1.8

Arthropod Pest Management

Introduction: Managing Arthropod Pests

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 problematic arthropods within the standards set for certified organic production systems. 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.

Lecture 1 introduces the basic biology and ecology of insects as they relate to identification for management purposes, including the concept of trophic levels, and introduces the issue of pesticide resistance. Lecture 2 discusses the components of a pest management program in organic farming systems, outlines basic arthropod monitoring procedures, and discusses specific practices used in sustainable production to prevent the growth of pest populations beyond economic thresholds. The design principles and practices used to enhance biological control through the use of non-crop vegetation are also introduced.

Through demonstrations, students will practice insect sampling, identification skills, and the use of online identification and diagnostic tools.

MODES OF INSTRUCTION

> LECTURES (2 LECTURES 1.5 HOURS EACH; INCLUDES 0.5 HOUR FOR DISCUSSION, QUESTIONS AND ONE BREAK)

Lecture 1 introduces the basic biology and ecology of insects, includes the orders of insects most pertinent in agriculture, and discusses the issue of pesticides and mechanisms of chemical resistance

Lecture 2 discusses the importance of arthropod pest control, outlines principles and components of a pest management program, and contrasts preventive vs. suppressive control strategies.

> DEMONSTRATION 1: INSECT MONITORING AND SAMPLING (0.5 HOURS)

Students will practice sampling techniques (hand-held vacuum, sweep net, beat-sheet, etc.) to collect insects from various crop plants.

> DEMONSTRATION 2: INSECT IDENTIFICATION (1 HOUR)

Students will be provided with key taxonomic features to distinguish previously-collected insects of various orders, families, and feeding guilds. Corresponding feeding damage will also be displayed, when possible.

> DEMONSTRATION 3: ONLINE TOOLS FOR (1 HOUR)

Students will practice using online tools to identify arthropods and diagnose arthropod damage, and to find information about alternative control options.

> POWERPOINT

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

LEARNING OBJECTIVES

CONCEPTS

- Basic arthropod biology and ecology as they relate to management and classification
- Issues of pesticide use and chemical resistance
- 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

SKILLS

- How to sample for arthropods
- 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: Basic Biology & Ecology of Insects; Pesticides & Chemical Resistances

Pre-Assessment Questions

1. What are the major stages in an insect's life cycle?
2. In terms of pest management, what is meant by a "weak link" in the chain of an insect's life cycle?
3. What is a "trophic level"? Can you give some examples of different trophic levels?
4. What are some of the major orders of arthropods found on farms and in gardens?
5. Why are pesticides ineffective in controlling insect pests?

A. Basic Biology and Ecology of Insects

1. Taxonomy and taxonomic organization of insects
   a) Example:
      Kingdom (Animalia)
        Phylum (Arthropoda)
          Class (Insecta)
            Order (Hemiptera = true bugs)
              Family (Miridae)
                Genus (Lygus)
                  Species (hesperus)
                    Common name = lygus bug
   b) Currently, there are 26 orders in the class Insecta 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 the U.S. and Canada
      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 Ephydridae) 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 diversity
   a) The number of described insect species
      i. Example: There are over 250,000 described species of Coleoptera (beetles)
      ii. The vast majority of insect species have yet to be described. This is especially true in the tropics, where only a small fraction of species has been formally studied.
   b) Estimates on the number of insect species yet to be described
      i. Anywhere from 2-100 million, although frequently estimated at about 30 million. Not surprisingly, much of this untapped knowledge lies in the tropics, where at least 6-9 million species have yet to be described.
   c) Raw abundance: E. O. Wilson estimates there are 10 quintillion (10^{18}) insects in the world

