Penn State Extension

Vegetable Integrated Pest Management with an Emphasis on Biocontrol

A Guide for Growers in the Mid-Atlantic
# Contents

Preface .................................................................................................................................................. iii

Integrated Pest Management Basics ............................................................................................... 1

Soil Health and Pest Management .................................................................................................. 14

Biological Control .................................................................................................................................. 19

Vegetable Crop Families and Their Common Pests ....................................................................... 34

- Amaranthaceae (formerly Chenopodiaceae):
  - Beets, Chard, Spinach .................................................................................................................. 35
- Amaryllidaceae: Garlic, Onions ....................................................................................................... 38
- Brassicaceae: Broccoli, Brussels Sprouts, Cabbage, Cauliflower ......................................................... 41
- Convolvulaceae: Sweet Potato ......................................................................................................... 45
- Cucurbitaceae: Cucumber, Melon, Pumpkins, Summer Squash, Winter Squash, Watermelon ....... 48
- Fabaceae (Legumes): Peas and Snap Beans (Green Beans, String Beans, Wax Beans) ................. 52
- Poaceae: Sweet Corn ......................................................................................................................... 55
- Solanaceae: Eggplant, Pepper, Potato, Tomato ............................................................................... 58

Common Vegetable Pests .................................................................................................................. 62

- Aphids .................................................................................................................................................. 63
- Armyworms ......................................................................................................................................... 68
- Brown Marmorated Stink Bug ........................................................................................................... 73
- Cabbage Looper ................................................................................................................................ 76
- Cabbage Maggot ............................................................................................................................... 79
- Colorado Potato Beetle ..................................................................................................................... 82
- Corn Earworm, Tomato Fruitworm, or Podworm ........................................................................... 85
- Cucumber Beetles ............................................................................................................................. 89
- Cutworms ............................................................................................................................................ 92
- Diamondback Moth ........................................................................................................................ 96
- European Corn Borer ..................................................................................................................... 99
- Flea Beetles ......................................................................................................................................... 103
- Harlequin Bug .................................................................................................................................... 106
- Hornworms ......................................................................................................................................... 109
- Imported Cabbageworm .................................................................................................................. 112
- Leafminers .......................................................................................................................................... 115
- Mexican Bean Beetle ..................................................................................................................... 118
- Onion Maggot ..................................................................................................................................... 121

- Potato Leafhopper .......................................................................................................................... 124
- Seedcorn Maggot ............................................................................................................................ 127
- Squash Bug ......................................................................................................................................... 130
- Squash Vine Borer ............................................................................................................................ 133
- Thrips .................................................................................................................................................. 136
- Tortoise Beetles ............................................................................................................................... 141
- Two-spotted Spider Mite .................................................................................................................. 144
- Wireworms .......................................................................................................................................... 148

Common Beneficial Insects ............................................................................................................. 151

- Ground and Tiger Beetles .............................................................................................................. 152
- Hover Flies ......................................................................................................................................... 156
- Insect-parasitic (Entomopathogenic) Fungi .................................................................................... 159
- Insect-parasitic (Entomopathogenic) Nematodes ........................................................................... 162
- Lacewings .......................................................................................................................................... 166
- Lady Beetles ....................................................................................................................................... 170
- Minute Pirate Bugs .......................................................................................................................... 173
- Parasitoids .......................................................................................................................................... 176
- Praying Mantids .............................................................................................................................. 181
- Predatory Midge .............................................................................................................................. 184
- Predatory Mites ............................................................................................................................... 187
- Predatory Stink Bugs ...................................................................................................................... 190
- Spiders ............................................................................................................................................... 193
- Viruses ............................................................................................................................................... 196

Photo Chart of Major Vegetable Pests .......................................................................................... 199

Photo Chart of Major Beneficial Insects ......................................................................................... 205

Control Timing Calendar ................................................................................................................ 209

Pest Degree Day Table .................................................................................................................... 212

Biocontrol Table ............................................................................................................................... 214

Glossary ............................................................................................................................................... 216

References ............................................................................................................................................ 220

Contact Information ......................................................................................................................... 235
Acknowledgments

