

Fruit Crop Ecology and Management

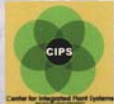




Fruit Crop Ecology and Management



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Preface

In 1998, a team of Michigan State University scientists, Extension workers and farmers led by Dr. Richard R. Harwood published *Michigan Field Crop Ecology*. This colorfully illustrated book presented a new view of the biology behind sustainable field crop production. Readers encouraged the authors to develop a second book that would further discuss pest management within a sustainable field crop system. Harwood recruited Dr. Dale R. Mutch to organize a team to produce the second publication, *Michigan Field Crop Pest Ecology and Management*. In 1999, MSU fruit specialists led by Dr. Charles E. Edson began organizing funding and authors to produce a third book featuring similar principles for fruit production. *Fruit Crop Ecology and Management* is the result of these efforts. We wish to thank Dr. Harwood and the previous authors for inspiring us to develop this publication. Their legacy continues in this book as we explore fruit crop ecology and management concepts.

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Cover:

Annemiek Schilder: raspberry, diseased grape leaf
Tyler Fox: ants tending aphids
Rufus Isaacs: scout checking data, bee hive
Ron Perry: pruning fruit trees
Ted Cline, Photair Inc.: Aerial view of lake and orchards
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Steve Deming: grape cluster



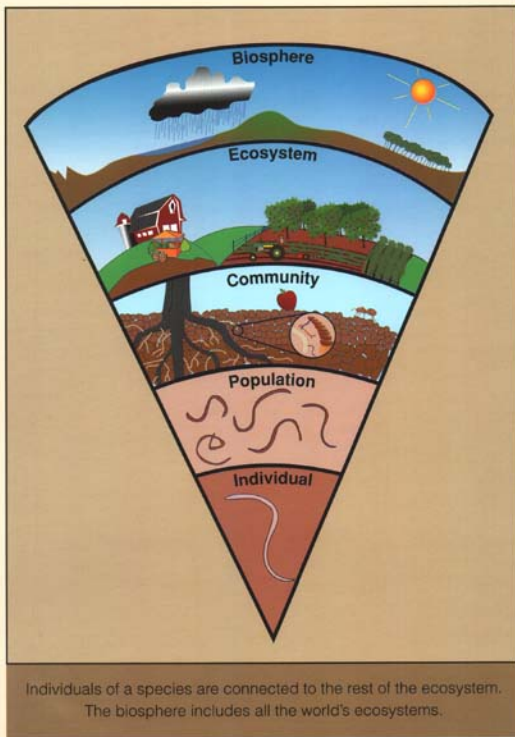
Introduction: An ecological approach to growing fruit

*Joy N. Landis, Jose E. Sanchez, Richard H. Lehnert, Charles E. Edson,
George W. Bird and Scott M. Swinton*

What is fruit crop ecology?

Biological and social factors are driving the need for new farming practices. Fruit crop ecology is the study of the interactions among the many biological, environmental and management factors that make up and influence fruit production. This book explores growing fruit within a complex web that connects soil, plants, animals, humans, landscapes and the atmosphere. An ecological approach to fruit production recognizes that these factors interact in a changing environment and that it is impossible to change one aspect of a farming system without affecting others.

Growers and consumers have benefited greatly from technological advances in fruit production that have increased yields and reduced labor costs. There have also been some unexpected environmental and social consequences, such as pesticide resistance, loss of biodiversity, potential water pollution, consumer concerns



about chemical residues and issues of worker safety. Growers and scientists are looking for better ways to work within a healthy system of soils, plants and animals.

Many pieces of the ecological systems described throughout this book are familiar to horticulturists. This publication's goal is to present a fresh look at the connections among the pieces and help farmers better understand their ecosystem. They can use ecosystem knowledge to design operations that result in high quality fruit, a healthy environment and confident consumers.

We hope this book's readers will find it a useful tool for examining their practices and evaluating new alternatives. An ecological approach will help fruit producers:

- Produce quality fruit.
- Enhance profitability.
- Adopt new practices.
- Reach new markets.
- Interact with the environment surrounding their farm.
- Comply with evolving laws and restrictions.
- Respond to neighbors' questions or concerns.

Understanding the system

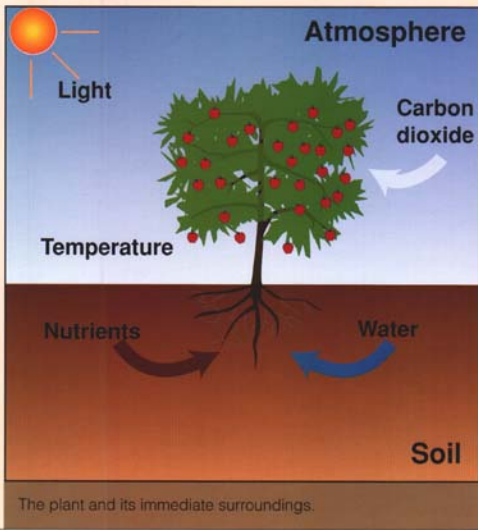
Using light energy, plants take carbon from the air and water and nutrients from the soil and assemble them into molecules that store the sun's energy and the earth's minerals in the organic matter we consume as food. Through the process of photosynthesis, plants are the primary producers of organic matter and storers of the sun's energy.

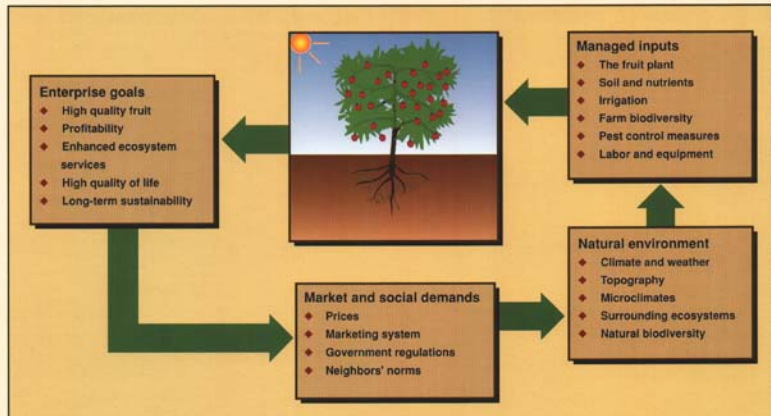
Sounds simple. But between sun, photosynthesis and shiny red apples lie grower management and the need for fundamental knowledge upon

which to make decisions.

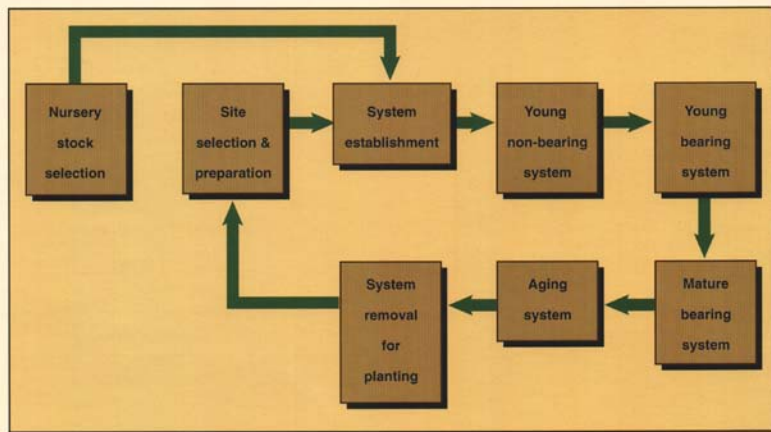
A grower must operate within the natural environment — climate, weather, surrounding ecosystems — and apply management. Management decisions are made in response to the natural environment and socio-economic conditions.

Within the context of a constantly changing environment, management decisions are heavily influenced by the developmental stage of the fruit system. Managing young non-bearing trees is different from managing a mature orchard.





The fruit enterprise and its environments.



Fruit system dynamics.

A guide to reading *Fruit Crop Ecology and Management*

This book explores fruit production at three different scales. Imagine looking down at the Earth from a satellite equipped with a powerful telescope. You can focus in on a single leaf or zoom out to a larger scale until you see the entire orchard or field surrounded by its landscape setting. Also envision you have a special filtering lens that reveals the human setting of markets, neighbors and policies that affect fruit production. These diagrams illustrate the three scales that organize the flow of information throughout this book.



Chapter 1. The agricultural ecosystem.

In **Chapter 1**, we zoom in for a close look at the fruit plant and the natural and managed environments that surround it. Climate and weather, topography, surrounding ecosystems, the soil and farm

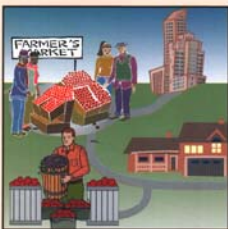
biodiversity are all contributors. The mix of sunlight, temperature, water, essential elements, soil quality and biodiversity at your site affects management decisions and the resulting outcomes. For optimal results, we need to understand how the plant and soil take up carbon and minerals and transform them to perform a range of functions.



Chapter 2. Managing the community of pests and beneficials.

In **Chapter 2**, our perspective shifts to view the community of organisms around the plant. These insects, mites, microbes and nematodes are very important ecological elements in the orchard, vineyard or field. Climate and weather add to the complexity, driving organism spread and development and at the same time offering important

information for monitoring and preventing pest problems. A look at landscape ecology reveals the effects of the immediate surroundings and regional landscape on the community of organisms.



Chapter 3. The human setting.

We filter the information in **Chapter 3** to view the people of the farm community and the world beyond as they affect production decisions. Every grower and consultant feels the pressure of integrating economics and marketing with the biology of the system while respecting the law. For fruit crop ecology, this means meeting quality standards of consumers and processors, building mutually beneficial interactions between farm and non-farm residents, and providing a safe, attractive place in which to live and work.

In **Chapter 4**, we set aside the imaginary telescope and consider what the three perspectives tell us about producing fruit sustainably. Management moves beyond a pest-by-pest focus to a community focus. We note the environmental impacts created by management practices and aim to limit any negative ones while producing quality fruit. You should leave this book equipped with new ideas for managing a sustainable fruit

production system that is rooted within and at ease with the larger community.

Fruit Crop Ecology and Management is an effort to encompass ecological principles and horticultural practices for both tree fruits and small fruits. At times this requires the reader to examine examples from one crop and make their own connection to another. Our primary region of reference is the U.S. Great

Lakes region, but much of the information can be applied well beyond that area. In general, we present fundamental knowledge rather than specific recommendations and anticipate growers will seek additional references for details about practices for integrated pest management or organic or other approaches to farming.