3. Insect anatomy and development
    a) Three body segments: head, thorax and abdomen
        i. Each segment responsible (primarily) for collecting sensory stimuli, movement and respiration/digestion/reproduction, respectively
    b) Metamorphosis
        i. 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.
        ii. "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
        iii. "Incomplete" metamorphosis (hemimetabolism): Somewhat more recently evolved insect orders, such as the grasshoppers and crickets, preying mantids, termites, planthoppers and true bugs exhibit "incomplete metamorphosis", in which juveniles look very much like adults, except for size, and the presence of sex organs and wings during the adult phase of the life cycle
        iv. "Complete" metamorphosis (holometabolism): The most recent evolutionary development regarding insect maturation made a radical shift in strategy—one that ended up being highly successful. Insect orders that exhibit complete metamorphosis (e.g., beetles, flies, ants, and butterflies) are able to manifest entirely different body forms between sexually immature and mature stages.
4. Life stages and their relevance to pest management
    a) 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. Nymphs: The immature stages of insect orders having incomplete metamorphosis (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 adults. As nymphs cannot fly and often lack structural defenses, they are also a preferred target for pest management programs.
        iii. Larvae: The immature stages of insect orders exhibiting complete metamorphosis (e.g., butterflies, flies, and wasps) are called larvae. Larvae look nothing like their adult counterparts and are adapted for entirely different functions. Larvae 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. While larvae can posses structural (spines) or chemical defenses, their poor mobility makes them a good life stage to target for control. For instance, parasitoids often effectively seek out larvae for egg-laying, and some of the most effective and selective OMRI-approved materials (approved for use in certified organic systems) target pestiferous larvae.

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 metamorphosis. 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 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.

v. Adults: This life stage is often the least desirable with respect to targeted pest management: Greater mobility (via flight) and improved structural defenses make adults difficult to manage. Pheromone traps are one important exception, however, as they target adults seeking out reproductive opportunities.

5. Basic ecological categories: From a practical perspective, 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 be seen right away by a non-specialist, but with a little training and experience a majority of insects 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 (vegetation eaters), 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. Herbivores: Almost 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, i.e., when the financial loss caused by a pest surpasses the cost of pest control.

      ii. 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, both pest and beneficial, that they can feed on.

      iii. Parasitoids: Parasitoids are defined as insects that lay eggs inside the eggs or bodies of other insects. These eggs hatch and the emerging larvae consume 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 reaching high numbers in the first place. A coordinated strategy of using predators and parasitoids may be most effective in reducing and maintaining pest populations.

iv. Hyperparasitoids: Hyperparasitoids are parasitoids of parasitoids

v. 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.

b) Functional groups: Functional groups are a non-definitive but quick and easy means of categorizing insects based on the farmer or gardener's experience of what insects in their 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 examples include: "brassica-feeding beetles," "egg parasitoids," "aphid parasitoids," "stem-boring moths," "hunting spiders" and "web spiders." 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. Pesticide Use and the Mechanisms for Chemical Resistance

1. Insects—selected orders

a) Grasshoppers and crickets (Orthoptera)

i. Almost always herbivorous, although often not numerous enough in California to be considered "pests"

b) Planthoppers, leafhoppers, aphids, scale, and mealybugs (Homoptera)

i. Always herbivorous, often pestiferous, sometimes vectors for fatal plant pathogens

c) True "bugs" (Hemiptera)

i. Herbivorous, carnivorous, and omnivorous, these bugs play important roles in both creating and preventing crop losses in agriculture

d) Flies (Diptera)

i. Some flies are serious pests (e.g. fruit flies), while others are important predators or parasitoids

e) Butterflies and moths (Lepidoptera)

i. Always herbivorous and can be pestiferous as larvae

f) Beetles (Coleoptera)

i. As beetles occupy nearly every terrestrial niche, they play important roles in both creating and preventing crop losses in agriculture

g) Bees and wasps (Hymenoptera)

i. While often helpful as parasitoids, some hymenopterans (e.g. ants) can also be problematic by protecting homopteran phloem-feeders

2. Arachnids

a) Spiders (Araneae)

i. Tremendous (and often underappreciated) generalist predators

b) Mites (Acari)

i. Large herbivorous mite populations can be problematic and are mitigated by predatory mite species

