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SARE
Sustainable Agriculture Research & Education

A Whole-Farm Approach to Managing Pests



Examples of ecological pest management practices include (clockwise from left): crop scouting *(photo by Carol Glenister)*, **rotating crops** *(photo by Stacie Clary, Western SARE)* **and the use of no-till and cover crops** *(photo by Michael Nolan)*.

SUCCESSFULLY MANAGING PESTS IS ONE OF THE BIGGEST challenges for farmers and ranchers who want to run their operations sustainably. In order to reduce their use of off-farm chemical inputs, they need management options that are reliable and profitable. More and more, farmers across the United States are realizing that ecological pest management strategies can provide what they're looking for. For example, practices that promote natural enemies of pests on the farm provide an estimated $4.5 billion worth of pest suppression each year nationwide. Other common practices include rotating in new crops that disrupt pest cycles, enhancing a crop's ability to compete against weeds and building soils that naturally suppress disease microorganisms. The ecological approach uses knowledge, biodiversity and resource management to produce healthy crops and keep pest insects, weeds and diseases at bay.

Ecological pest management is part of a holistic approach to farming, with benefits that go beyond limiting pest populations and the damage they cause. Improving soil health, supporting beneficial organisms, and maintaining plant and animal diversity all improve other aspects of farm management. The benefits can include, for example, more efficient management of soil nutrients and water. Also, a whole-farm approach improves risk management, which makes the farm more resilient to market fluctuations, extreme weather events associated with climate change, and other production challenges. These benefits can add up to improved profitability, either through lower production costs, more consistent yields, or both.

Pests in Farming Systems Versus Natural Systems

Agricultural pests are any unwanted species of plant, animal, insect or microorganism that damages or reduces the productivity of crops and livestock. They may seem like an ever-present challenge in agriculture, but pest outbreaks are uncommon in natural landscapes, where they have to compete for limited resources and avoid their predators. For example, more than 100,000 species

Natural features in the landscape support biodiversity and protect soil. Tree lines protect fields from heavy winds and native plants attract beneficial organisms. *Photo by Stacie Clary, Western SARE*

of plants, insects, nematodes and other organisms (most are microscopic) may live on a typical farm. But in any given year, only about a dozen species might reach pest status. If you manage your farm correctly, there could be far more beneficial species than pests, and these beneficial species provide important *ecosystem services*, or benefits gained from biodiversity. The ecosystem services that beneficial species contribute to include nutrient cycling (by breaking down plant residues), crop pollination and pest regulation (by eating pests).

Think of pests as a symptom of ecological imbalances on your farm and in the surrounding landscape. In natural environments, pests do not typically reach threatening levels because they experience more competition and predation. In contrast, the management practices we use alter this balance and directly influence the likelihood of developing pest problems. Many agricultural systems are designed to maximize production of a few crop species. Excess tillage, over-fertilization, monoculture cropping and routine pesticide sprays are common examples of practices that disturb ecological processes and create environments favorable to pests. At the same time, these practices reduce biodiversity, meaning fewer beneficial organisms such as natural predators and parasitoids are around to keep pests in check compared to natural systems.

Taking a Holistic View of the Farm

Ecological pest management goes beyond attempts to manage individual pests. Instead, the whole farm is managed to create environments that crops and livestock can thrive in. This systems-level approach considers the impacts of management decisions not only on your cash crops and their pests, but across the whole farm. This is a more knowledge-intensive approach. Growers work to strengthen on-farm ecosystem services by combining good agricultural practices with crop production needs. The goal is to focus on sustainable, proactive and preventive strategies that create healthy crop environments, rather

Growing tomatoes inside a high tunnel protects the crop from many pests and extends the market season. Straw mulch shades out weeds and limits the transmission of pathogens from the soil to plant leaves, while also improving soil health as it decomposes. *Photo by David Van Eeckhout, The Good Acre* than to rely on reactive, input-based controls that degrade the environment and promote pests in the long term.

Regular field scouting and record-keeping are integral to developing a holistic approach to farm or ranch management. Correctly identify and develop working knowledge of the pests and beneficials present in your fields and surrounding region, then use this knowledge to assess the pests' potential to damage your crops. Use an integrated set of strategies that includes cultural (planting dates, plant diversity, proper irrigation), biological (predators and parasitoids) and physical control (row covers, traps) methods, and use selective agrochemicals only as a last resort.

Who Can Use Ecological Management Strategies?

Managing pests with ecological strategies doesn't mean giving up farming the way you know it. Ecological strategies can supplement the unique pest management needs of your farm and provide benefits that go beyond pest management. Small adjustments like pushing back a planting date to avoid peak pest activity or including flowering species in hedgerows and conservation buffers can go a long way towards reducing your need for pesticides. Whether you work with row crops or specialty crops, there are ecological options you can use to rein in your pest problems.

Part One of this publication describes the principles that make up the foundation of ecological pest management. Part Two explains some of the most common ways to put these principles to work on your farm or ranch. To explore ecological pest management further, read this publication online at www.sare.org/pests, where you will find links to additional resources that were developed by SARE and SARE grantees.

Project Highlights

The "Project Highlights" boxes throughout this publication provide examples of SARE-supported farmers and researchers who have successfully used ecological principles to manage important pests in different cropping systems. For complete information on a project, visit our database of project reports (projects.sare.org/search-projects) and search by each project number listed in parentheses. A complete list of highlighted projects is on page 16.

Visit www.sare.org/pests for more information on ecological pest management.