S. Deming



Chapter 1: The agricultural ecosystem

Chapter questions:

- How do climate and natural ecosystems influence farms?
- How can I make my fruit plant efficiently use ecosystem resources?
- How can a more biologically active soil benefit sustainable fruit production?
- How does biodiversity promote the health of my farm?



Blooming fruit trees within a lakeside community.

A farm is a piece of a bigger ecosystem. An agricultural ecosystem is composed of all the populations in a given area and the physical environment within and beyond the farm boundaries. The non-living components include water, soil,

light, mineral nutrients and weather. The living components include plants and animals such as birds, rodents and insects, and microscopic organisms such as bacteria, fungi and nematodes.

In fruit production ecosystems, components can be natural or managed. The natural environment is the most important factor determining where, how and what kind of fruit is grown. The managed environment is the part of the ecosystem that contains the farm and its immediate surroundings. The managed environment consists of three interacting elements: the fruit plant, the soil and farm biodiversity. These elements should be clearly understood and managed so that natural processes enhance crop health, productivity and environmental quality. Management practices that affect these processes include those that allow better plant-climate relationships, such as orchard and vineyard design and pruning, and those that enhance plant-soil relationships, such as cover cropping, mulching and applying organic amendments.

The natural environment

Jeffrey A. Andresen, Jose E. Sanchez and George W. Bird



Key elements of the natural environment are weather and climate, geographical features and surrounding ecosystems. The natural environment drives ecological processes and affects management decisions. It affects the species and varieties of fruit that can be grown and determines the requirements for irrigation, supplemental fertilization, and control of diseases, weeds and insects. It influences the entire

ecology of the landscape, including the interests of people with whom fruit growers share the environment.

Weather and climate are two facets of the natural environment that fruit growers see daily and are vitally important to the management of fruit production. Understanding how weather and climate function helps growers turn the local forecasts into management decisions on their farms.

Climate and weather

"Climate" refers to weather conditions at a location averaged over long periods of time, usually 30 years or longer. "Weather" refers to current or recent conditions.

Temperature, wind velocity and precipitation are just a few of the weather conditions that are used to describe a location's climate. Climate and weather change over time and operate in cycles. Climate changes tend to occur over long periods; weather changes constantly. Climate and weather function on many scales, from the large — e.g., a jet stream — to the micro — underneath the leaf on a tree.

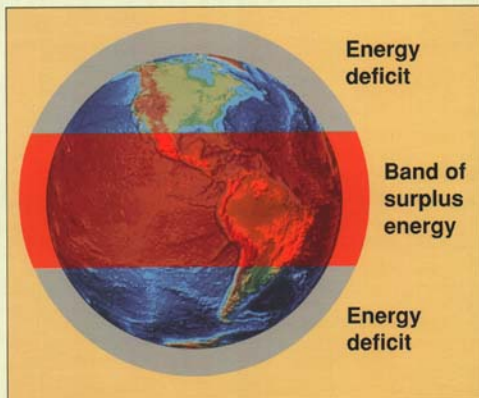
Examples of the three scales of climate and weather

Scale	Length/size	Area	Phenomenon
Macro	thousands of miles	USA	jet stream
Meso	regional	Michigan	thunderstorm, lake-effect
Micro	up to 0.5 mile	field	canopy leaf wetness

Global energy and water cycles

Three factors generally control climate: the amount of solar energy striking the surface, the rotation of the earth on its axis, and the distribution of land and water on the surface of the planet. The effects of direct

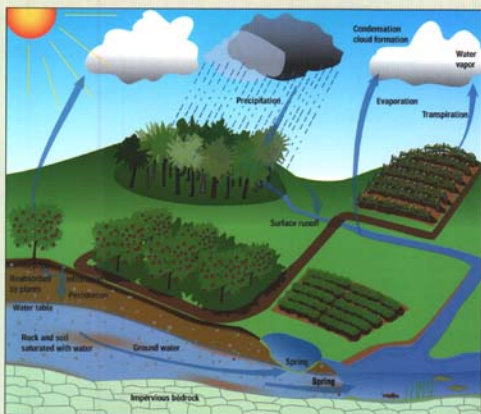
and slanting sun angles, day length and atmospheric obstructions such as clouds create regional differences in energy. Surpluses of energy occur in a broad belt around the Earth's equator, with a net energy deficit north and south of that belt to the poles. This surplus and deficit of energy



and the movement of energy as it seeks equilibrium are the major driving forces behind weather and climate. Fundamental laws of nature require energy to move from areas of greater to lesser concentration and seek equilibrium. About 75 percent of the energy imbalance between equator and poles is "corrected" by flows in the atmosphere; the rest of the energy is transferred by ocean currents.

Jet streams occur in both the north and south temperate zones. These rivers of faster moving air are several hundred miles wide and stream above and around both hemispheres. They mark the boundaries between areas of energy deficit to the poleward side and energy surpluses to the equatorial side. Jet streams act as steering mechanisms for weather disturbances in temperate climates of the world. The Northern Hemisphere jet stream is the key atmospheric feature affecting the fruit-growing regions of the northeastern United States. Its movement and configuration strongly affect day-to-day and week-to-week weather patterns.

Oceans are the ultimate source of all water on earth. A large amount of the sun's energy



The hydrological cycle shows how water circulates throughout a site where fruit is grown.

goes directly into evaporating water, which moderates temperature extremes and creates precipitation. If there were no water to evaporate, the temperature of the earth would be about 80 degrees F warmer than it is. Evaporation from the oceans also generates 86 percent of Earth's precipitation. The remaining precipitation comes from evaporation from soil surfaces and plant transpiration over land. Water in the form of vapor is moved inland by prevailing winds. In general, the farther a location is from an ocean, the drier its climate.

Climatological limitations to agriculture

In temperate areas, the most important climatic limitation is the change of the seasons. Temperate crop species must complete their reproductive cycle during the time of the year when temperatures are warm enough to allow growth and development. Other temperature-related constraints are day-to-day variability during the growing season and extreme cold temperatures during the off-season. Because temperature is difficult for a grower to modify, it is perhaps



Blueberry leaves show red fall color.

the most important constraint influenced by geography.

Water is another major limitation. Plants require water for both growth and temperature control. An actively growing plant transpires five to 10 times as much water per day as it holds at any given time. Water conservation and quality are very important for fruit growers. Other constraints include excessive wind, cloudiness and moisture.

The balance of energy at the surface

In addition to Earth's energy balance on a global scale, distribution and flow of energy take place on a much smaller (micro) scale. Balances are obtained when energy flows to and from matter, as by:

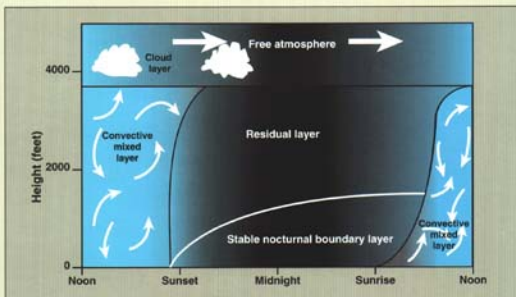
- Net radiation (radiant energy moving toward and away from surfaces).
- Energy changes associated with evaporation and condensation.
- Transport of heat energy by wind.
- Movement of heat into and out of the soil profile.

- Energy transfer associated with plant photosynthesis and respiration.

During photosynthesis, plants convert carbon dioxide gas and water into simple sugars (carbohydrates) and release oxygen. The energy captured and stored in this process is responsible for the growth and activities of all living organisms.

Daily cycle of the boundary layer

The planetary boundary layer of air surrounds Earth up to about 3,000 feet. Carbon dioxide, heat energy and water vapor move to and from the plant canopy within this layer. Changes in the amount of energy available on a landscape's surface directly affect the physical character of this layer. Higher amounts of



Example of the growth and decay of the earth's boundary layer throughout the day and night in a temperate climate with fair weather conditions. (Adapted from Stull, 1988.)

energy are usually associated with more rapid vertical movement and transport.

The typical daily pattern of the planetary boundary layer begins at sunrise with the air next to the ground heating and rising. This vertical motion creates turbulence that mixes the air. The layer reaches its maximum depth by late morning or early afternoon and begins to diminish shortly after sunset.

At sunset, the opposite process takes place. Without sunlight, the ground surface cools. Because air is an effective insulator, the surface and vegetation quickly become cooler than the air above them. This cooling results in the formation of a surface inversion layer that slowly grows deeper during the night. During inversions, ground temperatures may be several degrees cooler than the air above. This is why frost can be on the ground while the "official" temperature taken at 5 feet is in the mid- or upper 30s F.

Because cool air is denser than warm air, air cooled near the surface may flow downhill like a liquid moving under the force of gravity. This cold air drainage creates pronounced



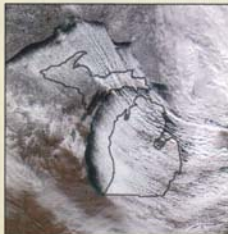
Vines growing in a low area of this vineyard are noticeably smaller.

microclimates as it quickly leaves some areas and pools in others.

Frost and its formation

Soil type and moisture content may affect frost formation. Ground heat flux, the movement of heat energy up out of the soil profile at night, influences the rate of surface cooling. The most common way of reducing this flux is to trap the heat by spreading mulch. In addition, keeping a soil well watered protects against frost formation. A soil with greater water content allows more heat to move toward the surface. Coarse-textured soil with lower water-holding capacity generally experiences more frost.

Frost formation is also affected by large bodies of water. Oceans or large inland lakes such as the Great Lakes modify air as it flows across the water. Water may either add or extract heat from the air flowing over it. In temperate climates, this moderation tends to result in fewer cold and warm



This satellite image shows clouds of precipitation streaming downwind from the Great Lakes on a December day. An outline of Michigan is drawn over the image.

temperature extremes and in seasonal delay in spring warm-up and fall cool-down. Cold, dry air flowing across warmer water surfaces can result in milder, cloudier and wetter weather downwind (called lake or ocean effect).

Surrounding ecosystems and natural biodiversity

The interaction between humans and natural ecosystems is so pronounced that we can no longer ignore the consequences of our actions on other species and natural habitats. Natural ecosystems include forests, grasslands, freshwater ponds and marshlands. They provide many benefits to society and enhance quality of life. Green plants produce oxygen. Plants and animals provide food and clothing, and fungi and bacteria produce life-saving drugs. Microorganisms recycle nutrients and help clean our waters. These ecosystem services are fundamental for the support of life on the planet. The natural world also contributes to the local economy by creating employment and economic benefits through tourism.