C. Pesticide Use and the Mechanisms for Chemical Resistance

1. Pesticide use rate in California: 173 million lbs. pesticide applied in 2010 (CDPR 2011)
2. Ineffective long-term control of pests with agricultural chemicals
   a) Development of genetic resistance in pest populations
      i. Natural selection in pest populations favors alleles (one of two or more alternative forms of a gene) that express resistance, remove alleles that promote susceptibility
      ii. Herbivorous insects have co-evolved with the defensive compounds produced by plants. Consequently, these insects have developed very efficient mechanisms for breaking down potentially harmful chemicals, which leads populations toward resistance. Repeated exposures to the same chemical (or chemical class) accelerate this process.
   b) Insecticide—induced resurgence due to disproportionate mortality of predaceous natural enemies
      i. In general, predacious insect populations do not have the ability to express resistance to the same extent as their prey. Consequently, predators are eliminated from cropping systems at higher rates than herbivores. Predator population re-establishment is then hampered by the need for adequate prey, which means that in a disturbed system, pest resurgence is often a prerequisite for restored predator abundance.
   c) Reduced efficacy leads to increased insecticide application rates
      i. Due to insecticide resistance and/or predator removal, late season insecticide applications may become more frequent or more concentrated to maintain comparable levels of pest management.
   d) While there is no doubt that insects 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
      i. 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
      ii. 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.).

Lecture 2: Pest Management in Organic Cropping Systems

Pre-Assessment Questions

1. Why is the management of arthropods important in crop production?
2. What would be the best ways to monitor for pests in the garden and small farm?
3. What is an economic threshold level?
4. What are several different organically acceptable ways to actively control pests?
5. Why are organic systems considered more resilient when it comes to resisting pest and pathogen outbreaks?
6. What would be some of the components of a sound pest management program for a certified organic farm or garden?

A. 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

B. Components of a Pest Management Program

1. Identifying pests and understanding the ecology of agronomically important arthropods
   a) An understanding of how environmental conditions affect populations of both pest and beneficial arthropods will help a grower make effective management decisions
      i. Key pest: An herbivore that is consistently present, and if not managed, likely to exceed economic thresholds
      ii. Secondary pest: An herbivore that is often present but rarely exceeds economic thresholds due to naturally-present predation and parasitism. An important exception is where broad-spectrum insecticides have reduced or eliminated these top-down controls. In these instances, secondary pests become very problematic.
      iii. Occasional pest: An herbivore that may cause problems once every few years; only occurs when environmental conditions strongly favor their development
2. Monitoring for presence and abundance of insect populations and damage
   a) Regular and systematic field assessments provide essential information on the status of the crop in relation to populations of pests and natural enemies. These assessments are critical for accurate Economic Injury Level (EIL)-based decisions (see more on EIL, be low).
3. Monitoring methods commonly used
   a) Visual inspection/observation: Regular visual inspection and observation of plants 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 *anrcatalog.ucdavis.edu/* 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 specific 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. Collection: Most effective in determining abundance and correlating arthropods with crop 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 created temperature development thresholds at which time management actions may best be taken

4. 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 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 by running your fingers through the soil (down to 4”) looking for small insects. Collect and identify samples (rear pupae to adults if necessary).

   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 (see Appendix 1, Arthropod Pest Management Field Observations Records Sheet):

   i. Date, time, crop, and weather conditions

   ii. Determine whether proper cultural care is being delivered (e.g., water, weed control)

   iii. Number of pests observed

   iv. Amount and type of damage (see below)