Project Coordinators

Mary Barbercheck, Professor of Entomology, Penn State
Sarah Pickel, Education Specialist, Pennsylvania Department of Agriculture
Brian Schildt, IPM Scouting Consultant, Pennsylvania Department of Agriculture
Cathy E. Thomas, PA IPM Coordinator, Pennsylvania Department of Agriculture

Contributors

Mary Barbercheck, Professor of Entomology, Penn State
Wade Esbenshade, Farmer/Grower and Former PA IPM Program Member
Sarah Pickel, Education Specialist, Pennsylvania Department of Agriculture
Elsa Sánchez, Associate Professor of Horticultural Systems Management, Penn State
Brian Schildt, IPM Scouting Consultant, Pennsylvania Department of Agriculture
Cathy E. Thomas, PA IPM Coordinator, Pennsylvania Department of Agriculture

Reviewers

Mary Barbercheck, Professor of Entomology, Penn State
Sarah Pickel, Education Specialist, Pennsylvania Department of Agriculture
Edwin Rajotte, Professor of Entomology, Penn State
Elsa Sánchez, Associate Professor of Horticultural Systems Management, Penn State
Brian Schildt, IPM Scouting Consultant, Pennsylvania Department of Agriculture
Cathy E. Thomas, PA IPM Coordinator, Pennsylvania Department of Agriculture

PA IPM Program Staff

Edwin Rajotte, Professor of Entomology and PA IPM Coordinator, Penn State
Cathy E. Thomas, PA IPM Coordinator, Pennsylvania Department of Agriculture
Kristie Auman-Bauer, PA IPM Public Relations and Outreach Coordinator, Penn State Department of Entomology
Amber Brunskill, Education Specialist, Penn State Department of Entomology
Lyn Garling, PA IPM Manager of Programs, Penn State Department of Entomology
Dion Lerman, Healthy Homes and Environmental Health Programs Specialist, Penn State Extension in Philadelphia County
Michelle Niedermeier, Community IPM and Environmental Health Programs Coordinator, Penn State Extension in Philadelphia County
Sarah Pickel, Education Specialist, Pennsylvania Department of Agriculture
Brian Schildt, IPM Scouting Consultant, Pennsylvania Department of Agriculture
The Pennsylvania Integrated Pest Management Program (PA IPM) is pleased to provide Vegetable Integrated Pest Management with an Emphasis on Biocontrol: A Guide for Growers in the Mid-Atlantic. Vegetable production is an important commodity in Pennsylvania with more than 4,000 vegetable growers throughout the state planting over 55,000 acres of vegetables for fresh and processing use. This manual is designed to help vegetable growers manage insect pests based on sound integrated pest management principles. PA IPM is a collaboration of the Pennsylvania Department of Agriculture (PDA) and The Pennsylvania State University. This partnership has resulted in excellent service to Pennsylvania growers as well as to growers in surrounding states. The institutional collaboration embodied by PA IPM allows us to draw from Department of Agriculture technical experts as well as Penn State faculty and extension educators.

How to Use This Manual

This guide was developed to help growers identify, monitor, and control insect pests in vegetable production. The pests included are common to Pennsylvania; however, many of these pests can be found throughout the Mid-Atlantic and Northeast regions of the United States.

1. Identify the vegetable species.
2. Refer to the “Vegetable Crop Families and Their Common Pests” section, which is devoted to discussing details related to field selection and preparation, soil health and nutrient management, seed and transplant production, planting, pest management, recordkeeping, and major pests.
3. Refer to the “Photo Chart of Major Vegetable Pests” at the back of this manual. This chart has a series of thumbnail photos of the damaging life stage of the pest and corresponding damage. Select the photo that best matches the pest and symptomatic plant or fruit damage. Refer to the appropriate “pest fact sheet(s)” for additional information. Each fact sheet provides useful information, including the preferred host crop, damage potential, signs and symptoms, identification, biology and life cycle, monitoring and management strategies, thresholds, and control options. Photographs contained in the fact sheets show damage symptoms and life stages of the pest throughout the growing season.

An added benefit to using IPM practices is the conservation of beneficial insects that can help control insect problems. Included in this manual is an entire section devoted to common beneficial insects found to have an impact on destructive pests. Each fact sheet provides information on preferred hosts, identification, biology and life cycle, and monitoring and cultural practices that promote and encourage the establishment of beneficial insects on the farm. As always, the cornerstone of every IPM program is having a consistent scouting program during the growing season. A control timing calendar has been included to highlight the best window of time for controlling pests.

