces or limits the development of populations of both arthropod pest and pathogens
2. Cover cropping: A form a crop rotation, cover cropping interrupts the host/pest cycle, and with certain cover crop species serves as habitat for natural enemies of insect pests, which often suppress pests. Be aware that inappropriate choices of cover crop species can increase pest populations (see Unit 1.6, Selecting and Using Cover Crops).
3. Polyculture cropping patterns: An agricultural landscape that is populated with a diversity of crops reduces the carrying capacity of the land for a given pest population and increases the possibility of supporting natural enemies of insect pests
4. Sound soil fertility management
 - a) Soil organic matter management: Regular additions of organic matter (e.g., compost, cover crops, and/or manure) stimulate soil biological activity and diversity, which may prevent certain pest populations from increasing beyond economic thresholds
 - b) Nutrient budgeting, soil amending, and supplemental fertilizing: Designing efficient amendment and fertilization plans around crop nutrient requirements and avoiding unnecessary nutrient inputs may prevent pest problems associated with both nutrient deficiencies and excesses
 - c) Sound irrigation and tillage practices: Maintaining desirable soil physical and chemical properties through properly applied irrigation and tillage will help prevent the pest problems associated with poor soil quality
5. Native plant associations, farmscaping, and the use of non-crop vegetation

A greater diversity of non-crop vegetation (native and planted) in and around the farm may increase the carrying capacity for natural enemies of arthropod pests that often suppress pests before they become a problem (see Bugg 1998)

 - a) Farmscaping may be defined as the use of non-crop vegetation for increasing and managing on-farm biodiversity to favor beneficial insects
 - b) Insectary plantings: Plants known to produce abundant nectar used by natural enemies as a secondary food source. Help provide habitat for beneficial insects.
 - c) "Trap crops": Intentionally planted alternative food sources for pest organisms. Trap crops reduce or prevent large numbers of pest arthropods from feeding on cash crops.
 - d) Companion planting: Plants intentionally planted adjacent to cash crops that repel pests
6. The use of resistant crop varieties: Certain crop species have undergone extensive selective breeding in order to develop greater resistance and resilience to common agricultural pests. Such varieties should be used where appropriate.

E. Components of a Pest Management Program for Certified Organic Farming Systems

1. Prevention of pests (see above): Sustainable agriculture practices, when properly used in concert, create the optimal growing conditions in which crop plants are more resistant and resilient to both pests and pathogens
2. Identifying pests and understanding the ecology of agronomically important arthropods
 - a) Accurate identification of arthropods is essential in assessing the potential for natural enemies to control pest populations and in determining the need for active control and the type of treatments that one might effectively use
 - b) An understanding of how environmental conditions affect populations of both pest and beneficial arthropods will further assist a grower in making effective management decisions

- c) Example: Degree days and the emergence of codling moth (*Cydia pomonella*)
- 3. Monitoring: Regular and systematic field assessments provide essential information on the status of the crop in relation to populations of pests and natural enemies (see below)
- 4. Establishment of thresholds for pest control intervention (see Flint 1998)
 - a) "Control action thresholds": Control action thresholds inform a grower when specific control actions must be taken in order to avoid additional crop damage or losses
 - b) Quantitative control action thresholds exist for some but not all crops and pests (see www.ipm.ucdavis.edu/; Flint 1998)
 - c) General rule: Any time you find a lot of one type of pest insect (more than 5 on 2–3 plants in a row with no predators found in that same area) the pest/beneficial ratio is out of balance and some outside control will be necessary
 - d) For those crops without control action thresholds, growers must determine thresholds themselves through observation, trial and error
 - e) As there are few control action guidelines that include monitoring of beneficial arthropods, growers or IPM specialists must use records of previous seasons' occurrences of pest and natural enemies to determine the need for treatment
- 5. The use of acceptable active (non-preventive) control methods when thresholds have been exceeded (see Flint 1998; www.ipm.ucdavis.edu/)
 - a) Biological control: Biological control may be defined as "the actions of parasites, predators and pathogens in maintaining pest density at a lower average population density than would occur in their absence"
 - b) Chemical controls: The use of least toxic materials that interfere with normal physiology or behavior of arthropods
 - c) Cultural controls: Altering the growing conditions such that arthropod pest populations are discouraged
 - d) Physical controls: Prevent access to the crop itself