   v. Presence and numbers of beneficials/natural enemies

   vi. Evidence of parasitism or predation of pest organisms

   vii. Stage of crop development

5. Management procedures
   a) Determine if control action/economic threshold has been exceeded (see below)
   b) Research control action options
   c) Implement control actions
   d) Document control actions taken and responses to treatment
6. Identifying types of pest-induced damage
   a) Direct damage: Marketable portion of the crop is negatively affected. Very little direct damage (from feeding, frass, egg-laying, etc.) is acceptable, in most cases. As a grower, it's vital that you are familiar with your customer base and their tolerance level for such damage. This varies greatly from one customer base to another (e.g., grocery store shoppers will have a vastly different idea of what's acceptable, when compared with a typical CSA member).
   b) Indirect damage: Portions of the crop that are not marketed are fed upon—roots, leaves, stems, etc. The ability of indirect damage to negatively affect yield varies significantly by crop and growth stage. Some indirect feeding is often tolerable. Vectors of plant pathogens should not be considered typical producers of indirect damage, as their feeding often influences yield.
7. Defining economic injury level (EIL) or economic threshold
   a) A crop's EIL helps a grower determine the point at which a pest population causes enough damage to justify the time and expense of active control measures
   b) This threshold is exceeded when the financial loss caused by the pest surpasses the cost of pest control
   c) Alternatively, control action thresholds could be defined as a point in time when an action must be taken to avoid additional crop damage
      i. This decision-making process relies heavily on documenting natural enemies to determine when yield reductions are otherwise unavoidable. For instance, there are no signs of predatory eggs or parasitized pests.
8. Searching for, and developing, crop-specific economic thresholds (see *www.ipm.ucdavis.edu*; Flint 1998)
   a) Quantitative control action thresholds exist for some but not all crops and pests
   b) For those crops without control action thresholds, growers must determine thresholds themselves through observation, trial and error
   c) Established control action guidelines do not include the influence of beneficial insects and spiders, and therefore often require adjusting
      i. For example, the (unofficial) allowable pest density in organic strawberries for lygus bugs is more than double the acceptable density in conventionally-managed strawberries
   d) The use of records from previous seasons documenting pest and beneficial insect densities will help determine the need for treatments
   e) 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 (Bill Settle, pers. comm.)
9. Temporal pest management considerations
   a) When are pests capable of causing economic damage? Depending on the crop, herbivores may not be capable of causing "damage" during the entire crop cycle, but only during certain developmental windows. Actionable decisions should only be made pertaining to these periods of susceptibility.

b) What temporal requirements do relevant beneficial insects have and how does this influence a crop's EIL? For instance, many species of female syrphid fly will only lay eggs once a prey-density threshold has been exceeded (e.g., approximately 50 aphids/broccoli plant), which usually takes 3-4 weeks. Consequently, early aphid arrivals that promote an accelerated syrphid response should be welcomed, and not treated with insecticide.

C. Integrated Pest Management for Certified Organic Farming Systems

1. The definition of integrated pest management (IPM) stresses pest prevention. Instilling preventative mechanisms into an agroecosystem is particularly relevant to organic farming for two reasons: First, properly managed organic systems have the potential for tremendous resiliency towards pests and pathogens that help prevent these outbreaks from occurring. Second, organic growers do not have the "tools" to suppress pest outbreaks that their conventional counterparts possess.
   a) Pest avoidance is the first step towards prevention
      i. Temporal avoidance, e.g., by isolating a vulnerable crop stage from a period of heavy pest pressure either by planting during a pest's "off season" (if possible) or by using degree day models to forecast a pest's arrival. For instance, when possible, harvest corn prior to the arrival of the corn ear worm, which can be anticipated through degree day accumulations and records of previous growing seasons.
      ii. Spatial avoidance, e.g., by avoiding regions or crop/landscape configurations with especially high pest pressure. For instance, as native vegetation is a reservoir for certain fruit flies, avoid planting adjacent to forest edges. Alternatively, crop rotation relocates specific crops to prevent pests from becoming spatially concentrated and is particularly relevant for minimizing levels of soil-borne pests (e.g., cabbage maggot), sessile feeders (e.g., aphids, scale, etc.) and soil pathogens (e.g. Verticillium wilt). Rotating a cole crop (e.g. broccoli or kale), which is resistant to Verticillium wilt, into a space after a Verticillium wilt-susceptible crop (e.g. strawberries or lettuce) was grown is one such example.
      iii. Physical avoidance, e.g., row covers, plastic mulch and fences can all act as physical barriers that prevent pest access. These exclusion techniques are often used during periods of high plant susceptibility. For instance, row covers protect young transplants that are especially vulnerable to defoliators, such as flea beetles.
   b) Field sanitation to remove pest habitat and reduce reproductive opportunities
      i. Depending on the crop, remove fruit, fully disk and incorporate crop residue, and manage weeds to reduce habitat for pests. This is especially true for pupae, which can use these micro-habitats to overwinter in your field and emerge earlier than expected during the next cropping season.
   c) Sound soil fertility management and nutrient budgeting (see also Unit 1.1, Managing Soil Health, Unit 1.6, Selecting and Using Cover Crops, and Unit 1.11, Reading and Interpreting Soil Test Reports)
      i. 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
      ii. 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