We hope this manual will encourage growers to develop their own scouting program and become familiar with the IPM practices needed to preserve the beneficial insect complex to help keep pest populations in check, and provide a safe working environment for employees and family members.

Support for the development of this manual was provided by the Pennsylvania Department of Agriculture and The Pennsylvania State University.

Cathy E. Thomas
Integrated Pest Management Coordinator
Pennsylvania Department of Agriculture
Integrated Pest Management Basics
For all vegetable growers, whether commercial producers or home gardeners, insect pests are a major variable that can affect the success of vegetable crops. Insects can potentially damage the marketable portion of the crop or weaken the plant as a whole, so it is important to maintain a level of control. The best way to manage vegetable pests is to utilize integrated pest management, or IPM. IPM is a multipronged approach to keeping pests and pest damage to a minimal level with the smallest cost to health, environment, and budget. Prevention strategies and low-impact management tactics work together to make IPM a long-term solution in the battle against vegetable pests. Different management tactics utilized in an IPM program include cultural, mechanical or physical, biological, and chemical (using both biorational and conventional pesticides). This manual aims to help growers and gardeners use IPM to prevent or manage insect pest issues. Key information will allow you to help crops withstand pest attack and damage by optimizing crop growth, preventing pests from flourishing by understanding pest life cycles and needs, and enhancing populations of natural enemies. These are all principles embraced by IPM. This section will spell out some of the specific steps that are involved in an IPM program: (1) crop planning, (2) pest identification and knowledge, (3) monitoring, (4) setting and evaluating thresholds, (5) selecting management options, and (6) evaluating results.

**Step 1. Preparing for IPM: Planning and Prevention**

IPM practices are generally aimed at an established crop, but some practices can help prevent pest populations before the crop is even planted. Consider the following points before planting to give the crop the best possible start.

**Property Assessment**

Finding the optimum location on a property to plant vegetable crops will play a large role in the success of those crops. Property assessment may include soil testing to determine soil pH, nutrient levels, organic matter content, and cation exchange capacity (Figure 1.1); determining property slope, aspect, and topography; and assessing water drainage rates and sunlight exposure. Historical meteorological information and knowledge of past crops can also be useful. Talking to other area growers and your local extension office about what pest problems (insect, mite, disease, mammal, etc.) to expect is also beneficial.

**Vegetable Crop Selection**

Selecting vegetable crops best suited to the property is the next step. This will involve research and may mean learning that the site is not appropriate for the originally intended species. Through the use of printed publications, online resources, information from seed companies, and advice from other growers, the success of various crops can be predicted. When possible, choose pest-resistant cultivars.

**Cultural Practices**

Preparation of the growing site can involve making a number of decisions regarding cultural/best management practices. Most important is rotation of vegetable crops from one vegetable family to another to manage soil nutrients optimally and prevent buildup of pest problems. After assessing the property and selecting the crop, decide what soil amendments (lime, calcium carbonate, compost, etc.) should be added for optimum plant health, and whether a cover crop should be planted to suppress weeds, add organic matter, and/or add nutrients (Figure 1.2).
Planting
Proper planting of seeds and transplants is critical to the success of a vegetable crop. There are several factors to consider when planting.

Timing
Vegetables need to be transplanted in the field at the optimum point in the season. Vegetables that thrive in the cool temperatures of early spring will not be nearly as successful when planted in summer’s peak temperatures. Consult production guides to find preferred planting temperatures for specific crops and then follow those recommendations.

For some crops, planting time can be adjusted to avoid peak pest populations either before or after the pests emerge. With this flexibility, either plants will be more mature at the time of pest emergence and less susceptible to serious damage, or pests may have moved to another area in search of food and will not be present when the seedlings emerge.

Spacing
It’s important to follow recommendations for plant spacing of vegetable types. Spacing can affect air circulation and therefore disease susceptibility. Although using the closest spacing may allow for more plants per field, using wider spacing may mean those plants will be healthier and thus more pest resistant (Figure 1.3).