F. Arthropod Monitoring and Management Procedures

- 1. Monitoring methods commonly used
 - a) Visual inspection/observation: Regular visual inspection and observation of plant parts in field and lab is the most effective monitoring method for small growers.
 - b) Pest-specific monitoring and sampling procedures for the garden and small farm (see Flint 1998)
 - c) Larger-scale monitoring and sampling: See ucanr.org for a listing of IPM manuals for crop-specific monitoring and management
 - d) Arthropod sampling techniques for the garden and small farm
 - i. Traps: Less effective as they tell what is on the farm and not necessarily what is affecting the crops. Traps may also catch arthropods that come from outside the farm or garden.
 - Pheromone traps: Attract insects by chemical lure
 - Sticky traps: Capture flying adult insects
 - Light traps: Select for nocturnal insects
 - Pit fall traps: Capture ground-dwellings arthropods and spiders
 - ii. Catching: Most effective in determining abundance and correlating arthropods with damage
 - Sweep nets: Use to capture insects on vegetation
 - Aspirators: Use to capture very small insects on vegetation

- Shaking plants: Shaking or beating plants or branches onto paper for later sampling is a useful way to gather insects for identification that might normally go unseen
 - iii. Degree-day monitoring: For some pests and beneficial insects researchers have developed temperature development thresholds at which time management actions may best be taken
2. Monitoring protocol for in-field visual inspections
- a) Survey crops systematically and on regular basis
 - i. Frequency: 1x/week; 2x/week during peak growing season
 - ii. Vegetable crops:
 - Walk furrows and check both sides of leaves on every few plants
 - Remove wilted plants and examine root system for indications of soil borne insects, pathogens
 - Root crops: Check the soil before you plant from the soil level to 4 inches down by running your fingers through the soil looking for small insects. Collect and identify samples.
 - iii. Orchards
 - Check trunk for injury (e.g., sap oozing from wounds)
 - Check fruit for scars or points of entry
 - Check interior of grounded fruit for pest presence
 - Examine both sides of leaves on each side of the tree
 - b) Assess and record the following:
 - i. Date, time, crop, and weather conditions
 - ii. Determine whether proper cultural care is being delivered (e.g., water)?
 - iii. Number of pests observed
 - iv. Amount and type of damage
 - v. Presence and numbers of beneficials/natural enemies
 - vi. Evidence of parasitism or predation of pest organisms
 - vii. Stage of crop development
3. Management procedures
- a) Determine if control action threshold has been exceeded
 - b) Research control action options
 - c) Implement control actions
 - d) Document control actions taken and responses to treatment

G. Select Examples of Commonly Used Forms of NOP-Certified Control Strategies

1. Biological control methods
 - a) Classical biocontrol: The importation and release of exotic biocontrol agents, with the expectation that the agents will become permanently established and no further releases will be necessary
 - b) Inoculative biocontrol: Natural enemy releases are made when pest populations are low, giving the population of natural enemies enough time to develop with the pest population. Inoculative biocontrol relies on subsequent generations to manage the target pest. As the released natural enemies are not necessarily adapted to the release environment populations, releases (inoculations) are made at the start of each growing season.

- c) Inundative biocontrol: Similar to the use of chemical pesticides, this method relies on mass releases of natural enemies to control a large population of target pests that are causing damage close to the economic threshold. Relies on sheer numbers and periodic and seasonal releases to suppress a given pest population.
 - i. Microbial biocontrol
 - *Bacillus thuringiensis*—Bt
 - Naturalis
 - Predatory nematodes
 - Your own collections
 - ii. Selected beneficial insects
 - Aphytis
 - Encarsia
 - Lacewings
 - Ladybugs
 - Geocoris
 - Praying mantids
 - Predatory mites
 - Trichogramma wasps
 - Anaphes
- 2. Examples of chemical control methods
 - a) Powders, soaps, and oils
 - i. Diatomaceous earth
 - ii. Drax
 - iii. Soaps
 - iv. Oils and neem oil
 - b) Botanicals
 - i. Garlic barrier
 - ii. Hot pepper wax
 - iii. Neem extracts
 - iv. Pyrethrins
 - v. Rotenones
- 3. Examplese of cultural control methods
 - a) Changes in frequency or timing of irrigation
 - b) Pruning to increase air circulation or prevent contact with soil
 - c) Field sanitation between cropping
- 4. Examples of physical control methods
 - a) Row covers
 - b) Solarization
 - c) Vacuums
 - d) Traps
 - e) Flooding
 - f) Tillage
 - g) Field sanitation
 - h) Netting