2. Suppressive measures
   a) Pheromones
      i. The chemical sex attractant used by many insect species to draw mates
      ii. Trapping out: The use of pheromone traps to trap and kill
      iii. 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

         Pheromone dispensers, often in the form of twist-tie dispensers attached to plants or caneberry hedgerow wires, emit large doses of female attractant to chemically saturate an area, such that male moths are unable to locate females and reproduce. Examples include codling moth pheromone in apples, light brown apple moth pheromone in strawberries, and leafroller pheromone in caneberries (in these cases, hundreds of twist ties are applied per acre).
   b) Habitat management examples
      i. Farmscaping: Managing or manipulating agricultural landscapes to positively affect insect trophic interactions and thereby reduce subsequent crop damage. These techniques improve the ability of predators and parasitoids to maintain pest populations below damaging levels, direct pests away from cash crops by utilizing behavioral traits, and generally seek to create systems that are more robust (i.e., less prone to crop damage), often without additional chemical inputs.
      ii. Trap crops: Incorporating plants to attract key pests away from cash crops and into small spatial concentrations, where they can be removed via cutting, vacuuming, or insecticide application. Successful examples of trap cropping include alfalfa added to cotton and strawberry for lygus bug control, cherry pepper added to bell pepper for pepper maggot control, and squash added to watermelon for squash bug control.
      iii. Beneficial insectary habitats: Incorporating plants to provide predators and parasitoids with floral resources that would otherwise be lacking, and thereby improve their ability to reduce pest pressure in the cash crop. E.g., sweet alyssum is often planted as an intercrop with lettuce and cole crops to improve the fecundity of syrphid flies, whose offspring devour aphids. Hedgerows, which are stands of flowering perennials (often native plants) established adjacent to cultivated lands, are also used to provide floral resources to beneficial insects and pollinators.
   c) Biological control (BC) 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"
      i. Classical BC: The introduction and intended establishment of highly specialized herbivores, predators, and parasitoids to manage pest populations. Classical BC is often used for newly established exotic insect pests that lack predation and parasitism in their new habitat.
      ii. Conservation BC: Efforts to create habitat-based conditions that allow for optimal biological control of naturally-occurring parasitoids and predators. These conditions include floral resources, overwintering habitat, alternative host material, a lack of insecticide applications, etc.

iii. Augmentative BC: includes inoculative BC, in which natural enemies are released when pest populations are low, giving the natural enemies enough time to develop with the pest population. Inoculative BC 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. Inundative BC is also used and 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.

d) Mechanical control

   i. Examples include row covers, solarization, vacuums, traps, flooding, and tillage

e) Insecticides

   i. Botanicals: Plant derivatives; e.g. pyrethrum (from Chrysanthemum) or Azadirachtins (from the neem tree)

   ii. Soaps and oils: K fatty acids used for soft-bodied insects (e.g. M-pede®)

   iii. Microbials: Mass-produced entomopathic micro-organisms (often bacteria); e.g. Bt or Entrust® (from *Saccharopolyspora spinosa*)

   *Note: To meet organic certification requirements, materials must be in compliance with National Organic Program (NOP) standards. A complete list of brand names and generic materials allowed under certification is available from the Organic Materials Review Institute (OMRI) at *www.omri.org*.

Demonstration 1: Pest Monitoring & Sampling

for the instructor

OVERVIEW

This demonstration introduces students to the principles and practices of pest management and field monitoring for the garden and small farm. The act of collecting insects serves as a valuable exercise, as it familiarizes the participant with 1) various collection techniques, 2) an idea of how much effort is required to adequately search or scout for a particular insect, and 3) a firsthand experience of the countless insects thriving in a world that is rarely apparent to passersby.