Step 2. Identifying and Understanding Pests and Problems
The next focus of an IPM approach is preventing losses due to pest damage. The term “pest” may include any organism that is detrimental to the health of the plant: insect, mite, disease-causing pathogen, nematode, mammal, or bird. Physical environmental factors, such as weather events, may also cause damage. Understanding which type of pest or what factor is causing damage to a crop is essential to finding a means of stopping or managing the problem. In this manual, the focus will be on insect and mite pests.

Insects and Mites
Insects and mites are arthropods, or animals with jointed legs and exoskeletons, and although they are closely related, they have some distinct differences. Insects can be identified by three characteristics: the presence of antennae, three body segments, and six legs. Mites and spiders are classified as arachnids and can be identified by three characteristics as well: the absence of antennae, the presence of two body segments, and eight legs in the adult stage.

In this guide, we will focus mainly on insect identification. Recognizing insects can be challenging because all insects progress through different life stages (Figure 1.4). The process of transitioning to different life stages is known as metamorphosis. Insects can go through two different types of metamorphosis. Some insects go through “complete metamorphosis,” which means they change through at least four different stages, including an egg, a larva or immature stage, a pupa or resting stage, and an adult.

- Egg: This first stage is generally a tiny capsule that is often fertilized by a male; however, some species can develop parthenogenetically, without being fertilized. Eggs may be found singly or in groups, and may be attached to plant material. In some insect species, eggs pass through this first stage of life inside the female, so the female actually appears to give live birth (as with many aphids).
• **Larva:** This juvenile stage is wingless, often multisegmented, and wormlike (e.g., a caterpillar). A larva matures through several stages, or instars, each of which ends with a molt (the casting of skin that allows an insect to grow).

• **Pupa:** This is a resting stage that occurs after the final larval instar. The insect forms a hardened protective shell or spins a silken cocoon and undergoes a transformation inside the pupal case, often growing wings.

• **Adult:** The final stage in an insect life cycle (also referred to as an “imago”) emerges from the pupal casing. The adult insect has reached reproductive maturity and, in many instances, also formed wings.

Other insects progress through simple or “incomplete” metamorphosis, which means they move through at least three stages: egg, at least one nymphal stage, and adult. With incomplete metamorphosis, the immature stages look and function similarly to the adults.

• **Nymph:** This immature stage resembles the adult but is wingless and reproductively immature. An insect may go through several nymphal stages before maturing into an adult.

By having access to information on insect life cycles and habits, you should be able to determine the best method and timing for both scouting and, if necessary, control. Memorizing all the possible insect and mite pests that could cause damage on vegetable crops may not be practical, but by utilizing helpful resources such as this IPM guide and a good local diagnostic lab, you should be able to identify pests and find appropriate solutions.

Not all insects are pests. In fact, most are neutral or very beneficial to have on a vegetable farm. There are parasitic and predatory insects and mites that feed on other insects and mites as well as many weed seeds. Recognizing these beneficial insects, such as green lacewings and hover flies, can be very helpful. Taking steps to conserve and avoid killing these organisms can limit or even eliminate the need for chemical control measures.

### Diseases

Disease-causing organisms in vegetables include bacteria, fungi, nematodes, and viruses (Figure 1.5). While diseases are not addressed in this guide, it is very important to have an understanding of the diseases that can affect crops and the factors that provide the right environment for those diseases. Some factors that encourage the development of fungal disease are cool temperatures, high moisture, and low air circulation. In some cases, disease development can be prevented by taking steps to avoid providing the necessary environment for such diseases. Select clean, disease-free seed and seedlings, use clean water and appropriate levels of irrigation, plant in areas of good drainage, and provide adequate spacing to allow for good air circulation. All these practices can play a part in preventing disease development. Fungicides, or pesticides that inhibit or prohibit the growth of fungal diseases, may be needed in areas with high disease pressure, so knowing enough about the common diseases to recognize when to apply products is important.