- i) Hand picking
 - j) Reflective mulches
 - k) Petroleum oil barriers
5. Pheromones
- a) Pheromones defined: The chemical sex attractant used by many insect species to draw mates
 - b) Trapping out: The use of pheromone traps to trap and kill
 - c) Mating disruption: The timed mass release of synthetic pheromones with the mating times of agricultural pests resulting in the inability of mating pairs to form

Lecture 2: The Biology and Ecology of Arthropods

for the instructor

A. Basic Biology and Ecology of Arthropods

1. Taxonomic context
 - a) Systematics
 - b) Taxonomy
 - Kingdom (Animalia)
 - Phylum (Arthropoda)
 - Class (Hexapoda = Insects)
 - Order (Hemiptera = true bugs)
 - Family (Miridae)
 - Genus (*Lygus*)
 - Species (*hesperus*)
 - c) Orders of the class Hexapoda
 - i. 659 families for North America north of Mexico
 - ii. Family designation and the biology of an insect
 - iii. Example: “hover flies” (family Syrphidae) are predators on other insects
 - iv. Variation within families
2. Insect and spider body plans (illustrate with slides, transparencies, Powerpoint)
 - a) Head and mouthparts; thorax; abdomen
 - b) Circulatory system
 - c) Respiratory system
3. Insect development
 - a) Metamorphosis
 - b) “Primitive” metamorphosis
 - c) “Incomplete” metamorphosis
 - d) “Complete” metamorphosis
 - e) Life cycles of insects
 - i. Eggs
 - ii. Larvae/nymphs
 - iii. Larvae
 - iv. Pupae
 - Diapause
4. Basic ecological categories
 - a) Trophic levels
 - i. Scavengers
 - ii. Herbivores
 - iii. Predators
 - iv. Parasitoids
 - v. Hyperparasitoids
 - b) Functional groups

B. Arthropod Groups Commonly Found on the Farm and in the Garden

1. Arachnids
 - a) Spiders (Araneae)
 - b) Mites (Acari)
 - c) Harvestmen or “daddy long legs” (Opiliones)
2. Garden Symphylan (Symphyla)
3. Centipedes (Chilopoda)
4. Millipedes (Diplipoda)
5. Smaller crustaceans
 - a) Pillbugs or “Rolly-polly” (Isopoda)
6. Insects (Hexapoda)—selected orders
 - a) Spring-tails (Collembola)
 - b) Dragonflies (Odonata)
 - c) Preying mantids (Mantodea)
 - d) Grasshoppers and crickets (Orthoptera)
 - e) Planthoppers, leafhoppers, aphids, scale, and mealybugs (Homoptera)
 - f) True “bugs” (Hemiptera)
 - g) Beetles (Coleoptera)
 - h) Flies (Diptera)
 - i) Bees and wasps (Hymenoptera)
 - j) Butterflies and moths (Lepidoptera)

Lecture 2: The Biology and Ecology of Arthropods

for students

A. Basic Biology and Ecology of Arthropods

1. Taxonomic context

a) Systematics: The study of the diversity of organisms and of the relationships between them is called systematics. This discipline encompasses the study of the methods of classifying organisms, known as *taxonomy*. Systematics is one of the oldest areas of biological enquiry dating back to Aristotle in the fourth century B.C.)

b) Taxonomy: In a formal biological classification species are grouped according to estimates of their similarity into groups called taxa. These taxa are arranged in a hierarchical pattern; the most common levels as follows (using an insect example in parenthesis):

Kingdom (Animalia)

Phylum (Arthropoda)

Class (Hexapoda = Insects)

Order (Hemiptera = true bugs)

Family (Miridae)

Genus (*Lygus*)