A mixed vegetation buffer near a poultry house at Hill Farms in Houston, Del., offers habitat for pollinators and natural enemies, and reduces dust coming off of the poultry house. *Photo courtesy of Hill Farms*

Part One:

An Ecological Approach to Pest Management

Ecological strategies mimic and reinforce the natural relationships already built into farming systems.

Seeding a cover crop into corn in a no-till system. This is an example of how more farmers are taking advantage of holistic, ecological principles to manage pests, nutrients and water with fewer purchased inputs. *Photo by Edwin Remsberg*

STARTING IN THE 1950s, MOST GROWERS BEGAN TO RELY on agrochemical-based strategies to manage pests. Low-cost pesticides were seen as convenient "silver bullet" solutions, but that view is changing. Repeated use of pesticides has brought about resistance in many pest species. In addition, broad-spectrum insecticides not only kill crop pests but also important non-target predators and pollinators. These disruptions lead to pests resurging and returning to crops faster and in greater numbers, but with fewer predators and parasitoids to control them. In time, the repeated use of pesticides can create conditions where pests thrive, resulting in growers who feel compelled to lean more heavily on the same agrichemical controls that caused the problem; this situation has been named the "pesticide treadmill."

A paper wasp with cabbageworm prey in broccoli. *Photo by Russ Ottens, University of Georgia*

More and more farmers are becoming aware of these risks to their operations, human health and the environment, and are turning instead to ecological pest management strategies for solutions. Ecological strategies treat the farm like an agroecosystem, meaning they use good agricultural practices that mimic and reinforce the natural relationships already built into farming systems. Using cover crops instead of leaving the soil bare, for example, protects soil from erosion, shades out weeds, nurtures soil microbiology and attracts beneficial arthropods that eat pests, pollinate crops and recycle crop debris. In this way, good agricultural practices boost the natural defenses of your farm.

These good agricultural practices, however, require careful farm planning and habitat management, and they depend on two driving ecological concepts: *biodiversity* and *biological control*. *Biodiversity* refers to all of the living species found in and around the farm, including crop plants, weeds, livestock, woody plants and shrubs, arthropods, soil biology, wildlife and many other organisms. The interactions between these organisms and their environment provide valuable ecosystem services like *biological control*, or the use of natural enemies to reduce, prevent and delay pest outbreaks. Instead of reacting to pest problems with off-farm inputs, ecological strategies prevent problems from arising by proactively addressing their root causes, such as low biodiversity, stressed crops and degraded soils.

Ten vineyards partnered with Washington State University to improve or restore wildflower habitat near their fields. The result was fewer pesticide sprays and more beautiful scenery for visitors. *Photo by Lorraine Seymour*

Ecological Principles for Managing Pests

In general, sustainable pest management practices adhere to one or more of the following guidelines:

1. Promote biodiversity
2. Create healthy crop habitats
3. Reduce disturbance to soil and non-crop vegetation
4. Minimize off-farm inputs

These four guidelines are summarized in this publication. For more in-depth information on ecologically based pest management and the strategies that growers are using successfully, read through publications like SARE's *Manage Insects on your Farm* (www.sare.org/manage-insects).

1. Promote Biodiversity

Farming is possible thanks to the many complex relationships that exist between species across the farm, in fields and in the soil. Diversity in the crops you grow and in the way you manage them goes a long way toward reducing pest pressures. A diverse patchwork of crop and non-crop species attracts beneficial insects by providing them food and shelter. Including different varieties of the same crop species can provide plants with genetic resistance against disease-causing organisms and against pest insects. Diversity aboveground drives diversity belowground. For example, rotating plant species that have different growth habits, rooting depths and root exudates promotes the health of the soil, which influences crop defenses.

2. Create Healthy Crop Habitats

The first line of defense against pests is a healthy plant, and healthy soils produce healthy plants. Plant defenses work better when they grow in well-drained, porous soils that have a high level of biological activity. A robust community of soil arthropods and microorganisms promotes soil health and nutrient cycling, and may suppress disease-causing organisms in the soil. With adequate access to plant-available nutrients, crop plants become better competitors against weeds and can naturally defend themselves against insect pests that are feeding on them.

3. Reduce Disturbance to Soil and Non-Crop Vegetation

Agricultural disturbances include practices like harvest, tillage and pesticide applications. Disturbances provoke pest problems and create situations where crop plants are more stressed and vulnerable to pests. While some disturbances such as harvest are unavoidable, others can be minimized. Minimizing the disturbances caused by field tasks promotes undisturbed habitats that beneficial insects use for shelter and to forage for prey, nectar and pollen. Use tillage techniques that avoid stirring the weed seedbank, which could otherwise result in more problematic weeds coming to the soil surface. Frequent tillage also depletes soil organic matter and reduces important soil biology, both of which are vital for healthy soil and crops.

The Natural Defenses of Healthy Crops

What makes a healthy crop?

Healthy soil is the foundation of a healthy crop. Good tilth, drainage, water-holding capacity, high organic matter and fertility all provide a crop with the resources it needs to grow vigorously and respond to stresses from insects, diseases, weeds and harsh weather. Soil management practices such as crop rotation, cover crops, reduced tillage and application of organic materials contribute to cropping environments that are favorable for crop growth but unfavorable for pests.

What natural defenses do crop plants use?