Some helpful resources are the 2014 Commercial Vegetable Production Recommendations for Pennsylvania ([pubs.cas.psu.edu/PubTitle.asp?varTitle=Commercial+Vegetable+Production+Recommendations+for+Pennsylvania&Submit=Go](pubs.cas.psu.edu/PubTitle.asp?varTitle=Commercial+Vegetable+Production+Recommendations+for+Pennsylvania&Submit=Go)) and *Identifying Diseases of Vegetables* ([pubs.cas.psu.edu/PubTitle.asp?varTitle=Identifying+Diseases+of+Vegetables&Submit=Go](pubs.cas.psu.edu/PubTitle.asp?varTitle=Identifying+Diseases+of+Vegetables&Submit=Go)). Both are available for a fee through the Penn State College of Agricultural Sciences ([pubs.cas.psu.edu](pubs.cas.psu.edu)). Organic growers can find information on plant disease management at [eXtension.org](www.extension.org/pages/32637/organic-plant-disease-management:-thinking-like-a-system).

### Wildlife

Wildlife can be some of the most damaging pests and also the hardest to control. Mammals, such as deer, raccoons, groundhogs, and other rodents, and many kinds of birds enjoy eating farm-fresh produce just as much as human consumers do (Figure 1.6). Management tactics can be
applied, such as fencing, sound cannons, repellents, traps, etc., but weigh the cost of the damage against the cost of the control. Information on wildlife nuisance and damage is available on the Penn State Extension Wildlife Nuisance and Damage website at extension.psu.edu/wildlife/wildlife-nuisance-and-damage.

**Weeds**

Weeds are undesirable plants that interfere with growing crops (Figure 1.7). Generally herbaceous, they reproduce and spread primarily through seeds and rhizomes (underground stems). Weeds compete with the crops for soil nutrients, water, and sunlight. They inhibit good air circulation between crops, which can be a contributing factor for disease development. Weeds can serve as alternate hosts for insect and mite pests, as well as for plant-disease-causing organisms. Weeds also hinder the movement of people and equipment between rows, making good pesticide coverage difficult. Through good mowing, cultivation, and cultural practices and the assistance of herbicides, weeds can be controlled to a manageable level.

Weed control will not be covered in this guide. Information on weeds can be found on the Penn State Extension Weed Management website (extension.psu.edu/weeds).

Other state land-grant universities have additional weed resources. Organic growers can find information at eXtension.org (www.extension.org/pages/18532/an-organic-weed-control-toolbox).

**Environmental Factors**

Living organisms are not the sole cause of injury to vegetables. Environmental factors can negatively impact crops. Damage from severe weather can be equally as bad as or worse than a disease or insect problem. Frost, heavy wind, or hail can damage plants (Figure 1.8). Excess water or too little water can also damage crops. Unnatural environmental factors also exist. Pesticides and fertilizers applied at the wrong time of the growing cycle or in the wrong amounts will also damage crops. While weather damage may not be preventable, chemical damage can be prevented by carefully following label directions.

**Step 3. Monitoring Crops for Pest Populations**

Monitoring is the key to any successful IPM plan. On farms not using IPM, the process of pest control usually involves pesticide applications based on a calendar date. These types of applications are made regardless of the verified presence of the target pest. Another type of pesticide application on farms not using IPM is the "see and spray" method: spray only when the pest or damage is seen. At times, applications are made based only on damage symptoms, not on actual pest presence. IPM looks at pest management differently. Monitoring for pests and beneficial organisms to determine if there is a need to take action is more effective than either of the methods mentioned above.

Monitoring provides an accurate picture of the insect situation in a vegetable crop. The process involves regular, close visual inspection of plants, looking for symptoms or signs of pest activity and beneficial organisms (Figure 1.9). Symptoms
are actual damage or evidence of activity, such as holes in leaves or wilted shoots; signs refer to the organism causing the damage, such as cast aphid skins on the underside of a leaf or a cluster of cutworm eggs on a corn leaf. Becoming familiar with the common symptoms and signs most likely to appear in crops makes monitoring less of a mystery. When monitoring, record not only the kind of pests found but also the number of each kind of insect (useful in evaluating the level of infestation) and, if possible, the stage of development those pests are in. Also note which beneficial insects are present. Then an individualized, accurate, and timely plan of action can be created for each field. Monitoring can be done by a farm employee whose time is committed to scouting activity or by a professional scout hired as a scouting consultant. The key is to scout regularly—once or twice per week, not just once or twice per season.