Species (*hesperus*)

c) Orders of the class Hexapoda: Currently, there are 31 orders of the class Hexapoda listed in the most widely used taxonomic textbooks. A general field entomologist, or someone working at an ecosystem level, will be looking to identify insects to the family level.

i. 659 families are listed for North America north of Mexico

ii. The family level can often tell you a great deal about the biology of an insect. For example, all leafhoppers (family Cicadellidae) are plant-sucking herbivores.

iii. Similarly, all “hover flies” (family Syrphidae) are predators on other insects—especially aphids

iv. Variation within families: Even at the family level a great deal of variation can exist. For example, in the “shore flies” (family Ephydriidae) there is a range of species, some of which act as plant feeders, while others are detritus feeders (feeding on organic matter), and still others behave as predators and even as parasites.

2. Insect and spider body plans

a) Head and mouthparts; thorax; abdomen

b) Circulatory system

c) Respiratory system

3. Insect development

a) Metamorphosis: Insects grow by shedding their exoskeletons (molting), revealing a new, soft “skin” underneath that rapidly hardens into the next (larger) exoskeleton. Most insects go through several such molting stages before finally molting to the mature adult form.

b) “Primitive” metamorphosis: Very early insect groups and proto-insects such as collembolans exhibit a “primitive” metamorphosis, in which adults differ from juveniles only in that they are larger and have sex organs

- c) "Incomplete" metamorphosis: Somewhat more recently evolved insect orders, such as the grasshoppers and crickets, preying mantids, termites, planthoppers and leafhoppers exhibit "incomplete metamorphosis" in which juveniles look very much like adults, except for size, sex organs, and the existence of wings on the adults.
- d) "Complete" metamorphosis: Even farther down the evolutionary road insects made a radical shift in developmental strategy, one that ended up being highly successful. Insect orders that exhibit "complete metamorphosis" (e.g., beetles, flies, ants, bees and wasps, and butterflies) are able to manifest entirely different body forms between sexually immature and mature stages
- e) Life cycles of insects: When we find an insect what we see is only a snapshot of its entire life. One tactic in seeking a solution against a specific insect pest is to look for the "weak link" in the chain of its life cycle. (See Resources for a list of technical books on life cycles.)
 - i. Eggs: Insect eggs constitute a "weak link" for insect pests. Because they are stationary and lack an effective defense system, eggs offer an easy target for many predators, parasitoids, and parasites.
 - ii. Larvae/Nymphs: The immature stages of insect orders having incomplete metamorphosis or hemimetabolous insects (e.g., grasshoppers and true bugs) are called nymphs. Nymphs often look similar to their adult stage (usually just missing the wings and sexual organs, but often different colors as well). Similarly they are often found in the same location, and exhibit the same feeding behavior as their adults.
 - iii. Larvae: The immature stages of insect orders exhibiting complete metamorphosis, or holometabolous insects (e.g., butterflies, flies, and wasps) are called larvae. Larvae and adults of the holometabolous insects, on the other hand, look nothing like each other and are adapted for entirely different functions. Juveniles (both larvae and nymphs) are often difficult for all but an expert to identify. One tactic you can employ if you find an unknown larva attacking your garden is to conserve the larva, together with its fruit or vegetable meal, in a cloth-covered container for later identification as an adult.
 - iv. Pupae: For the orders that undergo complete metamorphosis, the larva must make a radical transformation from larva to adult. To do so requires more than a mere shedding of the skin; this process is usually accomplished by creating some kind of protected resting stage (e.g., spinning a cocoon) and then spending days or weeks undergoing a radical transformation. During this resting stage, pupae are mostly defenseless from attack by predators and parasitoids, and pupal mortality can be significant. As the pupal stage lends itself easily to a resting stage, many holometabolic insects choose the pupal stage as a convenient way to pass a long, cold winter or a hot, dry summer (where in both cases there may otherwise be no food for the insect). This resting stage is termed a physiological "*diapause*". Diapause can often be a convenient "weak link" for controlling insect pests, as many insects burrow into the ground to undergo diapause.
- 4. Basic ecological categories: From a practical perspective, with so many different kinds of insects one of the best ways to categorize insects you find in the field is by how they live; principally, how and what they eat, and where they are found. This can sometimes, but not often, be seen right away by a non-specialist, but with a little training and experience a majority of insects observed can be classified by their ecological role.
 - a) Trophic levels: The term "trophic" can be thought of as "feeding level" in a hierarchy. At the first level are the producers (plants and other chlorophyll-bearing organisms). The second level consists of the herbivores, followed by the "carnivores" in the broadest sense, who can themselves be separated out into different levels, depending on who eats whom. The scavengers are organisms that consume dead and decaying organic matter. For our purposes we can borrow from the trophic-level concept to create five useful categories:

- i. Scavengers, also called “detritivores”: Insects that consume dead animal or vegetable material as the first phase in the decomposition of organic matter. Scavengers are found everywhere on an organic farm, but are often mostly absent in commercial farms where little organic matter is returned to the soil, and where toxic chemicals are commonly used.
Scavengers can also play an important role as *alternative food sources* for generalist predators, a potentially important relationship that has been mostly overlooked by conventional agronomic science.
 - ii. Herbivores: Most every “pest” on the farm is an herbivore. Even herbivores that we easily identify as “pests,” such as spotted cucumber beetles, are only truly “pests” if their numbers are above an economic threshold for the farmer.
 - iii. Predators: Predatory insects and spiders kill and consume their prey, and tend to be “generalists.” That is, they have a fairly wide scope of arthropod prey that they can feed on.
 - iv. Parasitoids: Parasitoids are defined as insects that lay eggs inside the eggs or bodies of other insects. These eggs hatch and the emerging larva begins to eat out the insides of the “host” insect, eventually killing the host and emerging as a free-living adult. The difference between a “parasite” and a “parasitoid” is that the parasite (e.g., a flea or a tick) does not directly kill the “host.” The difference between a predator and a parasitoid is that the predator directly kills and eats the “prey,” whereas in the case of the parasitoid, it is the next generation or offspring that actually does the killing.
Parasitoids are mostly restricted to several dozen families of small to minute wasps, although there are several parasitic fly families as well. Parasitoids have been a favorite subject for biological control programs because they tend to be highly specific for one or a few species of host, and therefore can be used to target specific pests. Predators are generally better at reducing large numbers of pests, while parasitoids—because of their highly host-specific nature—are generally better at preventing populations of a pest from “escaping” to high numbers in the first place. A coordinated strategy of using predators and parasitoids may be most effective in reducing and maintaining pest populations.
 - v. Hyperparasitoids: Hyperparasitoids are parasitoids of parasitoids
- b) Functional groups: Functional groups are a non-definitive but quick and easy means of categorizing insects based on the experience of the practitioner of what insects in their farm or garden system *do*. This may give the practitioner a more “fine grained” description of his or her agroecosystem. Categories for functional groups commonly involve some, but usually not all of the following: Where an insect lives, its trophic level, how it feeds or what it feeds on, and some reference to a taxonomic label. Some hypothetical examples could include: “brassica-feeding beetles,” “egg parasitoids,” “aphid parasitoids,” “stem-boring moths,” “hunting spiders,” “web spiders,” and so on. You’ll find that defining a list of functional groups for the commonly found insects in your small farm or garden gives you around 15–20 different categories. This is just about the right size for properly defining the system without getting lost in non-intuitive names.

B. Arthropod Groups Commonly Found on the Farm and in the Garden

- 1. Arachnids
 - a) Spiders (Araneae)
 - b) Mites (Acari)
 - c) Harvestmen or “daddy long legs” (Opiliones)
- 2. Garden Symphylan (Symphyla)
- 3. Centipedes (Chilopoda)
- 4. Millipedes (Diplipoda)

5. Smaller crustaceans
 - a) Pillbugs or “Rolly-polly” (Isopoda)
6. Insects (Hexapoda)—selected orders:
 - a) Spring-tails (Collembola)
 - b) Dragonflies (Odonata)
 - c) Preying mantids (Mantodea)
 - d) Grasshoppers and crickets (Orthoptera)
 - e) Planthoppers, leafhoppers, aphids, scale and mealybugs (Homoptera)
 - f) True “bugs” (Hemiptera)
 - g) Beetles (Coleoptera)
 - h) Flies (Diptera)
 - i) Bees and wasps (Hymenoptera)
 - j) Butterflies and moths (Lepidoptera)