The natural defenses that plants use to minimize stress from insects, weeds and disease-causing pathogens are widespread and can take many forms. They also reduce the impacts of harsh conditions like droughts and floods. Some examples:

- Many types of plants produce physical barriers such as waxy coatings, thorns or plant hairs to stop herbivores from feeding, to reduce disease infection and to slow water loss during extremely hot conditions. Leafhopper-resistant varieties of alfalfa, for example, depend on plant hairs to stop their major pest, the potato leafhopper.
- Most plants produce chemical defenses in response to leaf damage. Some are toxic to insects and some have antimicrobial properties that degrade disease-causing pathogens. For example, cucurbits produce a bitter-tasting chemical that is toxic to insects and deters them from feeding. Brassica and mustard plants are known to produce chemicals that are toxic to nematodes. When incorporated into the soil, mustard crop residues release these toxic chemicals into the soil to suppress nematode pests such as root-knot nematodes.
- Plants can defend themselves by relying on beneficial organisms. When under attack by herbivores, plants release chemical signals to attract predators and parasites to defend them. For example, when attacked by aphid pests, tomatoes produce chemical signals that attract parasitic wasps, which then prey on the aphids. Plant roots often form beneficial relationships with soil fungi called arbuscular mycorrhizal fungi. In exchange for sugars from the plant, mycorrhizal fungi help the plant by expanding its root system and allowing it to access nutrients deeper in the soil. There is evidence that these colonized plants may be more resistant to infection from disease-causing pathogens.

When a plant is under stress, it must divert nutritional resources from growth to defense. A cropping system that emphasizes soil health and fertility provides plants with the resources they need to defend themselves while maintaining growth.

What causes stress and how do pests exploit this?

Stress reduces crop productivity and is caused by environmental conditions like poor soils, flooding, drought and other living organisms such as insects, weeds and disease-causing pathogens. Poor, compacted soils, for example, stunt root growth and reduce the crop's ability to take up water and to scavenge deeper into soil for important nutrients. Crop defenses are weakened under stressful conditions, and the impacts of pests on crop plants may be amplified. When crops are stressed, weeds can more aggressively compete for water, sunlight, space and nutrients, and they are capable of hosting crop diseases. Insect pests defoliate plants and can transmit disease-causing pathogens when they eat the crop. Disease-causing pathogens can more easily infect stressed plants, which have impaired defenses under stressful conditions.

Good agricultural practices should focus on reducing stress to the crop and making the environment less favorable for pests.

A mustard cover crop (left) included in rotation with potatoes (right) suppresses weeds, improves soil health and, when incorporated into the soil, decomposes and releases chemicals that suppress disease-causing organisms. *Photo by Edwin Remsberg*

Project Highlight: Cover Crops and No-Till Suppress Weeds

In the U.S. Virgin Islands (LS12-252), sunn hemp and sunflowers were used as a green manure mulch in order to suppress weeds in jalapeño pepper production. Researchers used a roller crimper to kill sunn hemp and sunflower cover crops before transplanting peppers directly into the residue. The living cover crops provided near-total weed suppression while growing, and cover crop residues provided weed suppression similar to full tillage for up to six weeks after termination.

4. Minimize Off-Farm Inputs

Synthetic fertilizers and pesticides that are improperly managed can worsen pest problems. Pest insects tend to be more attracted to heavily fertilized crops. When excess nitrogen and phosphorus are left behind in the soil, weeds use it to grow, shed seeds and compete with nearby crops. When you reduce off-farm inputs in favor of stable organic amendments such as cover crop residues and composts, which act as slow-release fertilizers, your crop will have access to nutrients when they are needed.

An informed nutrient management plan begins with a soil test. Use results from soil or plant tissue tests to match your fertilizer timing and rates to the needs of the growing crop. Improve nitrogen use efficiency on your farm through best practices like split rate applications, manure management and fertigation. If available, technologies like variable rate fertilization further improve your ability to target fertilizer applications to the crop's needs.

Part Two:

Applying Ecological Principles to the Farm

Diverse crop rotations are a critical pest management tool, especially for organic producers. *Photo by Deb Heleba, Northeast SARE*

THE GOAL OF ECOLOGICAL MANAGEMENT IS TO REDUCE pest abundance to tolerable levels through the use of multiple pest control tactics that integrate with crop and soil management. This is opposed to using silver-bullet solutions to control pests. Think of pest management strategies as individual tools in a tool box, which together create a positive environment for crops and beneficial organisms, and a stressful one for pests. Just as you wouldn't rely on a single tool to fix every problem, you should avoid relying on a single approach to manage pests.

When you integrate multiple control tactics, your production system benefits in the following ways:

- » The impacts of individual strategies are strengthened when used together.
- » The risk of crop failure is reduced because you are spreading the burden of crop protection across many tactics.
- » Environmental disruptions and threats to human health are minimized.
- » Pests' ability to develop resistance or adapt to individual tactics is slowed.
- » If properly integrated, operational costs are reduced and profitability is improved by reducing the need for purchased inputs.

Diversify Plants and Animals Within Agroecosystems

With knowledge of the pests and beneficials that inhabit your farm, think of ways you can add plant diversity to the system both across the farm and throughout the seasons. Adding a new crop or cover crop to the rotation can help break up the life cycles of soil-borne diseases, pest insects and weeds. However, be mindful not to follow a crop or cover crop with another from the same plant family (e.g., follow a legume with a legume), as this can make pest problems worse. For ideas about how to choose and integrate new crops into a rotation, explore SARE's *Crop Rotation on Organic Farms* (www.sare.org/crop-rotation-on-organic-farms). The SARE book *Managing Cover Crops Profitably* (www.sare.org/mccp) features in-depth profiles of common cover crop species and can help you think through appropriate cover crops to use. Or visit *Cover Crops for Sustainable Crop Rotations* (www.sare.org/cover-crops) to explore resources on the multifaceted benefits cover crops provide to your farm.

Think of pest management strategies as individual tools in a tool box.