Using the demonstration outline, the instructor should review with students the basic steps in visually monitoring different types of crops and documenting the presence and abundance of insect pests, pest damage, and beneficial arthropods. 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. Samples will be used in Demonstration 2 to practice insect identification (note that they can be frozen for later use).

PREPARATION AND MATERIALS

- Gardens or fields with actively growing crops
- Insect traps (pitfall or yellow sticky traps placed in several field/garden locations several days prior to instruction
- Sweep nets
- Aspirators (bug-vacs)
- Beat sheets
- Film containers (for insect samples)
- Alcohol (for insect samples)
- Ziploc bags (for storing samples in freezer)

PREPARATION TIME

1 hour

DEMONSTRATION AND DISCUSSION TIME

1 hour

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 procedures, including the following (see Appendix 1, 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. Pitfall and/or yellow sticky traps
3. Aspirators
4. Beat sheets
5. Hand picking
6. Preservation in alcohol and Ziploc bags
7. Sampling damaged plants

Demonstration 2: Insect Identification

for the instructor

OVERVIEW

In this demonstration, students will practice identifying previously-collected insects (see Demonstration 1) and associated insect damage using taxonomic characteristics and other resources to distinguish previously-collected insects of various orders, families and feeding guilds. Knowing these distinctions is important to farmers and horticulturalists because it improves the accuracy of field scouting and the quality of decision making. Understanding insect taxonomy also provides a great way to appreciate and gauge the biological diversity on one's farm. When possible, feeding damage that corresponds with collected insects should also be displayed.

Working in small groups in a laboratory setting, students will review specimens collected in Demonstration 1 and practice identifying the collections to order, family, common name, and/or genus and species (where possible), as well as feeding guild. 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

- Insects collected by students in Demonstration 1 (or by instructor, if Demonstration 1 is not used)
- Examples of insect-damaged plants
- Notebook for documenting lab observations
- Hand lenses and/or dissecting scopes with external light source
- Lab with multiple computer terminals with internet access (see Resources for identification websites)
- Insect identification books (see Flint 1998 in Resources)
- White board for drawing insects

PREPARATION TIME

1 hour (or longer, if insects are not already collected)

DEMONSTRATION

1 hour

DEMONSTRATION OUTLINE

A. Provide students with key taxonomic features to distinguish previously-collected insects of various orders, families and feeding guilds

1. Grasshoppers and crickets (Orthoptera)
   a) Key characteristics: Enlarged hind femur, well developed cerci, chewing mouthparts
2. Planthoppers, leafhoppers, aphids, scale, and mealybugs (Homoptera)
   a) Key characteristics: Piercing-sucking mouthparts, four wings of uniform texture, two to three ocelli may be present
3. True "bugs" (Hemiptera)
   a) Key characteristics: Apparent piercing-sucking mouth (beak or rostrum) extends down much of ventral side, forewings only half membranous, scutellum apparent in most species
4. Flies (Diptera)
   a) Key characteristics: only one pair of true wings; hind wings modified into halteres, frequently sucking or sponging mouthparts, antennae are often short and located between eyes, sometimes with arista
5. Butterflies and moths (Lepidoptera)
   a) Key characteristics: Four enlarged wings with scales, long and curled proboscis, antennae often clubbed or plumose
6. Beetles (Coleoptera)
   a) Key characteristics: Front wings hardened with elytra, well developed mandibles, antennae sometimes strongly clubbed
7. Bees and wasps (Hymenoptera)
   a) Key characteristics: Four true wings, antennae usually elongate, ovipositor well developed, attachment point between thorax and abdomen (propodeum) sometimes constricted
8. Arachnids
   a) Key characteristics: Two body segments, eight legs
      i. Spiders (Araneae)
      ii. Mites (Acari)

B. Provide Students with Crops Damaged by Pest Insects

1. Potential examples include "cat-faced" strawberries, broccoli floret with cabbage aphids, corn with the corn ear worm, codling moth larvae in apples, cole crops with flea beetle foliar damage, etc.