Demonstration 1: Pest Monitoring, Sampling, and Identification

for the instructor

OVERVIEW

This demonstration introduces students to the principles and practices of pest management field monitoring for the garden and small farm. Using the demonstration outline, the instructor should review with students the basic steps in visually monitoring crops and documenting the presence and abundance of insect pests, pest damage, and beneficial insects. Following this, the instructor introduces several field sampling techniques commonly used in pest management monitoring on small farms and gardens. Then ask students to collect samples of crop damage and arthropod samples using sweep nets and aspirators, and retrieve insect samples from previously placed traps.

Working in small groups in a laboratory setting, students will then review collected specimens and practice identifying the collections to Order, common name, and/or genus and species. Using printed visual keys and on-line resources, help students identify the insects they've collected as either "pest" or "beneficial." After identifying the insects and crop damage, students should research and discuss the thresholds for each of the pests observed, and the National Organic Program-accepted control options available had the thresholds been exceeded.

PREPARATION AND MATERIALS

- Gardens or fields with actively growing crops
- Insect traps placed in several field/garden locations several days prior to instruction
- Sweep nets
- Aspirators
- Film containers (for insect samples)
- Alcohol (for insect samples)
- Notebook for documenting field observations
- Hand lenses and/or dissecting scopes
- Lab with multiple computer terminals with internet access (see Resources for identification web sites) and/or
- Insect identification books (see Flint 1998 in Resources)

PREPARATION TIME

1–2 hours

DEMONSTRATION TIME

2 hours

DEMONSTRATION OUTLINE

A. Review Monitoring Protocol for In-field Visual Inspections

1. Surveying crops systematically and on regular basis
 - a) Frequency: 1x/week; 2x/week during peak growing season
 - b) Time of day to sample
 - c) Vegetable crops
 - i. Demonstrate walking furrows and checking both sides of leaves on every few plants
 - ii. Demonstrate removing any wilted plants and examining root system for indications of soil borne insects or pathogens
 - d) Orchards
 - i. Demonstrate checking trunk for injury (e.g., exuding sap)
 - ii. Demonstrate checking fruit for scars or points of entry
 - iii. Demonstrate checking interior of grounded fruit for pest presence
 - iv. Demonstrate examining both sides of leaves on each side of the tree
2. Review record keeping including the following (see Appendix, Arthropod Pest Management Field Observations Records Sheet)
 - a) Date, time, crop and weather conditions
 - b) Is proper cultural care being delivered (e.g., water)?
 - c) Number of pests observed
 - d) Amount and type of damage
 - e) Presence and numbers of beneficials/natural enemies
 - f) Evidence of parasitism or predation
 - g) Stage of crop development
 - h) Management actions taken

B. Demonstrate Sampling Procedures

1. Sweep nets
2. Aspirators
3. Hand picking
4. Preservation in alcohol
5. Sampling damaged plants

C. Students Collect Samples and Return to Lab for Identification Exercise

1. Instructor demonstrates use of on-line and printed resources in identifying samples of arthropods and plant damage (see Resources section)
2. Working in small groups, students practice identifying the collections to order, genus, and species (when possible), common name, “pest” or “beneficial” designation
3. Small student groups share/report identification to peers and instructor
4. Instructor confirms identification
5. Students research and discuss the thresholds for each of the pests observed on the crops (whether or not a threshold has been exceeded should include a discussion of the presence and abundance of natural enemies)
6. Students research and present NOP-accepted physical, biological, and chemical control options available had the thresholds been exceeded
7. Instructor shares anecdotal information on control options

Demonstration 2: Field Observations

for the instructor

OVERVIEW

In this field demonstration students will visit a working farm to review the pest management program different growers have developed for their certified organic farming operations. Request from the grower a brief overview of the current soil fertility and pest management practices used in the operation. The overview should include the components outlined below.