Grafting and Selecting Resistant Varieties

Some vegetable crops, such as tomatoes, peppers and squashes, include varieties that are genetically resistant to common crop diseases like blights and mildews. Choosing a variety that is resistant to diseases typical of your area is

These sheep at a vineyard in Winters, Calif., were trained to ignore grape leaves while grazing on vegetation such as weeds and cover crops. *Photo courtesy University of California Extension*

Weed Control with Sheep

Integrating livestock into cropping systems can bring many benefits to the farm. Increasingly, farmers are coming to view grazing sheep as an effective way to manage weeds and cover crops instead of chemicals, tillage or mowing. For example, sheep can replace the use of herbicides or mowing to manage floor vegetation in vineyards and orchards. They are also being used by hops growers not only to manage weeds, but also to eat the lower leaves of hops plants. This opens up air flow and can help with disease management.

Adding a flock of sheep to the operation represents an opportunity to diversify, but if this isn't feasible, there might be sheep farms in your area willing to rent out their herd. Important considerations when grazing with sheep include the need for regular rotations, temporary fencing and protection against predators. Also, make sure sheep cannot eat the crop itself, which is critical to vineyard managers, for example. University of California livestock specialists partnered with vineyard managers and sheep managers in a SARE-funded project to develop workable grazing strategies for both weeds and cover crops (FW08-315). The team focused on aversion training, or teaching sheep to avoid eating grape leaves while grazing on weeds and cover crops. Dwarf breeds are another option.

Sheep can also be used to manage weeds and cover crops in field crop systems. The SARE fact sheet *Sheep Grazing to Manage Crop Residues, Insects and Weeds in Northern Plains Grain and Alfalfa Systems* (www.sare.org/sheep-grazing) describes how sheep can be used to graze crop residue and summer fallow as a way to control alfalfa weevils and improve residue management without the use of chemical inputs. Separate research at Montana State University looks at how sheep can be used to terminate cover crops in organic wheat systems instead of tillage, which oftentimes leads to soil erosion problems. Because of their small size, sheep cause less compaction than cattle and are easier to transport.

a proactive and relatively simple step you can take to greatly reduce the severity of crop damage from diseases and insects. But it is unlikely to eliminate problems in the long term. Pest outbreaks can still occur in spite of having planted resistant varieties if environmental conditions or poor crop management decisions create the conditions that are ideal for them. Also, repeated use of the same resistant crop variety in a field can encourage more aggressive pathogens that are unaffected by the resistance to thrive. Therefore, you should use resistant varieties in combination with other disease management strategies, such as crop scouting, equipment sanitation and crop rotation. Disease-resistant varieties can have flavor or yield characteristics that are different from available varieties, and these factors should be taken into account.

Project Highlight: Evaluating Winter Squash Varieties

Seeking new ways to help farmers manage soil-borne diseases and increase their winter sales, Oregon State University researchers used two SARE grants to explore the potential of different winter squash varieties (SW15-021 and OW16-008). They looked at everything from disease management to storage and marketability. In one project, the team shared integrated disease management strategies with Willamette Valley farmers, including fungal disease symptoms and scouting, crop rotation, fungicide treatments and the use of disease-resistant varieties. In the other project, they used on-farm trials to assess the profitability of different squash

In Oregon, farmers and Extension specialists worked together to expand the local market for winter squash. They identified varieties that would produce well using integrated disease management strategies, would keep in storage, and were marketable to chefs and consumers. *Photo by Alex Stone, Oregon State University* varieties, worked with chefs to assess characteristics such as flavor, and created marketing materials for the best-performing varieties. Dozens of farmers in the area adopted new practices as a result of this work.

Grafting is an increasingly popular way to gain the benefit of disease resistance without sacrificing a crop's desirable characteristics. Grafting is especially useful for organic producers, whose disease management options are more limited, and for growers of heirloom crops, as those crops often lack adequate disease resistance. Because grafting is time consuming, you should reserve it for high-value crops such as tomatoes, peppers and melons. The SARE fact sheet *Tomato Grafting for Disease Resistance and Increased Productivity* (www.sare.org/tomato-grafting) describes the grafting process in detail and presents information on the relative resistance of popular tomato varieties to common diseases.

Project Highlight: Grafting Heirloom Tomatoes

A University of Florida horticulture scientist worked with Frog Song Organics in Hawthorne, Fla., to assess the performance and economics of grafted heirloom tomato varieties in an organic high tunnel system (OS13-083). In the SARE-funded project conducted from 2013 to 2017, the team grafted four heirloom varieties (the "scions") onto two commercial rootstocks and compared them to the heirloom varieties with no grafting. They found that grafting was effective at managing Fusarium wilt and resulted in healthier, higher-yielding crops overall. In spite of the higher cost of grafting, some scion-rootstock combinations increased revenue 4.5 times due to improved yields.

Wildflower habitat on a Georgia apple farm designed to attract beneficials and native pollinators. *Photo by Candace Pollock-Moore, Southern SARE*

Include Natural and Semi-Natural Habitats on the Farm

Another way to add diversity is to include perennial plants such as wildflowers, fruit trees and grasses in and around field edges. Flowering perennials stay in place and bloom each year, providing undisturbed habitat rich in nectar, pollen and alternative prey, all of which are attractive to beneficial insects such as lady beetles, ground beetles, lacewings, minute pirate bugs and parasitoids. Perennials boast other benefits, such as extensive rooting systems that trap excess nutrients and pesticides in the soil while promoting soil health, soil biology and water infiltration.