C. Students Conduct Identification Exercise

1. Instructor demonstrates use of key features (outline above), along with on-line and printed resources to identify 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, feeding guild, "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

Assessment Questions

1) Describe five practices used in sustainable horticulture and agriculture, 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 detrimental? 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 horticulture and agriculture 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 detrimental? 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

Altieri, Miguel, Clara I. Nicholls, and Marlene A. Fritz. 2005. *Manage Insects on Your Farm: A Guide to Ecological Strategies*. Handbook Series Book 7. Beltsville, MD: Sustainable Agriculture Networks.

Offers information on how to set up your farm to mitigate the effects of certain insect pests. California orientation.

Caldwell, Brian, et al. 2013. *Resource Guide for Organic Insect and Disease Management, Second Edition*. New York State Agricultural Experiment Station. Ithaca, NY: Cornell University. *web.pppmb.cals.cornell.edu/resourceguide/*

Provides a useful and scientifically accurate reference for organic farmers and agricultural professionals who are searching for information on best practices, available materials, and perhaps most importantly, the efficacy of materials that are allowed for use in organic systems. Available for free download.

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, M. L., and S. H. Dreistadt. 1999. *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.

Gurr, G., and S. D. Wratten, eds. 2002. *Biological Control: Measures of Success*. Springer Science + Business Media B.V.

Includes a review and discussion of how and why various attempts at biological control were either successful or fruitless; discusses considerations for how the prospects of future biological control projects can be improved upon.

Gurr, G., S. D. Wratten, and M. Altieri, eds. 2004. *Ecological Engineering for Pest Management: Advances in Habitat Manipulation for Arthropods*. Csiro Publishing.

Discusses international farmscaping efforts to reduce crop loss; new approaches are included, such as molecular analyses, cutting-edge marking techniques and remote sensing; possible interactions with genetic engineering are also discussed.

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

A comprehensive investigation of conservation biological control through habitat manipulation; provides case studies from across the globe, including vineyards, orchards and hedgerows.

PERIODICALS

Bio-Integral Resource Center:

Common Sense Pest Control Quarterly

www.birc.org/

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

Bio-Integral Resource Center:

The IPM Practitioner

www.birc.org/

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).

Entomological Society of America:

Journal of Integrated Pest Management

esa.publisher.ingentaconnect.com/content/esa/jipm/

Free online peer-reviewed journal covering topics in IPM.

University of California, Division of Agriculture and Natural Resources:

California Agriculture

californiaagriculture.ucanr.org/

Free online peer-reviewed journal covering contemporary agricultural issues in California.

WEB-BASED RESOURCES

Agriculture Research Service Plant Sciences Institute

www.ars.usda.gov/

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/

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.

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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 non-pesticide alternatives for managing insect, mite, nematode, weed, and disease pests in agricultural crops, floriculture and ornamental nurseries, commercial turf, and in homes and landscapes.

Center for Invasive Species Research

cisr.ucr.edu/

Provides a forward-looking approach to managing invasions in California by exotic pests and diseases. The CISR is heavily involved with classical biological control research.

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

www.biocontrol.entomology.cornell.edu/

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).

International Organisation for Biological Control

www.iobc-global.org/

Promotes environmentally safe methods of pest and disease control.

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.

Organic Trade Association

ota.com/

Provides organic statistics and serves as a clearinghouse for pesticide studies pertaining to public health and the environment.

Peaceful Valley Farm Supply

www.groworganic.com

Contains listings 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.

Pesticide Action Network of North America (PANNA)

www.panna.org

Advances pesticide alternatives worldwide, supports research on impacts of pesticides, and provides technical support to partners interested in decreasing or eliminating pesticide use.

Rincon Vitova Insectaries

www.rinconvitova.com/

California-based commercial insectary for augmentative biological control services.

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

anrcatalog.ucdavis.edu/

Contains an online 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 online 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 website 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 1: 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				