DEMONSTRATION TIME

2 hours

DEMONSTRATION OUTLINE

A. Soils and Soil Fertility Management

1. Soil textural classification
2. Hydrology of fields
3. History of cultivation
4. Tillage and irrigation practices
5. History of soil testing and amending
6. Organic matter management: Cover crops, compost, and manure application rates and timing
7. Crop rotation
8. Supplemental fertilizers and tillage practices used

B. Pest Management

1. Persistent pests
2. Persistent diseases
3. Plant growth response and/or crop quality concerns
4. Brief overview of the arthropod monitoring practices
5. Explanation of the treatment options used, including at what defined thresholds they were applied and how effective the treatments have been

Assessment Questions

- 1) Describe five practices used in sustainable horticultural and agricultural and how they serve to prevent the growth of pest populations beyond economic thresholds.
- 2) What are the essential components of a sound pest management program for a certified organic farm or garden?
- 3) Describe the protocol you would use in monitoring your fields for insect/arthropod pests and natural enemies.
- 4) List five arthropod pests and the crops they affect in your region. What are the National Organic Program-certified physical, chemical, biological, and cultural control options available for these pests?
- 5) How might non-crop vegetation help manage insect pests? How might it be harmful? Name five different non-crop plants that farmers use in your area to enhance biological control. How do each of these plants serve to enhance biological control?

Assessment Questions Key

1) Describe five practices used in sustainable horticultural and agricultural and how they serve to prevent the growth of pest populations beyond economic thresholds.

- *Crop rotation: Crop rotation interrupts pest/host cycle by changing the crop grown on a given piece of ground.*
- *Cover cropping: Cover cropping is a form of crop rotation; some cover crop species attract natural enemies of agricultural pests. Many cover crops also have allelopathic qualities that suppress pest populations. It's also important to avoid choosing inappropriate crops that would attract pests.*
- *Polyculture cropping patterns: Provide greater plant diversity within the agricultural ecosystem, thereby maintaining the carrying capacity for pests at a lower level than in a monoculture. Also increase the possibility of beneficial insect habitat.*
- *Sound irrigation and tillage practices to retain essential plant nutrients, avoid soil erosion and compaction, and maintain desirable soil physical properties.*
- *Maintain native plant associations in and around the farm and farmscaping: Serve to attract natural enemies of agricultural pests or repel pests*
- *The use of resistant crop varieties*

Sound soil fertility management including the following components:

- *Soil organic matter management (maintaining soil organic matter levels ideally between 3–5%) will help maintain soil biological activity and diversity, optimizing soil physical properties and some naturally occurring pest suppression.*
- *Supplying optimal levels of essential plant nutrients without overfertilizing. Through soil analysis and accurate nutrient budgeting, combined with efficient soil amending and supplemental fertilizing, pest problems associated with both overfertilization and plant nutrient deficiencies should be reduced.*

2) What are the essential components of a sound pest management program for a certified organic farm or garden?

- *The use of preventive agricultural and horticultural practices (above)*
- *Systematic monitoring and documentation of pest populations, crop damage, and the presence and abundance of beneficial insects*
- *Accurate identification of arthropods present in the farm and garden and an understanding of the ecology of agronomically important arthropods, including natural enemies of agricultural pests*
- *Research and establishment of control action thresholds for each crop*
- *Active (non-preventive) control methods: Physical, cultural, chemical, and/or biological control options*

3) Describe the protocol you would use in monitoring your fields for insect/arthropod pests and natural enemies.

- *Survey crops systematically for visual inspection/observation 1x/week, and 2x/week during peak growing season*

For vegetable crops:

- *Walk furrows and check both sides of leaves on every few plants. Collect samples and identify.*
- *Remove wilted plants and examine root system for indications of soil borne insects or pathogens. Collect and identify samples.*

For root crops:

- *Check the soil before you plant from the soil level to 4 inches down by running your fingers through the soil looking for small insects. Collect and identify samples.*

For orchards:

- *Check trunk for injury*
- *Check fruit for scars or points of entry. Collect samples and identify.*
- *Check interior of grounded fruit for pest presence. Collect and identify.*
- *Always examine both sides of leaves on each side of the tree.*

Assess and record the following:

- *Date, time, crop, and weather conditions*
- *Is proper cultural care being delivered?*
- *Number of pests observed*
- *Amount and type of damage*
- *Presence and numbers of beneficials/natural enemies*
- *Evidence of parasitism or predation*
- *Stage of crop development*
- *Management actions taken*

4) List five arthropod pests and the crops they affect in your region. What are the National Organic Program-certified physical, chemical, biological, and cultural control options available for these pests?