Visit the Native Plants and Ecosystem Services (www.canr.msu.edu/nativeplants/plant_facts/) website developed by University of Michigan researchers, with support from SARE, for information about native plants and their attractiveness to beneficial insects. Wherever possible, consider practicing agroforestry and silvopasture

Details of the process for grafting tomatoes. *Photo courtesy Cary Rivard, Kansas State University* by combining trees, shrubs and perennial grasses with crops and livestock to improve habitat continuity for beneficials throughout the farm. The Center for Agroforestry's (University of Missouri) *Agroforestry Training Manual* and *Handbook for Agroforestry Planning and Design* describe agroforestry practices and identify particular species that can be profitably integrated on your land.

Enhance Natural Enemies

In the United States, natural enemies provide an estimated $4.5 billion worth of pest suppression annually. To take advantage of this valuable service, avoid cropping practices that harm beneficials and instead adopt the practices that support them. In addition to perennials, annual cover crops like buckwheat and cowpeas can establish quickly and provide an early-season food source for natural enemies when their prey is typically scarce. The added ground cover harbors predators such as ground beetles and rove beetles that eat weed seeds and insect pests hiding in the soil. Include vegetative borders and corridors around crop fields to connect beneficials to field edges. Flowering plants established in a field or inside a greenhouse (either in designated rows or in a perimeter) can support natural enemies that are readily available to move into your crop to attack pests. Non-crop vegetation may also hide the crop from pest insects capable of colonizing the crop. Experiment with small plots of vegetational diversity and be sure to consult with local experts.

SARE's bulletin *Cover Cropping for Pollinators and Beneficial Insects* (www.sare.org/cover-crops-pollinators) has information on the ways you can use cover crops to support important natural enemies and pollinators, and to gain their other benefits. Again, *Manage Insects On Your Farm* (www.sare.org/manage-insects) covers whole-farm strategies to support beneficials and includes success stories that illustrate farmer innovations.

An insectary border of buckwheat around a cornfield can attract beneficial insects such as lady beetles and hoverflies for pest suppression (top). Lady beetles and hoverfly larvae are natural predators of common corn pests like aphids and corn borers (bottom). *Photos by Jermaine Hinds, SARE*

Manage Soil to Produce Healthy Crops

Understanding the link between soil health and healthy plants is fundamental to developing ecological pest management strategies. Practices such as conservation tillage, cover cropping and composting promote healthy crops by improving their growing conditions.

Conservation tillage reduces disturbance to the soil's structure and to soil food webs. It leaves vegetation on the surface that protects the soil from erosion. Cover crops add living roots in the soil that compete with weeds, keep soil in place and reduce compaction.

Once terminated, cover crop residues add organic matter that promotes important beneficial soil biology. This includes soil invertebrates and microorganisms like mycorrhizal fungi that help your crop scavenge otherwise out-of-reach nutrients, as well as other beneficials that prevent disease-causing organisms from infecting the crop.

Composts and manures improve water-holding capacity, suppress disease organisms and provide stable plant-available nutrients to your crop. When grown in healthy soils, crops have access to enough nutrients to support the natural physical and chemical defenses they rely on to resist pathogens and insect pests.

Learn more about soil health practices by exploring SARE's *What is Soil Health?* (www.sare.org/what-is-soil-health) interactive infographic and *Building Soils for Better Crops* (www.sare.org/bsbc) book. SARE's *Steel in the Field* (www.sare.org/steel-in-the-field) includes profiles of weed and soil management implements.

Cowpeas are intercropped with squash to attract pollinators and beneficial insects, and to add nitrogen to the soil. Straw mulch adds organic matter, shades out weeds, improves water retention and minimizes disease transmission from the soil to plant leaves. *Photo by Beatrice Dingha, North Carolina State A&T University*

Project Highlight: Rolled Cover Crops

In vegetable production trials (LNE10-295) at Rodale Institute in Kutztown, Penn., rolled cover crops provided effective weed suppression compared to the use of black plastic mulch. At the same time, the cover crop significantly reduced labor costs and eliminated plastic waste. A rolled rye and rye-vetch cover crop had only 5% of the weeds as compared to beds planted with black plastic. In addition to smothering weeds, the cover crop provided organic matter and reduced soil erosion. Learn more about ecological approaches to weed management in Rodale's guidebook, *Beyond Black Plastic* (www.sare.org/beyond-black-plastic).

Minimize Agricultural Disturbances on the Farm

Although they are sometimes necessary for pest management, agricultural disturbances should be minimized to avoid disrupting the beneficial relationships and processes that ecological strategies build. Think of ways to reduce excessive tillage. This can be done by adopting conservation tillage options like no-till, strip-till and ridge till, as well as by reducing the frequency of tillage. Switching to a less disruptive implement like a chisel plow instead of a moldboard plow is another way to reduce soil disturbances. In no-till settings, growers typically rely on residual and pre-emergent herbicide applications to keep weeds low, but this encourages herbicide-resistant weeds to develop. Combine no-till with high-biomass cover crops like cereal rye to ease the pressure of herbicide-resistant weeds. Integrate grazing, wherever feasible, to manage weeds in reduced-till and no-till fields.

Techniques such as strip till and crimping to terminate a cover crop, as pictured on this Colorado farm, minimize soil disturbances and provide weed control. *Photo by Michael Nolan, Mountain Roots Produce*

Tennessee State University (TSU) researchers established these maple trees in a field of crimson clover and wheat to see if the cover crop could deter pests and suppress weeds. The cover crop needed to be replanted in the tree rows, and ultimately it provided effective pest management (right). *Photo by Karla Addesso, TSU*

The SARE bulletin *Cover Crop Economics* (www.sare.org/cover-crop-economics) provides a detailed explanation of how a cereal rye cover crop can pay for itself within the first two years when used to manage herbicide-resistant weeds. When the cereal rye produces enough biomass to smother weeds, growers can get by with fewer applications of lower-cost residual and post-emergent herbicides.