Temperature Monitoring and Growing Degree Days

Having an understanding of when certain pests are likely to be found is helpful when inspecting fields for pest activity. The calendar may give a general idea of the pest activity window (see page 210), but there is another, more accurate method for predicting specific pest activity. This method, referred to as growing degree day (GDD) tracking, involves measuring daily temperatures. For insects, mites, and plants, development is triggered when daily average temperatures rise above a certain base temperature. (Disease progression is based on host-plant development, so it won’t be dealt with here.) Tracking GDD accumulation can be a valuable tool in a pest monitoring program.

Growing degree days are used to determine when the insects or plants have been exposed to enough heat units for an event such as emergence from winter dormancy, egg hatch, pupation, etc., to occur. These events occur within a range of GDDs. For example, flea beetle adults emerge from their overwintering habitat sometime between 150 and 200 GDDs above 50°F. A scout can more effectively monitor for a pest by knowing the range of GDDs for the target stage of each pest. GDD ranges for many vegetable pests can be found in the Pest Degree Day Table on page 212 and individual pest sections in this guide.

To calculate GDDs, record daily average temperatures (using low and high temperatures for a 24-hour period) and subtract a specific base temperature from each average (see formula below). Insects and plants have a minimum temperature below which development will not proceed. For most of insects, 50°F is used as the base temperature, but some do begin development at lower temperatures, such as 38°F or 43°F. Unless otherwise noted by DD38 or DD43, GDDs in this manual will use a base of 50°F. After calculating each day’s GDD value, numbers above zero will be added to an accumulated total (negative numbers are not included in the total). See the box for sample calculations.

**GDD Formula**

\[
\text{Low Temperature} + \text{High Temperature} - 50°F = \text{Total GDDs}
\]

\[
\text{Average Temperature} - \text{Base Temperature} = \frac{\text{Total GDDs}}{\text{Number of Days}}
\]

---

**Sample Calculations**

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Air Temperature</th>
<th>Daily GDD</th>
<th>GDD Running Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>High</td>
<td>Average</td>
</tr>
<tr>
<td>3/24</td>
<td>5:30 PM</td>
<td>45°F</td>
<td>73°F</td>
<td>59°F</td>
</tr>
<tr>
<td>3/25</td>
<td>5:30 PM</td>
<td>35°F</td>
<td>55°F</td>
<td>45°F</td>
</tr>
<tr>
<td>3/26</td>
<td>5:30 PM</td>
<td>46°F</td>
<td>60°F</td>
<td>53°F</td>
</tr>
</tbody>
</table>

March 24: \(\frac{45 + 73}{2} = 118 - 50 = 9\) GDD \(\text{Positive number can be counted.}\)

March 25: \(\frac{35 + 55}{2} = 90 - 50 = -5\) GDD \(\text{Negative numbers are not added.}\)

March 26: \(\frac{46 + 60}{2} = 106 - 50 = 3\) GDD \(\text{Positive number added to total.}\)
As a general rule, begin recording GDD temperatures on March 1. However, during some warm springs, GDDs may begin accumulating in February. In some cases, GDD tracking will begin after a specific occurrence in an insect life cycle (e.g., after heavy pheromone trap catches of cutworm adults). Temperature should be tracked using a minimum (low)/maximum (high) thermometer capable of storing readings for several days. Minimum/maximum (min/max) thermometers are the least expensive method of gathering data to calculate GDDs. Several other types of equipment will gather GDDs in the field. These are commonly called biophenometers, data loggers, or weather monitors. Prices vary, but they are generally more expensive than a simple min/max thermometer. GDD calculators are available online; for example, see www.degreedays.net. Weather services, both paid and free, are also available to provide required data. Skybit (skybit.com) is a subscriber-based service located in Pennsylvania. The National Oceanic and Atmospheric Administration’s (NOAA) National Weather Service provides daily low and high temperatures from weather stations. That data will not be specific to your area and should not replace on-farm temperature collection. In Pennsylvania, GDDs can be found through PA PIPE, the Pennsylvania Pest Information Platform for Extension and Education (extension.psu.edu/pa-pipe).

Monitoring Techniques

Finding insects by visual inspection can be challenging when the insects are fast moving or hiding in lush foliage. In these cases, it may be necessary to employ some scouting techniques that use specialized tools.

Sweeping

Quick-moving insects such as leafhoppers and flea beetles are best counted after being captured in a fine-gauge material net, known as a sweep net. While walking through a field, a scout will sweep the net in front of him/her, moving it from right to left and back to the right in an arc motion (Figure 1.10). Divide the total number of insects by the number of sweeps made to get an average number of insects per sweep.