(answers will vary)

5) How might non-crop vegetation help manage insect pests? How might it be harmful? Name five different non-crop plants that farmers use in your area to enhance biological control. How do each of these plants serve to enhance biological control?

(answers will vary)

Resources

PRINT RESOURCES

BOOKS

Flint, Mary Louise. 1998. *Pests of the Garden and Small Farm: A Grower's Guide to Using Less Pesticide, Second Edition*. Publication 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 95 common pests; includes symptom-identification tables organized by crop. Recommended methods rely primarily on organically acceptable alternatives.

Flint, Mary Louise, and Steve H. 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.

A valuable resource for biological control of pests and pathogens.

Pickett, Charles H., and Robert Bugg, eds. 1998. *Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests*. Berkeley: University of California Press.

PERIODICALS

Common Sense Pest Control Quarterly

www.keyed.com/birc/index.html

Features least-toxic solutions to pest problems of the home and garden.

The IPM Practitioner

www.keyed.com/birc/index.html

Focuses on management alternatives for pests such as insects, mites, ticks, vertebrates, weeds, and plant pathogens. Each issue contains an in-depth article ("Updates") on a research topic in integrated pest management (IPM).

WEB RESOURCES

Agriculture Research Service Plant Sciences Institute

www.barc.usda.gov/psi/

Includes links to information on insect biocontrol, systematic entomology, insect behavior, and other research efforts within the USDA.

Association of Natural Biological Control Producers

www.anbp.org/index.htm

Resources, meetings, and other information on biocontrol

ATTRA: Farmscaping to Enhance Biological Control

www.attra.org/attra-pub/farmscape.html

Excellent "how-to" information on increasing and managing biodiversity on a farm to favor beneficial organisms. Can be downloaded in PDF format.

Bioquip

www.bioquip.com

Books, equipment, and supplies for entomology and related sciences.

Brooklyn Botanical Garden Natural Pest Control

www.bbg.org/gar2/pestalerts/

Lists "alerts" on insects, diseases, and invasive plants.

California Pest Management Guidelines

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

Database supplies the University of California's 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.

Cornell University Biological Control: A Guide to Natural Enemies in North America

www.nysaes.cornell.edu/ent/biocontrol

Provides photographs and descriptions of biological control (or biocontrol) agents of insect, disease, and weed pests in North America. It is also a tutorial on the concept and practice of biological control and integrated pest management (IPM).

Peaceful Valley Farm Supply

www.groworganic.com

Contains listing of many Organic Materials Review Institute-approved pest management resources for monitoring and control.

Pennsylvania State University IPM Links

paipm.cas.psu.edu/websites/Links.html

Links to a wide variety of sites on IPM, biological control, insects, invasive species, etc.

University of California Division of Agriculture and Natural Resources (UC DANR)

ucanr.org

Contains a on-line catalogue of UC DANR crop-specific IPM publications and links to IPM websites.

UC IPM Publications and other educational materials

www.ipm.ucdavis.edu/IPMPROJECT/pubs.html

A guide to publications, newsletters, slides, videos, and other educational material produced by the University of California's IPM program. Some materials is available on-line in PDF format.

UC Sustainable Agriculture Research and Education Program (UC SAREP)

www.sarep.ucdavis.edu

Includes information on biologically integrated farming systems and other alternative pest management programs.

USDA Forest Service and the Bugwood Network

www.insectimages.org

More than 5,400 high-quality insect and insect damage photographs available in digital format. Entries are classified by subject, common name, scientific name, life stage, and host. From the easily navigated web site one can quickly click to the desired target. Available for downloading and use for educational applications with no royalties or fees required, as long as appropriate credit is given to the source.

Appendix: Arthropod Pest Management Field Observations Records Sheet

	Crop:	Crop:	Crop:	Crop:
Date, time				
Stage of crop development				
Is proper cultural care being delivered? Describe				
Genus, species, common name of pests observed				
Number of pests observed				
Amount, type of crop damage observed				
Name, number of beneficial insects				
Evidence of parasitism or predation				
Description of control action threshold for pest				
Management actions taken and date				