Pesticides are often another source of disturbance on the farm. They reduce biodiversity by destroying non-crop vegetation, which is an important overwintering site for beneficial organisms. They may also kill non-target insects that are beneficial or that serve as alternative prey to important natural enemies. Consider strategies like perimeter trap cropping, where you surround the perimeter of a crop field with another, more attractive variety that lures problem pests away from the cash crop. Target the trap crop border with a selective pesticide to kill the target pests and reduce the total volume of pesticide applied.

Project Highlight: Trap Cropping

In muskmelon production in Iowa, a combination of perimeter trap cropping and delayed row cover removal (LNC13-350) showed promise for managing cucumber beetles and the bacterial wilt pathogen that these beetles transmit. Researchers found that a two-row perimeter of the more attractive buttercup squash lures colonizing cucumber beetles away from the muskmelon cash crop. Applying an insecticide to only the trap crop reduces the overall amount of insecticide used by 59% and maintains effective insect and disease suppression.

An attracticidal sphere deployed in a blueberry field attracts and kills Spotted wing drosophila, an important pest of berry crops. *Photo by Tracey Leskey, USDA Agricultural Research Service*

Create Multiple Stresses for Pests

A key tenet of ecologically based pest management is to create a healthy environment for the crop and one that stresses and deters pests. Knowledge of problem pests, their behaviors and life cycles is critical when determining the tactics to use. Consider the pest's resource and habitat needs, when and how they colonize crop fields, and the beneficial organisms that attack them. Then, apply ecological strategies that will work against their preferences.

Project Highlight: Deterring a Pest with Cover Crops

The flatheaded appletree borer, a longtime orchard pest, has a hard time finding host trees to lay eggs in when cover crops are involved. A farmer and a team of researchers from Tennessee State University (OS14-084) overseeded winter cover crops into their maple nurseries to manage appletree borers and weeds. They found that growing a mix of crimson clover and annual rye between transplanted trees reduced borer damage by up to 95%. The cover crop created unfavorable habitat for the pest by acting as a barrier that hid host tree trunks from foraging appletree borers. Further, the cool, shaded environment provided by the cover crop reduced weeds and deterred appletree borers, which prefer to lay their eggs on warm, sunny, low-lying areas of host trees. The cover crop was as effective as the conventional approach, which used insecticides and herbicides.

For example, disrupt a pest's habitat by rotating to a new non-host crop. Insects and diseases that specialize in a particular crop will have a hard time without their host. Reduce weeds' access to sunlight by using narrower crop row spacing or with cover crop residues. Experiment with wider row spacing to minimize the humid conditions that fungal and bacterial crop diseases thrive in. Disrupt the ability of insect pests to disperse across your farm by bordering crop fields with non-host plants. This strategy works by jumbling the visual and chemical cues that pest insects use to locate host crops. Mating-disruption pheromone traps can confuse mate-seeking insects and lower the pest's ability to reproduce. Sanitizing your harvest and weeding equipment between uses can also reduce the spread of weed seeds or pathogens across your farm.

The SARE fact sheet *Ecological Management of Key Arthropod Pests in Northeast Apple Orchards* (www.sare.org/apple-pests) provides examples of these strategies in action for common orchard pests in the Northeast.

Project Highlight: Physical Pest Exclusion

Plagued with the invasive spotted wing drosophila (SWD) on her farm in New York, berry producer Dale Ila Riggs recalled losing 40% of her blueberry crop and 25% of her raspberry crop to an infestation in 2012. With the help of a SARE grant (FNE14-813), she tested exclusion netting as a tactic to keep the flies off her berry crops and to keep the number of sprays down. Riggs found that exclusion netting worked very well on her operation, reducing infestation levels of SWD in covered berries to less than 1%. The next year, exclusion netting was even more effective at reducing SWD compared to uncovered, sprayed berries that received as many as five insecticide applications during harvest season. Read more about SWD management in these related publications:

- Management Recommendations for Spotted Wing Drosophila in Organic Berry Crops
- Integrated Strategies for Management of Spotted Wing Drosophila in Organic Small Fruit Production
- Spotted Wing Drosophila Pest Management Recommendations for Southeastern Blueberries

For further reading about high tunnel production, visit SARE's *High Tunnels and Other Season Extension Techniques* (www.sare.org/high-tunnels).

Reduce Excess Sources of Nitrogen

Fertilizers may be important tools in crop production, but when applied in excess they can inadvertently support pests and impair water quality. For soil fertility, have your soil tested regularly to identify and set nutrient management goals. Legume cover crops can provide supplemental nitrogen and grass cover crops can take up soil nitrogen. Manures and composts can provide much-needed nutrients in their organic forms. Organic amendments like cover crop residues, manures and composts slowly release plant-available nutrients that feed the crop and soil biology, and build soil organic matter. SARE's *Building Soils for Better Crops* (www.sare.org/bsbc) provides an in-depth discussion on producing resilient crops by managing soil health and nutrients.

Alabama farmer Will Mastin (right) worked with Alabama Cooperative Extension entomologist Ayanava Majumdar (left) to evaluate the use of shade cloth on his high tunnel as a physical barrier to large-bodied insects. Shade cloth still allowed air to flow through the structure.