Conserving biodiversity is essential for the environment and for a sustainable way of life. Natural biodiversity consists of a variety of plants, animals and other life forms that exist in an area, from the smallest microbe to the largest trees. Individual species such as the white pine, sparrow hawk and brown bat, and communities of species such as hardwood forests and marshes are all components of biodiversity.

Many medicines, improved crops and pest control benefits are derived from the genetic and species diversity of natural ecosystems. Natural ecosystems serve as a refuge for animals beneficial to agricultural production. For example, lady beetles that prey on aphids and insects, and rodents and birds that feed on weed seeds all depend on natural habitat for their survival.

Successful conservation of natural ecosystems and their diversity depends on good stewardship of the land founded in ecologically sound management practices. These practices should be promoted and undertaken by landowners and managers of public lands and supported by the general public.



A biologically diverse ecosystem includes a variety of organisms such as these, which are found throughout the Great Lakes states.



Black raspberries ripening in the sun.

The fruit plant

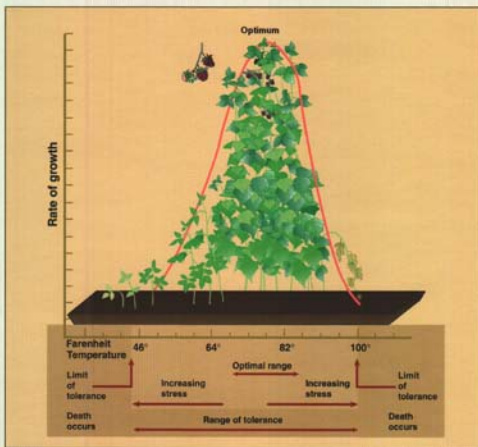
James A. Flore, Jose E. Sanchez,
Dario Stefanelli, Roberto J.
Zoppolo and George W. Bird

The fruit plant is a constantly evolving factory that utilizes ecosystem resources to produce fruit. It is important to understand how this factory works and which factors can be controlled to achieve the best plant performance with the highest quality fruit. In all plants, photosynthesis is the cornerstone of growth and development.

Life depends on energy captured from the sun.

Photosynthesis is the process used to capture this energy and make it available. During photosynthesis, carbon dioxide is taken from the air and combined with water in green leaves. Using the sun's energy, the plant produces carbo-

hydrates (sugars and starch), proteins, oils and fibers, and releases oxygen as a byproduct. The leaves are the most important structures responsible for trapping energy and producing carbohydrates used throughout the plant. More than 90 percent of a plant's dry matter is carbon.



Conceptual plant growth and survival curve.

Every factor influencing growth, reproduction and survival has an optimum level. Above and below the optimum, stress increases until survival becomes impossible at the limits of tolerance. The total range between the high and low limits is the range of tolerance. (Adapted from Wright & Nebel, *The Structure of Ecosystems*, pg. 41, Fig. 2-17.)



R. Zappalo/C. Stefanini



R. Zappalo/C. Stefanini

At left, a shoot during tip growth and (at right) after tip growth has stopped.



R. Zappalo/C. Stefanini

The first pruning after planting shortens the tree height to less than 3 feet.

Time: the growth cycle

A plant's annual growth cycle is a sequence of vegetative and reproductive processes driven by temperature. This cycle changes as the plant ages. The vegetative and reproductive phases differ among species and cultivars.

Vegetative growth

Roots, shoots and leaves are the main vegetative structures of fruit plants. Because they're underground, roots have different growth requirements than shoots and leaves.

A plant's root system grows throughout the year, but the rate varies, depending on temperature, water, nutrients and oxygen availability. The temperature range for growth varies among species. In general, the optimum temperature for root growth is lower than that for shoot growth. Depending on the species, there are generally two major peaks of root growth for fruit plants — one occurs in

spring and ends at the time of vigorous shoot growth, with the second during late summer and fall after shoot growth ends. This change in rate may be due to competition between shoots and roots for carbohydrate reserves.

Shoot growth builds the structure of the tree, which supports fruit and leaves. The rate of shoot growth peaks after fruit set and decreases when fruit starts the phase of fast growth. Generally, each species has an optimum ratio between root and shoot that can be expressed by dry weight or length. When this ratio is disturbed, as by pruning or pest damage, the plant seeks to restore balance by increasing or decreasing shoot or root growth.

Vegetative and reproductive growth can be adjusted through management of water, nutrients and pruning. The structure of the plant for the reproductive stage is built through pruning and training during the early years after planting.



R. Zappalo/C. Stefanini

Next, the tree is pruned to remove all of the weak feathers and branches with too narrow an angle.



R. Zappalo/C. Stefanini

After pruning is complete, the newly planted tree's branches are well distributed with good angles.



Cherry trees in bloom.

Temperature controls the stages of plant development. Vegetative and reproductive buds go through three distinct stages of dormancy. During paradormancy, buds are dormant, inhibited by plant parts outside the bud. Endodormancy is related to factors inside the bud, and during ectodormancy, the dormant bud is able to grow but does not because of unfavorable environmental conditions. Paradormancy and endodormancy cannot be broken; buds will not grow until certain requirements are met. These stages can be measured as the number of hours needed to reach bud break. The value varies, depending on species and varieties.

the basis of temperature accumulation (growing degree-days at a species-specific base temperature) after the chilling requirement is met. Growing degree-days (GDDs) for every phenologic stage depend on the species. (Further explanations of biofix and GDDs are included in Chapter 2.)

Preliminary research in cherry, for example, found that spurs are fully developed 350 GDD after bud break, which occurs, depending on the year, within 20 to 33 days. The canopy is 50 to 60 percent developed within 30 days of bud break and fully developed by two months. Shoots (longer than 3 inches) are developed after 850 GDD, which takes place in 55 to 65 days. Leaf fall occurs

after the first killing frost, usually between early October and early November.

The leaves, the tree's factories for producing energy and carbohydrates, are on the cherry tree for only about half of the year. Biological or environmental disturbances such as pest damage or drought stress can have profound effects on both the current and future years' crops and may affect tree survival. While leaves are present, the shoots and trunk continue to increase until the growth tissue becomes dormant after leaf fall.

Tart cherry trees have both vegetative and reproductive buds, which may have different chilling requirements for breaking dormancy. It is common in Michigan to see flowering before vegetative development.

Reproductive growth

Flower bud initiation occurs almost a year before the corresponding harvest. Many environmental, biological and

Apple bud phenologic growth stages



cultural factors — such as crop load, leaf health and pruning — influence it. In Michigan, flower buds begin to form in late June and early July. They continue to develop, even during the winter, and aren't fully developed until just prior to bud break the following spring. Species and cultivars differ in their periods of flower bud initiation and flower development. The timing of cultural practices such as thinning or summer pruning can profoundly affect flower bud formation, especially if they're done just prior to bud formation.

Fruit development has three distinct stages:

- Cell division, which determines fruit size potential.
- Seed development during a time of limited growth.
- Cell enlargement, when fruit increases by 40 to 60 percent to full size.

Growers who understand fruit development stages can adjust their practices. During cell enlargement, biological or environmental stresses such as those caused by pests or drought affect the current crop and bud formation for the next crop.

Balanced growth

Crop productivity can be explained as a balance between root and shoot growth. The shoots generate carbohydrates and sugars; the roots send water and nutrients to the shoot system. There must be a balance between carbohydrates and nutrients throughout the plant. Stress and cultural practices affect this balance.

Optimal fruit yields are obtained when vegetative growth is well balanced to crop load throughout the plant's life. If the balance goes toward shoot growth, the plant will become vegetative and crop load will suffer. Conversely, if shoot growth is too low with a high crop load, not enough carbohydrates and sugars will be available to sustain the current load or the next year's crop. This balance should be kept in mind when making cultural decisions such as when and how much to fertilize or thin. Maintaining a plant's balance is at least as important as timing of cultural practices such as pruning.



This Gala apple tree was winter pruned for appropriate branch distribution that will balance growth and production.



Another Gala apple tree is overcropped due to unbalanced growth.

Plant management

Fruit production management systems should be designed to maximize light interception and minimize internal shading within the plant.

Fruit growers have a variety of tools for manipulating the vegetative structure of plants while providing better conditions for plants' interacting with the soil and climate. Selecting rootstock and scion, planting design and spacing, and pruning and thinning are the most common examples of these practices.

Site selection

Selecting the planting site is one of the most important

R. Ziegler



On this farm, early blooming sweet cherries are planted on the hilltops to minimize frost damage. In the valleys where cold air pools and frost is more likely to occur, tart cherries, which bloom later, are planted.

decisions a fruit grower makes. In the ideal site, the interaction between plant, soil and environment results in optimum production of high quality fruit. The site should provide an adequate natural environment of climate and weather, air

drainage and water availability. It should be located on well drained and good quality soil and close to inputs, processing plants, transportation and markets.

Rootstock and scion selection

Rootstocks are chosen for their effects on orchard/vineyard performance, including tree/vine vigor, cropping, fruit quality, resistance to pests and adaptability to soil conditions. Selecting a scion cultivar depends on specific objectives such as improved cropping, fruit size, color, disease resistance, overall quality and market opportunities. Choosing the best rootstock is a compromise that requires consideration of site characteristics as well as marketing. Growers must identify a rootstock with good

R. Perry



Compare properly pruned trees, at left, to those needing to be pruned, at right.

grafting compatibility that will induce the best performance for the variety chosen. Disease and stress resistance are increasingly important attributes that help achieve an ecologically balanced system, which reduces costs in the long term.

The next priority is to consider the quality of the plants coming from the nursery: size, age, shape and health. Healthy nursery stock is pathogen-free with excellent ability to resist degradation and respond to management. Investing in top quality plants will always pay back in the future.

Planting design and spacing

Establishing a new orchard, vineyard or field is a significant expense and is worth careful planning of the design and spacing. Planting design and density depend on several factors, including economics, growth habits, pruning and training, site factors, and type and size of mechanical equipment. Rootstock vigor and characteristics of the variety are the main factors in defining the plant spacing. For berries, whether the plants are upright or bushy and dense or sparse flowering affects plant spacing. Maintaining



At the time of planting, it is important to keep the grafting union above the ground level to prevent the scion from rooting and to express the desired rootstock's characteristics. Using a 2- by 6-inch board on edge to align the tree at the correct height above ground keeps the planting level.