Beating

In larger, bushy plants, such as potatoes, monitoring may be easier by knocking plants over a beating sheet (canvas stretched between two wooden dowels) and dislodging any insects on the plants (Figure 1.11). Do this in several locations throughout the field to get an overall picture of the pest situation.

Trapping

Several types of insects can be monitored using traps. Different types of traps are available to aid in monitoring. One type of trap is baited with pheromones, or chemicals insects produce as a means of communicating. Pheromone traps are used primarily to lure lepidopteran (moth) pests and trap the insects in either a funnel-style trap (Figure 1.12) or a flat sticky-bottomed trap. When these traps are monitored regularly, collection data can help with timing of control applications.
Black light traps also may be useful. The black light trap uses ultraviolet light to lure insects into the center of the trap where they drop into a canister. The challenge with using this trap can be that many types of insects are attracted to it and the result may be a whole batch of unwanted insects to sort through. An electrical source is also needed. A pitfall trap is another option. This trap consists of a container buried so that the opening is flush with the ground surface. The container should be filled with a killing agent and preservative, such as low-toxicity antifreeze or soapy salt water. Ground-dwelling insects simply fall over the edge of this trap and get caught in the preservative. These are nondiscriminant traps that capture both pest and beneficial arthropods, so the ability to distinguish pests from nonpests is necessary in order to use information from these traps in implementing an IPM program.

Monitoring Tools
When monitoring, a scout must have a few very important tools. Keep these tools together in a backpack or bag so you can conveniently carry them around the fields on each visit.

- **Hand lens**: This small magnifier allows a scout to see insects, mites, and disease fruiting bodies that would otherwise be too small to see (Figure 1.13). These can be purchased in a variety of magnification strengths: 10X, 16X and 20X. The 16X hand lens is a good strength to use and still has a reasonably sized field of view. (See pages 238–240 for supplier information.)
- **Notebook and pen**: Use these to record symptoms, signs, population stage and size, damage severity, field or weather conditions, and location. This information can be a reference for the current season, but it can also be a resource that shows pest and beneficial activity previous seasons.
- **Flagging tape**: Brightly colored flagging tape can mark symptomatic plants so they can be readily located at a later date. Use a permanent marker to record specific information on the tape.

**Monitoring Tips**
1. During the growing season, a scout should monitor fields weekly to look for evidence of beneficial organisms, pests, diseases, and other issues.
2. If possible, scout on cloudy days. The muted sunlight makes observing chlorotic, or yellowed, symptoms in the field easier. Some insects are also more visible in subdued light.
3. When monitoring for pests and beneficials, scouts should walk through the field keeping an eye out for obvious problems and select plants in a random pattern to inspect more closely. Scouts should look for discoloration, wilting, stunted growth, feeding holes, and other obvious symptoms.

**Diagnosis**
Properly identifying the insects found through monitoring is an important next step in the pest management process.

**Step 4. Setting an Action Threshold**
The action or control threshold refers to the population level for a specific pest at which some control measure is justified in order to avoid economic loss or aesthetic damage to a crop.
When the damage becomes unacceptable, the crop has passed what is known as the economic and/or aesthetic injury level. To avoid crops reaching an unacceptable level of damage, the point at which to take control action, or the action threshold, will be reached before the injury level has been reached.

Because pests vary in the severity of damage they cause, action thresholds will also vary. A pest that has great potential to damage or disfigure the fruit or saleable portion of the crops, such as corn earworm, will have a lower threshold than a more minor pest, such as potato aphid on pepper, for which some damage may be acceptable. Action thresholds are also influenced by the market outlet. Commercial processors may set levels of insects or damage allowable in the vegetable being sold. Action thresholds are further discussed in the individual pest sections found in this guide. Threshold information can also be found in state commercial vegetable production guides.

Step 5. Selecting Management Options

In an IPM program, pest management does not rely on only one method of control. Often a combination of methods is employed to achieve a well-rounded, long-lasting management program.

Cultural Control

This category of control involves altering a pest's habitat—in this case, the vegetable production environment—so that it is less favorable to a pest. Pests may be thwarted by making simple changes to planting procedures, such as adjusting planting schedules, rotating crops, and planting trap crops that draw insect pests, or providing habitat for beneficial organisms. Some of these techniques are further explained below.