Photo by Candace Pollock-Moore, Southern SARE

Project Highlight: Targeted Sprays Control Stink Bugs

Research in New Jersey (ONE14-217) found that producers can reduce insecticide applications by as much as 75% to manage brown marmorated stink bugs and other orchard pests. Knowing that brown marmorated stink bugs colonize orchards from woody field edges, producers targeted the orchard perimeter with insecticide applications, instead of targeting the entire plot. This method, when combined with IPM-based monitoring and trapping, conserved natural enemies in the orchard by reducing the total volume of insecticide applied and saved growers 25–60% in application costs. *Ecological Management of Key Arthropod Pests in Northeast Apple Orchards* (www.sare.org/apple-pests) is a related fact sheet that discusses ecological strategies to manage this pest complex in apples.

As a Last Resort, Use Targeted Attacks

Because of their potential to reduce on-farm biodiversity and harm the environment, pesticides should only be used as a last resort. Use Integrated Pest Management (IPM) scouting guidelines to determine if and when a pesticide is needed. (Learn more at www.ipmcenters.org/about/what-is-ipm.) Visit the National Integrated Pest Management

Regularly scouting your fields to better understand your pest challenges and to look for signs of damage is the first step of an ecological management plan.
Photo by Lance Cheung, USDA

Database and the Regional IPM Centers Resource Database. They are searchable databases, maintained by USDA's Regional Integrated Pest Management Centers, that contain crop profiles, fact sheets, pest management guidelines and strategic plans.

- **Identify:** Begin by scouting plants regularly to identify problem pests and to monitor their numbers.
- **Evaluate:** With the help of local Extension agents and publications, evaluate whether the pests you identify are economically important by comparing them against pest thresholds.
- **Prevent:** Early on, plan for and integrate biological and cultural management options that promote beneficial ecosystem services and prevent pest problems.
- **Action:** In the event that a pest reaches its action threshold, take action by determining the appropriate pesticide or biological control tactics to use.
- **Monitor and evaluate:** After treatment, continue to monitor pest numbers in order to evaluate the effectiveness of your strategy.

As a general rule, begin with the least toxic products if a reactive control is required. Examples include selective pesticides, growth regulators, microbial toxins, feeding deterrents, pheromones and plant-based oils that target problem pests. Natural predators are not as affected by these controls and thus are better able to continue their attack on crop pests. Be sure to keep a running log of the pests and beneficials that visit your fields. This information can help you forecast and plan for pests that may show up. You can also use this information to plan and refine your pest management plan in future years.

Project Highlight: Control of White Mold with a Biopesticide

White mold, an important fungal disease in snap beans and other vegetable crops nationwide, is managed with the help of a fungal parasite, *Coniothyrium minitans*. Applied as a fungal biopesticide, *C. minitans* specifically attacks and kills the pathogen that causes white mold. Adding cultural practices like resistant variety selection, crop rotation and reduced tillage lowered white mold disease severity in beans from 11% to 3% during a SARE grant project (SW09-031).

Taking Stock: The Basics of Crop Scouting

The first step in any pest management plan is to properly identify and assess the pest and beneficial species that are inhabiting your farm. Assessing pest levels is especially important when considering the use of pesticides because it informs both the type of pesticide needed for your specific pest and whether they are at levels threatening enough to need an application. Make a habit of getting out and regularly scouting your fields, high tunnels and greenhouses. Examine plants and the soil below for pest insects, weeds, diseases and their accompanying symptoms and disorders. Look for beneficial insects such as generalist predators and parasitoids. Here are a few broad guidelines for scouting your fields for pests and beneficial organisms:

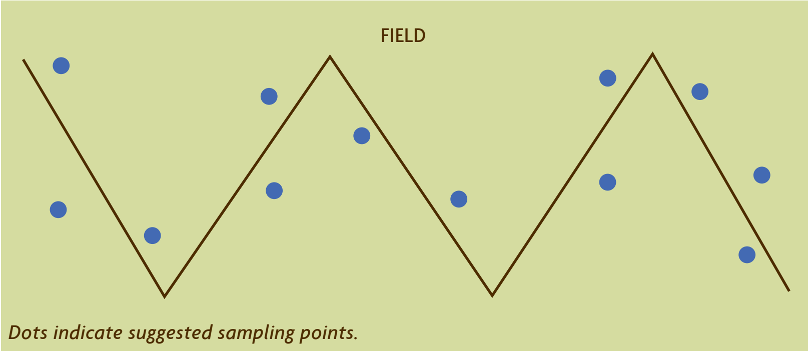
- Scout early and often. Weekly is a good rule of thumb, but consult with local experts and production manuals to make informed decisions.
- Make a map of your field, high tunnel or greenhouse and inspect individual plants following a zig-zag, W or X pattern at a predetermined number of locations throughout the area (Figure 1).
- At each location, look for signs of pest activity by carefully examining all plant parts, including upper and lower leaf surfaces, growing points and fruits. Examine the soil below for weed seedlings and insect pests.
- Consult with local Extension agents, field manuals or local university departments to confirm any signs of pests and beneficial species you have identified. This is important because two pest species may resemble each other but may require different management strategies. Pests may also resemble beneficial species.
- Keep a detailed log of pest and beneficial species you find, where and when. Be sure to record important information related to crop growth stage, pest abundance (e.g., number of insects per plant, number of weeds per row) and their life stages. For diseases, use a simple rating scale to measure severity of disease symptoms. Over time you can use these notes to anticipate the arrival of pest species and, if needed, plan the appropriate controls.
- Pay special attention to pest-prone areas. These include field edges, waterlogged areas and high-traffic areas where pests are more likely to colonize.
- Use regionally available forecasting applications like Penn State's PestWatch, Oregon State's USPest or Cornell's Network for Environment and Weather Applications to forecast the arrival of specific pests.