Planting density

Species	Low density ⁽¹⁾	Plants per acre	Moderate density ⁽¹⁾	Plants per acre	High density ⁽¹⁾	Plants per acre
Apple	10-15 x 20	145-217	6-10 x 12-18	242-605	3-6 x 8-16	454-1,815
Peach	20 x 20	108	15 x 20	145	10 x 15	290
Cherry (tart)	20 x 20	108	15 x 20	145	10 x 18	242
Cherry (sweet)	10-15 x 20	145-217	6-10 x 12-18	242-605	3-6 x 8-16	454-1,815
Plum	20 x 20	108	15 x 20	145		
Apricot	20 x 20	108	15 x 20	145	10 x 15	290
Pear	10-15 x 20	145-217	6-10 x 12-18	242-605		
Blueberry	5 x 10	871	4 x 10	1,089	3 x 10	1,452
Grapes	8 x 10	544	6 x 10	726	4-5 x 6-8	
Raspberry	3 x 10	1,452	2.5 x 10	1,742	2 x 10	2,178
Strawberry	2 x 4	5,445	1.5 x 4	7,260	1 x 4	10,890

⁽¹⁾ In-row and between-the-row distances are expressed in feet.

ecologically based ground cover and diversity management practices such as use of cover crops, mulch and compost application may alter the design. Keep in mind that extremely high densities will make it harder to balance the entire farm ecosystem.

Generally, rows should be oriented north to south to optimize sun exposure. When cool air drainage is important, rows should run downhill instead of across the slope or on the contour.

Pruning and thinning

Pruning is probably the most important operation to maintain plant vigor and productivity, achieve large fruit size and superior quality, reduce insect and disease pressure, and develop appropriate growth habits for harvesting. It also provides better conditions for spray and light penetration and reduces the need for fruit thinning. Proper pruning balances good fruit production with growth of vigorous new vegetation. Pruning too lightly can lead to dense and weak plant growth because plants fail to develop strong branches for future production. In contrast, severe pruning results in fewer and larger fruit and stimulates new vegetative growth.

C. Edson



Excessive vigor created a dense canopy blocking the flow of air and light in these Vignoles grapes.

C. Edson



The bunch rot that developed from the dense canopy conditions is evident.

Pruning can also spread infectious diseases, especially those caused by bacteria. In cherry production, the ideal conditions for pruning are dry, warm periods to prevent dispersal of bacterial canker (*Pseudomonas syringae*).

Thinning improves fruit quality and maximizes yield and production in the following season. Fruit can be thinned by chemicals or by hand. The amount of fruit that should be removed varies, depending on the variety, the age and vigor of the plant, and the size and quality of the fruit desired. Timing and type of thinning depend on the organ targeted. Chemical flower thinning needs to be managed carefully because late spring frosts and pests can further reduce fruit

set and production. Timing of chemical fruit thinning also needs to be carefully determined — it depends on temperature and the size of fruitlets. Hand thinning can be done over a more extended period and so allows more accuracy in determining the amount of fruit left. Hand-thinned plants will be better balanced and fruits will be of better quality, but this method is more expensive than chemical methods.

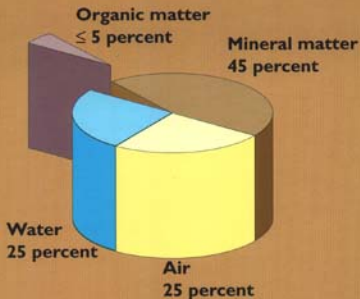
The soil

Jose E. Sanchez, Thomas C. Willson, Roberto J. Zoppolo, Dario Stefanelli and George W. Bird

Soil supplies minerals and water, anchors plant roots, and mediates interactions between plant roots and organisms such as soilborne pests and pathogens. For fruit production, soil and subsoil should be well drained but with enough water-holding capacity to provide a good reserve of water.

Soil is an ecosystem with regenerative properties. Its abiotic (non-living components) consist of mineral matter (clay, silt and sand), water, air and organic matter (plant and animal residues and humus). The soil's biotic or living

Abiotic soil components



Soil Management, Ontario Ministry of Agriculture, Food and Rural Affairs, 1994.

components include plant roots, bacteria, fungi, nematodes, protozoa, arthropods and earthworms

All of these elements interact in dynamic belowground food

webs similar to those in above-ground ecosystems. Working together, they transform and transport matter and energy throughout the system.

Biotic soil components

Plant roots

- Plant residues (roots and shoots) are the ultimate source of almost all carbon (energy) for soil organisms.
- There may be 1,000 times more soil microorganisms near plant roots than in soil farther away from roots.



K. Stepietz

Bacteria

- Bacteria and fungi are the most important groups in organic matter decomposition.
- Extracellular compounds help bind soil particles into aggregates.
- Specialized groups are involved in each portion of the nitrogen cycle.



M.J. Klug

Continued on next page.

Biotic soil components (continued)**Fungi**

- Fungi are the most important group involved in decomposing resistant compounds such as lignin.
- Hyphae grow extensively through soils, helping bind soil particles into aggregates.
- Some specialized fungi grow symbiotically with plant roots, increasing nutrient and water uptake and decreasing disease incidence.

M.J. Roy

**Actinomycetes**

- A type of bacterium with a growth form and function similar to those of fungi.
- Produce compounds that give soil its distinctive aroma.

S. Garay

MSU Center for Molecular Biology

**Nematodes**

- The most numerous animals in the soil.
- Help accelerate decomposition when they graze on bacteria, fungi and plant residues.

R. L. Goodland

**Protozoa**

- Help accelerate decomposition when they graze on bacteria, fungi and plant residues.

VNSB, Essex

**Arthropods**

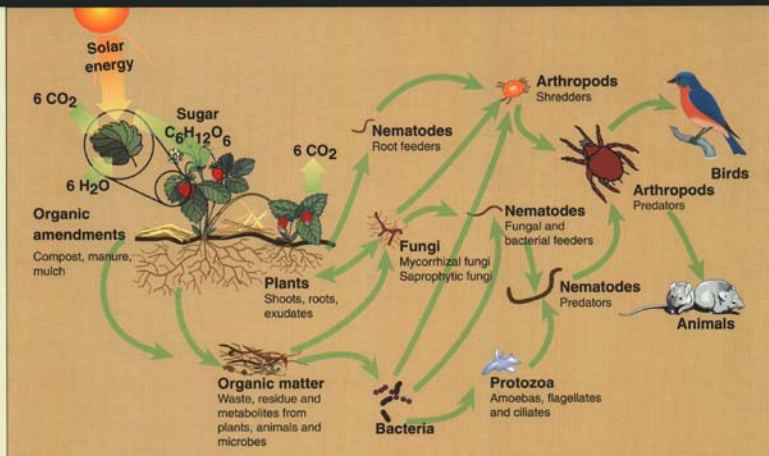
- Mites, collembola and other insects help accelerate decomposition when they graze on bacteria, fungi and plant residues.
- Collembola are an important arthropod in plant residue decomposition.

**Earthworms**

- Burrowing by worms mixes soils and creates macropores that increase water infiltration and flow and help aerate soil.
- Soil passage through guts increases aggregation and nutrient cycling.

R. Crutchfield





Interactions in a belowground food web.

Organic matter is a major food source for most soil organisms. There are three pools of organic matter. The resistant pool decomposes over tens to

thousands of years and is unavailable to most soil microorganisms. The slow pool requires three to 10 years to decompose. The third is the

active pool, which takes less than two years to decompose. Microbes readily decompose the organic matter in the slow and active pools.

Functions of some soilborne organisms

Photosynthesizers (plants, algae, bacteria)	Add organic matter to soil
Primary and secondary consumers (nematodes, insects, mites, rodents, etc.)	Feed on organic matter originating from plants
Decomposers (bacteria, fungi)	Feed on organic matter originating from plants
Mutualists (bacteria, fungi)	Two organisms living in beneficial association that enhance plant growth
Bacterial grazers (nematodes, amoebas, ciliates, flagellates)	Feed on bacteria
Fungal feeders (nematodes, insects)	Feed on fungi
Organic matter shredders (earthworms, insects)	Shred plant litter while feeding on bacteria and fungi

Desirable soil quality

A high quality soil resists degradation and responds to management. It has a dynamic belowground food web that transforms and transports the matter and energy required to develop and maintain successful fruit plantings.

High quality soil characteristics

- Provides suitable habitat to sustain biological activity, diversity and productivity.
- Stores, releases and cycles nutrients.
- Regulates water and solute flow without being excessively wet or dry.
- Provides ecosystem services such as filtering, buffering, degrading, immobilizing and detoxifying undesirable materials.

Indicators of soil quality

- Topsoil and rooting zone depth.
- Organic matter levels.
- Size of active and slow carbon and nitrogen pools.
- Biotic diversity (nematode community structure, for example).
- Water-holding capacity, infiltration and bulk density.
- pH and electrical conductivity.

Physical and chemical properties

Additions of organic materials in the form of crop residues or amendments such as composted manure increase the levels of the resistant and slow pools. These forms of soil organic matter are most responsible for improving the physical and chemical properties of the soil. Enhancing the resistant and

slow pools decreases soil compaction and erosion of fine particles. Other benefits are an increase in plant-available water, improved water infiltration and soil aeration, greater soil aggregate stability, increased ion exchange capacity and greater retention of nutrients. More easily decomposable organic matter is also important because during decomposition

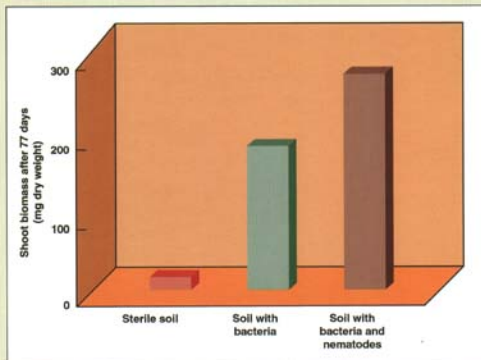
microorganisms excrete gels and slimes that bind soil particles together and improve soil structure.