Cover Cropping

Unwanted weeds, which may serve as alternate hosts for a number of vegetable pests and can compete with vegetable crops for space, water, and nutrients, can be reduced with the winter planting of a cover crop (Figure 1.14). Cover crops that do not survive the winter (e.g., forage radish) do not require killing in the spring and may be especially useful in early spring vegetable crop planting (see the Penn State Extension webinar "Using Winter Killed Cover Crops to Facilitate Organic No-till Planting of Early Spring Vegetables" at www.extension.org/pages/31013/using-winter-killed-cover-crops-to-facilitate-organic-no-till-planting-of-early-spring-vegetables-web).

Early or Delayed Planting

By knowing when a major crop pest will typically move into a crop and at what stage of the crop’s growth cycle that pest may cause the most damage, a grower can try to prevent those two stages from occurring at the same time by moving up or delaying the planting date. For example, early plantings of corn may have a chance to mature to less vulnerable stages before cutworms have a chance to damage the seedlings.

Crop Rotation

By moving a crop from a field where it had been planted for a year or more, growers can thwart the pests that had the opportunity to increase in population. By rotating the planting to a crop from a different family or a nonhost, insects that specialize on a particular family (e.g., Colorado potato beetle) will be forced to move to a different host and may or may not be able to feed on the new crop.

Trap Cropping

Planting a specific trap crop can be beneficial for two reasons. First, the potential pest of a desired crop can be lured away from the main crop and into a more appealing planting of an alternate host. In some cases, it may even be the same crop, simply an earlier planting of it. For example, an early planting of potatoes can be a trap crop that lures Colorado potato beetles away from a later planting of potatoes. The second benefit of trap crops is that they also often harbor beneficial natural predator insects, which helps in controlling pest insects. (See the Biological Control section on page 11.) Insect pests may need to be managed on the trap crop to prevent them from moving into the main crop as the trap crop senesces.

Figure 1.14. Buckwheat, a common cover crop planted in a field for added nutrient and weed control.
Mechanical Controls
Mechanical control involves preventing pest establishment in an environment through the use of physical barriers or mechanical equipment. Some examples of mechanic control in a vegetable production setting include the following.

Row Covers
This technique involves covering rows of vegetable crops with spunbond polypropylene fabric manufactured for this purpose. The fabric can be placed either directly on the plants or over low arches, forming a low tunnel (Figure 1.15). This cover serves two purposes: the crops are protected from both harsh weather conditions, such as cold, sleet, and wind, and insect, disease, and vertebrate pests. Some disadvantages include excess heat buildup and disrupted pollination, so row covers must be removed at or near flowering for insect-pollinated crops.

Staking/Trellising
Staking heavy, leafy plants to prevent them from falling over and resting on the ground provides them with better air circulation and access to sunlight (Figure 1.16). This makes for healthier plants. Staking also provides less opportunity for pathogen spores to be splashed from the ground to foliage surfaces.

Cultivation and Tillage
This is a means of turning the soil and placing weed and crop plant residue under the surface of the soil, effectively killing the living material and providing a prepared surface for planting (Figure 1.17). The process may use a number of implements, including plows, disc cultivators, rotary hoes, rolling cultivators, etc. Timing of this technique can greatly affect the success of weed control.

Mulching
The two categories of mulch are organic mulch, such as shredded or chipped bark, straw, compost, grass clippings, etc., and inorganic mulch, such as black plastic and weed cloth (Figure 1.18). Mulches help suppress weed growth, which also eliminates potential harborage for insect pests. Mulches can also help retain soil moisture and heat.

Trenches
Using trenches involves preparing a plastic-lined barrier ditch along the edge of a crop field. Trenches can be used to trap Colorado potato beetles or other walking pests as they move in and out of fields at the beginning and end of a season. The beetles, which move largely by walking, fall into one side of the ditch and are unable to climb out the other side.
The PA IPM Program is a collaboration between the Pennsylvania Department of Agriculture and The Pennsylvania State University aimed at promoting Integrated Pest Management in both agricultural and nonagricultural settings.
To purchase a hard copy or PDF visit pubs.cas.psu.edu/orders_CAS.asp