Beyond Pest Management

The strategies outlined in this publication focus on pest management, but their benefits do not stop there. Taken together, ecologically based practices can result in more efficient use of farm resources, lower input costs, a safer work environment and greater overall productivity. Cover crops are a prime example of a strategy with multifaceted benefits. Depending on how they are used, cover crops improve nutrient and water management, reduce erosion and protect water quality, in addition to managing pests. The SARE bulletin *Cover Crop Economics* (www.sare.org/cover-crop-economics) describes how cover crops can quickly become profitable when they are used in different management situations. These situations include when herbicide-resistant weeds are present, compaction is an issue, available water is at a deficit or irrigation is needed, or when nutrients need to be managed. Explore the bulletin to read further about different cases where using cover crops may be profitable for your operation.

Rotating your crops is another ecologically based strategy that provides multiple benefits, including breaking pest cycles. Creating conservation buffer strips at

Figure 1. Be sure to sample all areas of the field when monitoring pests. A ziz-zag pattern can help you do this.



Managing Pests in a Changing Climate

In a changing climate, unpredictable weather events like flooding and extended drought conditions, as well as shifting precipitation and temperature patterns, may impact the severity of insect, weed and disease pests. Changes in temperature and precipitation can influence insect pest dispersal patterns, abundance and survival. Warmer, wetter growing seasons may result in higher weed and disease pressures in important crops. Milder winters may result in higher survival by pests that normally die in cold winters. Wetter growing seasons mean less time available for field operations that depend on favorable weather conditions, such as cultivation or planting.

Producers are taking advantage of holistic ecological strategies that contribute to climate-resilient cropping environments. For example, a well-designed cover crop cocktail will oftentimes improve water use during a drought by adding surface residue and improving soil structure. This is in addition to the pest- and nutrient-management benefits associated with cover crops already described. Learn more about these and other strategies producers are using to mitigate climate risk in the SARE bulletin, *Cultivating Climate Resilience on Farms and Ranches* (www.sare.org/climate-resilience).

Aphids on sugar snap peas. *Photo by Candace Pollock-Moore, Southern SARE*

field edges protects water quality and supports wildlife while also providing habitat for important beneficial organisms. Along with allowing beneficial soil organisms to thrive, conservation tillage leads to lower fuel and labor costs. Practices that result in more careful use of inputs, such as scouting, monitoring, IPM and variable rate applications, not only create a more favorable growing environment for crops, but can also save money and protect both the natural environment and the health of agricultural workers.

The goal of ecological pest management is to produce healthy, high-quality food in a sustainable manner. Strategies that are not economically or socially feasible are not sustainable, so the practices outlined in this publication should be tested in small trials before scaling up. State and federal cost-share programs like USDA's Environmental Quality Incentives Program (EQIP) or Conservation Stewardship Program (CSP) provide financial and technical assistance that can help ease the costs of adopting new strategies like high tunnels, conservation buffers and cover crops. Your farming system may be unique, but the ecological principles described here are universal. Taking the ecological approach means discovering more about the natural processes on your farm and managing habitat to strengthen them in ways that maintain crop productivity. It represents a long-term commitment to testing, tweaking and learning.

Additional Resources

To explore ecological pest management further, read this bulletin online at www.sare.org/pest-bulletin, where you will find links to additional resources that were developed by SARE and SARE grantees.

Online Publications

Books, bulletins, fact sheets and other resources developed by SARE, free to access online.

Building Soils for Better Crops
www.sare.org/bsbc

Cover Crop Economics
www.sare.org/cover-crop-economics

Cover Cropping for Pollinators and Beneficial Insects
www.sare.org/cover-crops-pollinators

Cover Crops for Sustainable Crop Rotations
www.sare.org/cover-crops

Crop Rotation on Organic Farms
www.sare.org/crop-rotation-on-organic-farms

Cultivating Climate Resilience on Farms and Ranches
www.sare.org/climate-resilience

Ecological Management of Key Arthropod Pests in Northeast Apple Orchards
www.sare.org/apple-pests

High Tunnels and Other Season Extension Techniques
www.sare.org/high-tunnels

Manage Insects On Your Farm
www.sare.org/manage-insects

Managing Cover Crops Profitably
www.sare.org/mccp

Organic Production
www.sare.org/organic

Sheep Grazing to Manage Crop Residues, Insects and Weeds in Northern Plains Grain and Alfalfa Systems
www.sare.org/sheep-grazing

Steel in the Field
www.sare.org/steel-in-the-field

Tomato Grafting for Disease Resistance and Increased Productivity
www.sare.org/tomato-grafting

What is Soil Health?
www.sare.org/what-is-soil-health

Project Highlights

Topics and links to final reports of SARE-funded projects highlighted in this bulletin. Want to dig deeper? Search all project reports at projects.sare.org.

Control of White Mold with a Biopesticide
https://projects.sare.org/project-reports/SW09-031

Targeted Sprays Control Stink Bugs
https://projects.sare.org/project-reports/ONE14-217

Physical Pest Exclusion
https://projects.sare.org/project-reports/FNE14-813

Deterring a Pest with Cover Crops
https://projects.sare.org/project-reports/OS14-084

Trap Cropping
https://projects.sare.org/project-reports/LNC13-350

Rolled Cover Crops
https://projects.sare.org/project-reports/LNE10-295

Grafting Heirloom Tomatoes
https://projects.sare.org/project-reports/OS13-083

Evaluating Winter Squash Varieties
https://projects.sare.org/project-reports/SW15-021

https://projects.sare.org/project-reports/OW16-008

Weed Control with Sheep
https://projects.sare.org/project-reports/FW08-315

Cover Crops and No-Till Suppress Weeds
https://projects.sare.org/project-reports/LS12-252

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SARE Sustainable Agriculture Research & Education

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