Biological properties

The active soil organic matter pool is the main food source for microorganisms. Practices that increase this pool build microbial activity, enhance nutrient availability and may lower incidence of soilborne diseases. Such practices include planting nitrogen-fixing legume cover crops, adding compost or manure, and reducing tillage. Microorganisms also feed on root exudates released from living plants, so keeping cover crop roots active for as much of the year as possible promotes soil microbial activity. These practices frequently enhance soil biological diversity, such as by increasing beneficial populations of nematodes.

The role of nematodes

Most fruit growers think of nematodes as microscopic worms that cause infectious diseases or spread viruses. Nematodes, however, are a very diverse group of organisms, and most are beneficial. Though some species feed on plants, others feed on bacteria, fungi, other small animals or a combination



Two organisms are better than one.

Citation: Ingham, R., et al. 1985 *Ecological Monographs* 55:119-140.

Because of their diverse feeding habitats, nematodes are affected by crop management practices and can be used as indicators of soil quality. Research at the Northwest Michigan Horticultural Research Station found significantly more bacterial-feeding nematodes and fewer plant-feeding nematodes in systems with organic matter additions. Samples were taken in May 1999. For detailed management information, refer to the appendix at the end of this chapter.

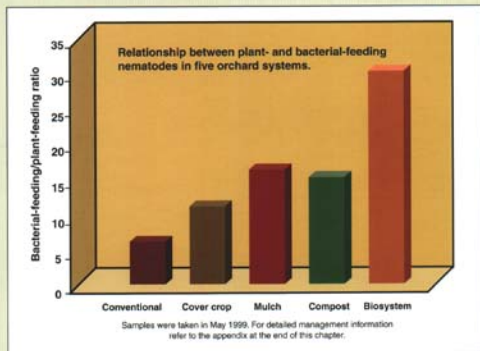
of these. Bacterial-feeding nematodes often live near the root surface, where they mineralize organic matter and make nitrogen available for plant uptake. Researchers have shown significant increases in plant growth when bacterial-feeding nematodes and their food source are present.

For example, when a root surface is colonized by bacteria (such as *Burkholderia cepacia*), the plant is protected from root-knot nematodes. The occurrence of bacteria near roots can increase fungal- and bacterial-feeding nematodes and decrease plant parasitic ones. It is likely that there are similar effects in other classes of organisms such as fungi, protozoa and microarthropods.

In food webs, both pathogenic and non-pathogenic species compete for space and resources while releasing substances toxic to their competitors.

Carbon transformations

Through photosynthesis plants convert atmospheric carbon dioxide into organic compounds. These materials



enter the soil when residues of plants and animals are placed in or on the soil. Soon after, soil organisms begin consuming the organic matter, extracting energy and nutrients, and releasing heat, water and carbon dioxide back into the atmosphere. A natural consequence of decay is a gradual disappearance of soil organic matter if it is not replenished. When residues are added to the soil at a faster rate than soil organisms can transform the organic matter into carbon dioxide, carbon will gradually be removed from the atmosphere and stored in the soil. Intensive tillage accelerates decomposition and the release of carbon dioxide. This loss of organic matter occurs because of increased soil aeration, triggering short-term, unwanted microbial activity and rapid decomposition.

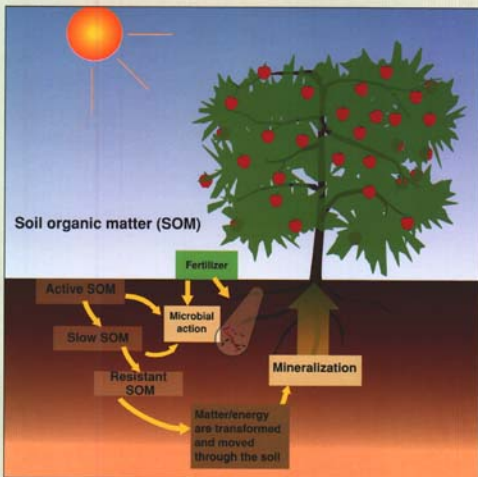
Nitrogen transformations

A complex community of soil organisms fixes nitrogen or decomposes and mineralizes organic matter. Species of bacteria living in roots of legume cover crops can fix considerable amounts of atmospheric nitrogen into plant-available forms. The plant obtains the fixed nitrogen in exchange for some of its

carbon needed by the bacteria. This nitrogen will end up as soil organic matter when the cover crop decays.

How can we increase and manage the active organic nitrogen and carbon pools? In most fruit systems, it is done by the use of cover crops, mulches, organic amendments from animal sources and reduced tillage. Data from a

long-term experiment at the Northwest Michigan Horticultural Research Station show that horticultural practices affect the active carbon and nitrogen pools. These pools were enhanced through use of mixed grass and legume cover crops, rye straw mulch and composted dairy manure. See table on next page.



Soil organic matter (SOM) contains large amounts of nitrogen, but it is not readily available to plants. It must first undergo decomposition by soil organisms, which will release any excess mineral nitrogen. The soil's nitrogen-supplying capacity is largely defined by the size of the active organic nitrogen and carbon pools and the soil microbes' ability to degrade them. The active nitrogen is the raw material; the active carbon provides the energy needed to transform organic nitrogen into inorganic forms available to plants.

Influence of tart cherry ground cover and nutrient management on the active carbon and nitrogen pool sizes.

Management systems	Active carbon Pounds per acre	Active nitrogen
Conventional	1,054	59
Cover crop	1,350	96
Mulch	1,409	85
Compost	1,348	108
Biosystem	1,680	110

Data are a two-year average of samples taken in May 1999 and 2000. For detailed management information, refer to appendix at the end of this chapter. Source: D.R. Mutch, C.E. Edson, T.C. Willson.

Plants rely on microbes to recharge the soil's supply of available nitrogen. This process requires careful management. Inorganic nitrogen does not simply accumulate in the soil. It may be taken up by microorganisms and plants and turned into new recyclable materials, transformed into gas and lost to the atmosphere, or leached below the root zone, where it has potential to contaminate groundwater. Nitrogen management strategies should stimulate mineralization during periods of plant uptake and minimize it when nitrogen is not needed.

Mineralization can be efficiently managed by controlling the organic matter supply (quantity, quality and timing) and its rate of decomposition. Cover crops, mulches, compost, manure and crop residues all increase soil organic matter, but the proportions of carbon and nitrogen vary tremendously

among materials. The goal is to balance the active pools of carbon and nitrogen. A well maintained, legume predominant ground cover and applications of manure or semi-composted materials are more likely to increase the active nitrogen. Release of mineral

nitrogen is faster when the ratio of the active carbon to nitrogen is below 20. When the ratio is greater, microbes immobilize nitrogen and its release may be very slow. Tillage is also important in regulating mineralization. Intensively disrupting the soil profile while incorporating organic matter will rapidly deplete the active nitrogen and carbon pools. Reducing tillage can help spoon-feed the nitrogen according to plant needs and avoid losses. There is no perfect recipe, but farmers need to explore the available tools and design a strategy best suited to their particular needs.



Impact of tillage on soil

After planting, deep cultivation should be avoided because it may severely damage the plant's root system and expose the soil to erosion losses. Shallow cultivation works for specific purposes such as strategic weed control or light incorporation of residues to enhance nutrient availability in the time of maximum crop uptake. Light incorporation may be needed if replanting is being done to alter the species mix in the ground cover.

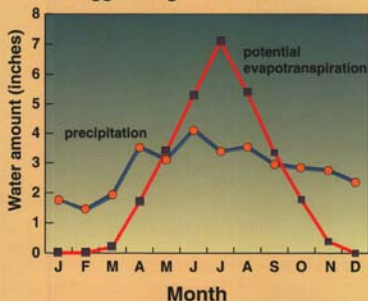


Irrigation and supplemental fertility

In the upper Midwest, water becomes limiting during summer. Irrigation during this period is essential for successful production of most fruit unless the soil's water-holding capacity is drastically improved or new drought-tolerant varieties are developed. It is important to determine the timing and the amount of irrigation on the basis of the real need of the plant to minimize stress and avoid yield reduction.

Influencing this need are several factors such as the components of the climate (sunshine, precipitation, humidity, temperature and wind speed); the characteristics of the soil, especially those related to its water-holding capacity; and the plants' specifics (density and soil coverage, age, etc). Precise irrigation requires understanding and measuring the influence of these factors. Plants are under severe stress when the foliage is wilting, and at that stage damage may have already occurred. The lack of clear early stress symptoms emphasizes the need for other tools such as evaporation pans and tensiometers to determine when to start irrigating.

Monthly average precipitation and potential evapotranspiration 1956-86, Kellogg Biological Station.



Common precipitation and evaporation pattern for southwest Michigan.

Fruits are composed primarily of carbohydrates and water and do not remove considerable amounts of minerals from the soil. The amount of nutrients needed varies by species and is related to the plant's age. Nutrients are used for

current year's growth, for replacing those used in production and for increasing reserves for a good start the following season. Excessive applications can generate an unbalanced condition with several negative conse-

R. Zippel/D. Stansell



A weather station and an evaporation pan generate data for pest management and irrigation decisions.

quences. Too much nitrogen results in excessive vigor. Applying nitrogen too late results in late-season growth that increases winter injury susceptibility. Excessive nitrogen also causes higher susceptibility to some pests and loss of fruit quality such as reduced color, firmness and storage life.

Before considering fertilizer application, the grower needs to credit the estimated contributions made by the original content of the soil, cover crop residues, compost or manure, and mulches. In this kind of system, soil tests may not accurately estimate the amounts of nutrients available throughout the season. Nitrogen — and, to a lesser degree,

phosphorus — resulting from mineralization are not accounted for. Fast and reliable analysis approaches are needed to satisfy needs of fruit growers using ecologically friendly strategies. In the meantime, chemical analysis of leaves and fruit may be the best indicators of nutritional needs.

Fertigation — the application of supplemental fertilization with irrigation — is increasingly being used in fruit production. This promising technique allows precise applications of fertilizer to supplement crop nutrition and minimize nutrient loss to the environment. Another fertilization practice that is becoming increasingly popular is foliar application. This type of application allows

better control of the amount and quality of nutrients. It should be integrated with the regular fertilization schedule to address specific needs rather than used as a substitute. Foliar fertilizers are quickly absorbed and can be readily available without the soil interaction to solve immediate nutritional problems such as bitter pit in apple or chlorosis in most fruit crops.

Farm biodiversity

Jose E. Sanchez, Dale R. Mutch and George W. Bird

Biodiversity promotes ecosystem health. When designing a fruit operation, growers and consultants should consider biodiversity above- and belowground.

Aboveground botanical biodiversity within and around the farm provides ecosystem services such as scavenging excess nutrients that could escape to groundwater or providing favorable habitat for wildlife and beneficial insects. The presence of flowering plants increases faunal diversity and encourages bees and other pollinators. Botanical biodiversity is achieved by using cover crops and creating refuge areas containing shrubs, berries and native plants.

C. Ebbon



An irrigation demonstration plot contrasts drought-stressed vines (foreground) with healthy, irrigated vines (background).





C. Edson

Diverse vegetative cover increases the quality of plant residues entering the soil. The continuous use of diverse cover crops plus organic matter additions through manure or compost and mulches increases belowground diversity. Soil microorganisms feed on the organic materials entering the soil. A more diverse food source will benefit a wider range of soil organisms and enhance soil and plant health. Levels of soil organic matter are affected by the diversity of materials. Diverse systems are more productive and accumulate more organic matter than less diverse systems. Research in Michigan cherries indicates that after five years, systems using cover crops, mulch or composted dairy manure had 20 percent more soil organic matter than systems with bare ground.

Practices enhancing biodiversity and much more

Soil management strategies traditionally have been developed to control weeds, reduce erosion, retain soil structure and decrease compaction. New integrated approaches designed to increase biodiversity allow us

to achieve these goals and increase organic matter at the same time. Combining practices such as using cover crops, mulches or other organic amendments is a desirable strategy to increase biodiversity while enhancing soil and water quality.

Cover crops. Soil erosion threatens soil quality and can pollute water. Cover crops prevent soil loss, help control weeds, gradually add organic matter to the soil, help retain nutrients near the root zone, and provide a firm surface for equipment without jeopardizing yields or plant health. Their contributions to improving soil organic matter and fertility vary according to type and growing



C. Edson

A tart cherry orchard with a ground cover of white and red clover, alfalfa and rye.

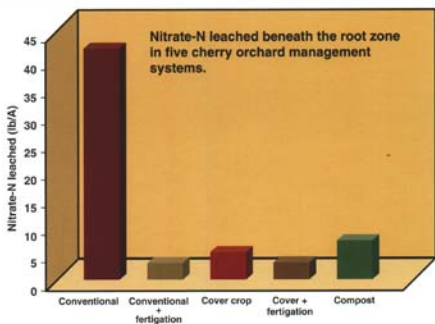
conditions. Residues of legumes such as clover or vetch are high in nitrogen and decompose quickly. They contribute more as a nitrogen source than as an organic matter source. In contrast, grass cover crops such as rye or barley accumulate more organic matter because they have a much greater ratio of carbon to nitrogen and decompose more slowly. The best practical strategy to enhance biodiversity, soil organic matter and nutrient availability is to maintain a well balanced mix of legumes, grasses and non-legumes such as crucifers or, in some cases, even weeds.

In fruit production, cover crops are sometimes avoided because they compete for moisture. Most growers see the benefits of having cover crops in the alleyway, but establishing cover crops in the rows is more controversial. The main challenge is to have as much coverage as possible while minimizing cover crop competition, especially in young plantings.

Much of the upper Midwest's drinking water filters through the soil before entering aquifers. Coarse-textured soils, which are often used for fruit production, are particularly vulnerable to nutrient and

pesticide leaching. Production practices relying on high rates of fertilizers and pesticides threaten water quality and raise concerns about elevated nitrate and pesticide levels in drinking water. Leaching data from five mature cherry production systems show how orchard floor and supplemental nitrogen management practices can have a tremendous impact on water quality.

Incentives to look at alternatives for successful fruit production are the negative environmental impacts of some synthetic inputs, increasing energy costs and risk generated by dependency on off-farm inputs.



Data are the average of four years (1996-99). For detailed management information, refer to appendix at the end of this chapter.

Mulching. Mulch is any material placed on the soil surface to protect the soil from freezing, wind, rain and excessive water loss through evaporation. Mulches help to reduce erosion and suppress weeds. In addition, organic mulches such as straw, leaves, sawdust or woodchips will break down and contribute organic matter to the soil. They improve soil aggregation and water-holding capacity, and



Hay mulch surrounds trees in this tart cherry orchard.

moderate soil temperature, reducing plant stress. Mulches are obtained from imported material and side-delivered from mowing the alleyway's cover crops. When mulch contains high quality materials such as legume residues, decomposition may also provide significant amounts of nutrients such as nitrogen, potassium and phosphorus. In orchards and vineyards, mulch can be placed around individual trees or vines, or in the entire row. The area immediately surrounding the trunk should be kept mulch-free to avoid disease, insect or rodent problems.

Manures and composted materials. If available, manures and composted materials can be used as primary means of replenishing organic matter. Like mulch, they improve the soil's water-holding capacity, structural stability and tilth.

Timely and proper applications of manure also provide readily available nutrients while stimulating microbial activity. Manure is more difficult to manage than compost because of its bulk and because it may contain larger amounts of mineral nitrogen than plants can take up. Limited amounts of manure, determined by its chemical

composition, can be applied near the time of maximum crop uptake. Large amounts of nitrogen from manure can be lost through volatilization during untimely applications (such as on frozen ground), and excessive applications can lead to serious leaching losses or become toxic to plants.

Composting raw materials such as animal manure or municipal wastes has several advantages. During composting, nutrients such as nitrogen and phosphorus are fixed into more stable forms that are less susceptible to loss. Wastes are more easily handled because composting reduces the volume and allows more even application.

Composting also reduces pathogen populations and toxicity to plants. The major disadvantage is that considerable amounts of nitrogen and high-energy carbon are lost during the composting process.

Impact of management on crop performance

In new plantings, vigorous, healthy vegetative growth is the primary goal. In this building stage, the fruit plant needs to grow with minimum competition from living ground cover (weeds or cover crop) near the trees or vines. In new plantings, the non-cover-cropped area should be



In this new orchard, alfalfa hay mulch was placed in the tree rows.

protected with mulch. In a mature planting, this competitive effect is reduced because the tree or vine root system can reach water and nutrients from greater depths. Recent data from a mature Montmorency cherry orchard indicate that alternative floor and nitrogen management systems did not reduce cherry yields. Instead, using supplemental mulch increased yields an average of 20 percent.

Tart cherry yields as affected by orchard floor, nutrients and water management systems.

Management systems	tons/ acre
Conventional	14
Conventional + fertigation	15
Cover crop	13
Cover crop + fertigation	14
Mulch	17
Compost	14
Biosystem	13

Data are the average of six years (1995-2000). For detailed management information, refer to appendix below.

Appendix for cherry research tables on pages 25, 27, 31 and 33. Description of management systems at the Northwest Michigan Horticultural Research Station.

Conventional: spring-applied simazine, postemergent herbicide as needed and full rate of ground-applied nitrogen (110 lb/acre).

Conventional + fertigation: spring-applied simazine, postemergent herbicide as needed and half of the full rate of nitrogen fertilizer (55 lb/acre) applied as fertigation.

Cover crop: ground cover (crimson clover, hard fescue, berseem clover), no herbicides, under-tree mowing, ground-applied nitrogen as needed.

Cover crop + fertigation: ground cover (crimson clover, hard fescue, berseem clover), no herbicides, under-tree mowing and half of the full rate of nitrogen fertilizer (55 lb/acre) applied as fertigation.

Mulch: ground cover using supplemental mulch (rye straw and hay) plus side-delivered biomass from alleyway, no herbicide and ground-applied nitrogen as needed.

Compost: ground cover maintained with side-delivery mower, mow under trees or postemergent herbicide as needed, no supplemental nitrogen.

BioSystem (consultant-provided regimen): compost, no herbicides, ground cover maintained with side-delivery mower, supplemental nutrition using alternative sources based on supplemental soil tests.



Chapter 2. Managing the community of pests and beneficials

Chapter questions

- Can I integrate ecological pest management into my farm?
- How does the way crops are managed affect pests and beneficials?
- How can weather information be used to predict pest development?
- Can I design my fruit production system to better integrate non-chemical approaches to pest control?
- How can I tell whether beneficials are helping control my pests?
- How do plants, pests and beneficials interact in my fruit farm?
- Is the surrounding landscape relevant to managing pests in my fruit crop?

The community

Larry J. Gut, Rufus Isaacs,
Annie C. Schilder and
Patricia S. McManus

An orchard, vineyard or berry planting supports many kinds

of organisms, including a rich array of pest and **beneficial** insects, mites, microbes and nematodes. These inhabitants interact in a variety of ways forming a **community**. This chapter introduces the inhabitants and discusses the biological factors that make fruit crop communities complex. Understanding why some community members become pests and others do not is important for implementing more ecologically and environmentally sound pest control and management strategies.

The inhabitants

Of all the organisms that live on a fruit farm, growers are often most familiar with the herbivores (organisms that feed on plants) because of the economic damage they sometimes create. **Herbivores** may be vertebrates (deer, rodents, birds), invertebrates (mites, insects, nematodes) or microbes (bacteria, fungi). Many herbivores share crop resources with growers without causing significant impact at harvest. It is only when herbivores reduce crop quality



Some of the organisms in a fruit crop community.

or yield to a level affecting profit that they are called pests. Economic impacts can result from feeding on the crop or indirectly by their presence as a contaminant at harvest. Microbes are called pathogens when they cause disease, which is defined as abnormal functioning of the plant.

Carnivores obtain their energy by consuming other animals. Hawks and coyotes are highly visible carnivores that feed on herbivores such as mice and groundhogs. It is more difficult to detect the many carnivorous insects, mites, nematodes and microbes. These beneficial organisms can play an important role in pest control because they primarily feed on herbivorous insects, mites and nematodes. Carnivorous insects can be further separated into predators and parasitoids (insects that live in or on the body of a host until it dies).

Many of the organisms living in fruit crops receive less attention than the herbivores and carnivores. Some of the least visible organisms feed on fallen leaves, fruit and woody material. These important members of the community are called **decomposers** and include bacteria, fungi and invertebrates such as earthworms. A broad survey of the

organisms in an orchard, vineyard or field reveals that many are simply visitors or transients. Various kinds of adult flies, such as March flies, gnats or mosquitoes, use the crop for shelter, finding mates or as a resting place as they move to other habitats. These visiting species are also important members of the community. Many are a significant part of the diet of generalist carnivores, such as spiders, which are less selective about what they eat.

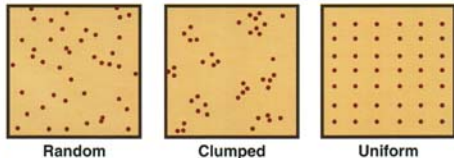
Species and populations

Organisms that can reproduce and produce viable offspring are members of the same **species**. For example, plum curculio is a species of insect found in many kinds of fruit systems. The fire blight pathogen is a species of bacterium that inhabits orchards.

Populations are groups of individuals of the same species living within specified boundaries of time and space.

Often these boundaries are somewhat arbitrary and are fixed for convenience by the ecologist, consultant or others involved in pest management decisions. In describing a codling moth population, for example, a speaker may use the term "population" to refer to all the codling moths in south-western Michigan, those on a particular farm within that region or those in a single orchard block on the farm.

Pest management decisions are often based on the density and dispersion of a population in the field. **Density** is the number of individuals in an area. **Dispersion** is the arrangement of the individuals within the field. Individuals in a population may be dispersed randomly, in a clumped fashion or uniformly. If an organism is randomly dispersed, then each individual is as likely to be found in one place as another. Management strategies may be very different for pest populations with a clumped versus random distribution. For example, apple maggot flies



Common dispersion patterns of organisms.

generally invade commercial orchards from nearby infested hosts where the pest is not controlled. Consequently, they are frequently in clumps within the orchard, with most individuals near the border. Appropriate management strategies for apple maggot may include placing all monitoring traps along the border and treating only the

Population genetics

An individual organism's genes determine its physical and behavioral traits. **Genes** are made up of chemical messages or codes that dictate which proteins a cell produces. Particular combinations of these proteins and environmental cues determine what an organism looks like and how it

mix of genes in a population is called the **gene pool**. The composition of the gene pool continually changes over time through a process called **natural selection**.

With the help of plant breeders, fruit growers have taken advantage of the gene pool's natural variability in a process known as **artificial selection**. The first step in this process is to identify desirable traits, such as flavor, color, or tolerance or resistance to a pest. Once desirable traits are identified, these can be incorporated into new crop varieties through conventional breeding or genetic engineering. For example, apples have been bred to create a few varieties that are resistant to apple scab. Even without specific breeding efforts, fruit crop varieties display a natural range of resistance to various pests and diseases. When monocultures of single varieties are planted, efficiency of production is traded for diversity of resistance to pests.

Repeated use of the same class of pesticides to control a pest can cause undesirable changes in the gene pool of a pest leading to another form of artificial selection, **pesticide resistance**. When a pesticide is first used, a small proportion of the pest population may survive exposure to the



R. VanderPoggen

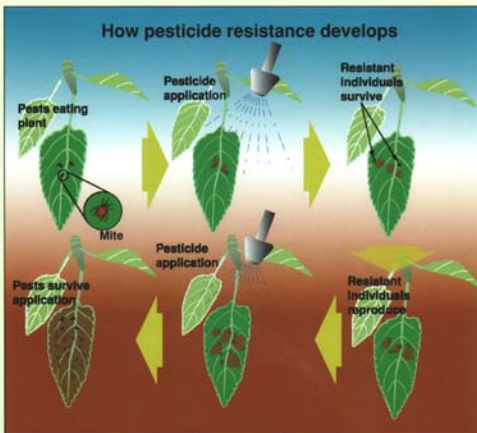
Only the borders of this orchard are being sprayed for a pest that is found along the orchard perimeter.

borders with insecticide. In contrast, spores of grape powdery mildew are easily dispersed over large areas by wind, resulting in a relatively uniform distribution of disease in a vineyard. Therefore the entire vineyard needs to be protected from this disease.

behaves. When individuals reproduce, they pass along unique combinations of genes to their offspring. Different environments favor individuals with different physical and behavioral traits. Individuals with genes that improve their survival will be more likely to pass along these genes than to the rest of the population. The

material because of their distinct genetic makeup. These individuals pass along the genes for resistance to the next generation. Subsequent uses of the pesticide increase the proportion of less susceptible individuals in the population. Through this process of selection, the population gradually develops resistance to the pesticide. Worldwide, more than 500 species of insects, mites and spiders have developed some level of pesticide resistance. The twospotted spider mite is a pest of most fruit crops and is notorious for rapidly developing resistance to miticides.

Some plant pathogens have also become resistant to pesticides. Among fruit producers in North America, apple growers perhaps have faced the most significant problems with pesticide resistance. Examples include streptomycin resistance in the fire blight bacterium and benomyl resistance in the apple scab pathogen. Although the precise genetic and ecological factors differ among pests that have become resistant, in all cases resistance is driven by one process — selection.



Source: Michigan Field Crop Pest Ecology and Management

Survival of the most resistant

Insecticide resistance

Selection for resistance can occur if a small proportion of the insect population is able to survive treatment with insecticide. These rare resistant individuals can reproduce and pass on their resistance to their offspring. If an insecticide with the same mode of action is repeatedly used against this population, an even greater proportion will survive. Ultimately, the once effective product no longer controls the resistant population.

Fungicide resistance

Single-step pesticide resistance arises suddenly in the field. A single gene or physiological function changes so that an individual becomes highly resistant to the pesticide. With just one or two sprays of the pesticide, the population shifts from mostly sensitive to mostly resistant individuals. This is the process by which populations of streptomycin-resistant fire blight bacteria

(continued on next page.)

Survival of the most resistant (cont.)

and benomyl-resistant strains of the apple scab fungus rapidly developed in commercial orchards.

Multistep pesticide resistance arises slowly in the field over many years. Rather than having distinct groups of sensitive and resistant individuals, the population consists of individuals with a range of sensitivities to the pesticide. With each pesticide application, those individuals at the more resistant end of the spectrum survive and reproduce. Over the years, the proportion of the population that can survive a pesticide spray increases until that pesticide eventually becomes ineffective. This process is underway in apple orchards where the sterol inhibitor (SI) fungicides have been used extensively to control scab. The shift toward resistance leads to a gradual erosion of control.

Resistance management

Growers can help delay the development of resistance by applying pesticides only when they are needed, by rotating between different chemical classes and by using rates of pesticides within the labeled range. Integrating non-chemical approaches such as pheromone mating disruption and cultural controls can also help delay resistance.

Population growth and regulation

Fruit producers know that pest populations build rapidly when food, water and space are plentiful and environmental conditions are favorable. For example, a few aphids per tree can become hundreds per shoot in a matter of weeks. Pathogens are even more prolific, producing thousands of spores in a single lesion. Under optimum conditions, it is

primarily an organism's capacity to reproduce and ability to invade new habitats that determine the rate of growth. The population will crash when basic resources are depleted.

In nature, however, interactions with other organisms usually limit populations. The maximum number of individuals of the same species that can be supported indefinitely by any given area is called the

carrying capacity. The carrying capacity is different for each species in each environment depending upon species' requirements for resources and the intensity of their interactions with other inhabitants of the community.

Population growth generally slows as a population nears its carrying capacity. If the carrying capacity is exceeded, population density will decline as some individuals starve, migrate or produce fewer offspring. The population density of an organism fluctuates around the carrying capacity. In fruit crops, where food is plentiful, carrying capacities of pest populations are often high enough to cause economic concern. One response to unacceptably high pest population densities is to apply a pesticide. This intervention by the grower temporarily lowers the carrying capacity by making the pest's environment less suitable for survival. Certain natural enemies (predators, parasites and pathogens) can lower the carrying capacity and keep pest populations below economically damaging levels. Pesticide usage often removes natural enemies, however, allowing the carrying capacity to rise once the pesticide residue has degraded.

Single and multicycle pathogens

Disease management may be guided by knowledge about a pathogen's life cycle. Single-cycle pathogens have one generation per year. They are limited by the amount of overwintered inoculum that exists at the start of the season, resulting in steady disease progress until the pathogen's food source runs out or the weather becomes less favorable (see line A in diagram). Removal of overwintered inoculum is a good control strategy for these pathogens. Multicycle pathogens, such as powdery mildews and downy mildews, have several generations per year and can reproduce rapidly

under the right conditions (line B in diagram). These diseases are more likely to be controlled through the use of fungicides or resistant varieties that limit the pathogen's rapid reproduction.

Community structure and organization

Three main factors play roles in shaping the community: the habitat, biotic interactions and life history traits of the organisms. Many physical and chemical characteristics determine the suitability of the



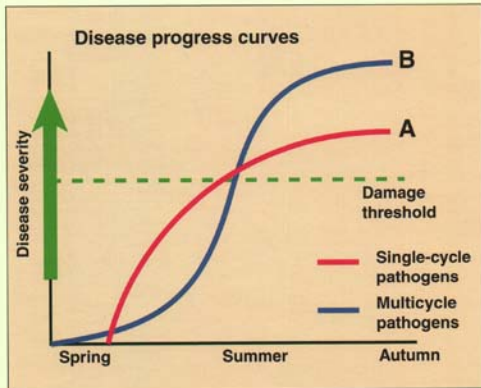
Orchard Pest Management, E. Biers

These pears have honeydew and russeting from pear psylla, a pest that attacks only pears.

crop as a habitat. Individuals in the community are bound together by biotic interactions such as predation, feeding and competition. Life history traits include dispersal capability and overwintering strategies.

The effect of crop habitat on community

Organisms use the crop habitat (the tree, vine or bush) in a variety of ways, including for food, shelter, mating or as a place to spend the winter. Some are highly specialized and utilize a single kind of plant. For example, the grape berry moth feeds solely on cultivated or wild grapes. Powdery mildew strains generally infect a single plant species. Other organisms have a wider host range, favoring similar kinds of crops. Plum curculio feeds on the fruit of



apples, cherries, blueberries, peaches and plums. Some are even broader feeders, consuming a wide variety of plants. The tarnished plant bug has a particularly broad range of suitable hosts and is an important pest of more than 100 annual and perennial crops.

Plant characteristics may be favorable or unfavorable for potential community

due to internal pressure. Cultural practices and variety selection that reduce cluster compaction can help avoid these problems.

Shape and color of the leaves, flowers or fruit may be important in attracting bees for pollination as well as insect pests. Aphids and other insects tend to be attracted to the color yellow, which is why sticky boards used for

The chemical characteristics of the crop, such as nutritional quality or the presence of volatile substances, also affect its suitability as a habitat. Ripe strawberry fruit with high sugar content provide an excellent food source for sap beetles, which tend not to attack unripe fruit. Apple maggot flies are attracted to odors given off by apple fruit.

The plant surface is home to numerous microbes, such as yeasts, bacteria and fungi. These organisms live off plant exudates, pollen, aphid honeydew and other food sources on the plant surface. Most microbes are harmless and can even be beneficial if they compete with pathogens for space or food. Sooty molds are fungi that use aphid honeydew on plant surfaces as a food source. Other than blocking light, these molds are harmless. The yeast *Saccharomyces*, common on fruit surfaces, is useful in winemaking. Some bacteria may also multiply on leaf surfaces until they have built up sufficient numbers to cause disease. Yeasts living on apple surfaces may be involved in fruit russetting. Unfortunately, not much is known about the microbes on the surface of fruit crops. Plant surface characteristics, surrounding vegetation, nutrients and



Apple trees with burr knots are more attractive to dogwood borers. Mounding soil to cover the burr knot creates a physical barrier that reduces borer infestation.

inhabitants. Sometimes the plant's physical structure aids a pest. Grape cultivars with tight fruit clusters tend to favor *Botrytis* bunch rot because of the humid environment within the cluster and berry splitting

monitoring insects are yellow. Blueberry maggot flies are attracted to berries that are just turning from green to blue, which provide the ideal substrate for egg laying.

pesticides can affect the nature and abundance of these microbes.

The plant roots make up the belowground crop habitat. Mostly hidden from view, the root zone is home to a diverse array of worms, insects, fungi and bacteria. Although the large majority of soilborne organisms are beneficial or neutral toward crop plants, some cause serious problems that can limit crop productivity.

In perennial plants, including most fruit crops, complex communities of microorganisms develop on roots. While some root exudates are known to attract swimming spores of water molds such as *Pythium* and *Phytophthora*, plants also have the ability to chemically promote the growth of beneficial bacteria and fungi. Some plant roots support the growth of fluorescent bacteria that preferentially bind iron, thereby making it unavailable to pathogens.

Host plant resistance

Plants vary in their ability to defend themselves against pest attack, with some being highly resistant and others quite susceptible. Plant defense mechanisms include physical "weapons" such as thick wax layers, tough skin, thorns and plant hairs. It is



Most wine grapes have thinner skinned leaves than juice grape varieties, making them more susceptible to potato leafhopper damage, as shown in this photo.

more difficult for leafhoppers to feed on the thick-skinned leaves of juice grape varieties than on the thin-skinned leaves of wine grape varieties. Plants also produce many kinds of defensive chemicals, such as toxins and enzymes, to ward off insect or pathogen attack. The chemical resveratrol, which occurs in grape skin and may be responsible for the human health benefits of wine consumption, also provides protection against infection by pathogenic fungi. Alkaloids in certain plant varieties are known to be lethal to insects. Some plants protect themselves by releasing odors that

signal predators when a pest feeds on them. These odors help predators locate the pest and reduce pest abundance.

Some varieties, even though attacked by pests as much as other plants, are less affected and therefore considered **tolerant**. For example, under moderate insect feeding on leaves, native juice grape varieties can still produce acceptable yields and fruit quality.

Growing pest- and disease-resistant fruit varieties is an excellent way to reduce the use of chemical or other control measures. It is often the



Red stele is evident in the strawberries at right, while those planted on the left are resistant to the particular race of the disease.

simplest method of pest control because the plant does all the work. Unfortunately, some pests can evolve to overcome plant resistance. Once this happens, resistant cultivars can lose their usefulness. For example, some strawberry cultivars are resistant to multiple races of the red stele fungus, but none is known to be resistant to all races. Efforts to find more durable forms of resistance to red stele have

cultivars that are highly susceptible to the disease. This problem is a bigger issue with perennial plantings that will be in place for many years.

been unsuccessful. If available, cultivars resistant to locally prevalent races of disease should be selected for planting. In general, one should avoid

Seasonal and long-term changes in habitat suitability

A plant is often susceptible to a pest or disease only during a certain period in its development. Usually younger, succulent tissues are more susceptible to pest attack. However, older tissues sometimes lose the defense mechanisms inherent in younger tissues and then provide fertile ground for pest and pathogen activity. The fire blight bacterium prefers to infect young, fast-



Rootstocks to the rescue

Ecological concept

Host plant resistance reduces pest damage.

Putting it into practice

Use only resistant rootstocks when planting susceptible grape varieties.

Grape phylloxera is an aphidlike insect that feeds on grape roots, stunting and sometimes killing vines. This pest is so damaging that when it was inadvertently introduced into

Europe from the United States in the 1860s, it nearly destroyed the French wine industry. The vines were saved by imported American rootstocks, which are resistant to phylloxera. Resistant rootstocks are still the primary method of phylloxera control. In the early 1980s, however, a biotype with the ability to colonize some resistant rootstocks appeared in California. This event has led to recent large-scale replacement of vineyards with vines grafted onto other resistant rootstocks.

growing shoots. In contrast, the fungus that causes gray mold on many crops does not manifest itself until flowers or fruit are senescing, sporulating heavily on the dying tissues. Insect infestations are also somewhat predictable. The blueberry maggot fly starts laying eggs on blueberry fruit only as it turns from green to blue, and climbing cutworms prefer young grape buds.

The perennial growth of fruit crops creates predictable long-term changes in the composition of habitats for pests and other plant-feeding species. For example, young apple trees have smooth bark, while older trees may have cracked and creviced bark. Therefore, older trees provide excellent overwintering sites for many pests, including codling moth. The fungal pathogen that causes peach leaf curl uses cracks and crevices in older tree bark to overwinter.

Knowing the critical period when the crop is susceptible *and* which pests or pathogens are present can help guide management activities and restrict pesticide applications to times when they are most needed.

Psylla psychology 101

Ecological concept

Habitat suitability influences pest abundance.

Putting it into practice

Manipulate shoot growth to reduce pear psylla numbers.

The pear psylla can complete its development only on pear. This important pest is very selective in choosing its host and suitable sites for egg laying. Pear psylla adults deposit most of their eggs on young succulent foliage, and hatching psylla nymphs feed on new shoot growth. Management practices that affect the vigor or period of new shoot growth will affect the severity of pear psylla attack.

Reducing overall shoot growth also reduces pear psylla numbers. Carefully manage horticultural practices to avoid excess tree stimulation. Manage fertility to limit new shoot growth but still achieve the desired fruit set and size. Prune trees each year to limit heavy shoot growth. Pull water sprouts from scaffold limbs through the center of trees to remove the tender foliage that psylla prefer. Pull the water sprouts by hand, rather than with loppers, to decrease regrowth. It may also be possible to use chemicals to reduce shoot growth.



With black rot of grape, the fungus can infect young grapes for only a limited period of time. About three to five weeks after bloom, the developing berries of many grape cultivars become naturally resistant to infection, so fungicide protection is not needed after that point.



Pear psylla young nymphs and honeydew on young pear foliage.

Windows of opportunity

Ecological concept

Host and pest development are synchronized.

Putting it into practice

Treat at the appropriate time to avoid infection.

To survive, pests and pathogens have to time their development to coincide with availability of susceptible host tissue. They often have a narrow window of opportunity for infection. One good example is mummy berry disease of blueberry. This fungus infects and produces spores on young succulent shoots in early spring. These spores in turn infect the flowers and the developing berries, which become mummified. The fungus overwinters in the mummified fruit on the ground. The mummies require a chilling period followed by a warmup

P. Wierstra



A mummified blueberry with apothecia.

in the spring to become active, similar to blueberry plants. Fungal activity coincides with early plant growth, so it is important to protect the young succulent shoots and flowers from infection.

are inherently prone to winter injury and splitting when branches are laden with fruit. Hail- and frost-damaged pear and apple shoots are particularly susceptible to the fire blight bacterium. Harvesting equipment may damage fruit plants, predisposing them to infestation by wood-boring insects.

Prior attack by pests or pathogens may also predispose plants to further attack by other pests. Grape berry moth damage can promote infection of grapes by gray mold and sour rot organisms. Nematodes feeding on strawberry roots can allow entry of root-rotting fungi such as *Pythium* and *Rhizoctonia*, which cause black root rot. In addition, strawberry plants may be predisposed to infection by freezing or waterlogging of the soil, soil compaction and herbicide damage. Other stresses, such as drought and nutrient deficiencies, can also render a plant more susceptible to pests and diseases.

Factors that predispose plants to pest attack

A variety of stresses can affect the plant's ability to defend itself against attack by pests. Wounding, for instance, may

predispose plants to infection. *Eutypa* dieback infections of grapevines usually begin in pruning wounds. *Leucostoma* canker, a common disease of peach, nectarine and sweet cherry, often develops in narrow crotch angles, which

A wound in sheep's clothing

Ecological concept

Wounds predispose plants to disease.

Putting it into practice

Avoid wounding plants when pathogens are active.

The causal fungus of cane blight can enter raspberry and blackberry canes only through wounds. The fungus eventually causes cane death. The most common entryways are wounds caused by pruning, mechanical harvesting, canes rubbing against each other and insect damage. It makes sense, therefore, to avoid pruning during wet periods in the summer when fungus spores are plentiful and

infection is likely. Tying or trellising the canes to avoid excessive movement by wind can also reduce wounding. In addition, applying fungicides following pruning will protect the canes when they are most vulnerable to infection.



Evidence of cane blight.

either the fruit or leaves, but the developing larvae require fruit to complete their development.

Several other fruit pests overwinter on wood in various life stages, later moving to fruit and leaves to deposit eggs and feed. Some species spend the winter on the ground or in more distant non-crop habitats such as woods and fields and must recolonize the fruit crop each year.

Insect and mite life cycles

The general life cycle of insects and mites includes egg, immature and adult stages. The immature and adult forms of mites and some kinds of insects may look the same but differ in size. These undergo gradual metamorphosis. The young are called **nymphs** and lack wings and reproductive organs. Adults and nymphs usually share the same habitat and feed on the same host. Aphids and leafhoppers are two important fruit pests that develop in this manner.

In other insects, the young and adult stages look very different and often live in different habitats. These undergo complete metamorphosis. The young are called **larvae**. The larvae of moths are caterpillars, fruit fly larvae are maggots, and beetle larvae are grubs.

Life histories

A life history describes characteristics such as the way an organism develops, reproduces and feeds. Individual life history characteristics, such as dispersal ability and overwintering strategies, play a major role in shaping the community. Species can colonize and persist in a

habitat only if they are adapted to the available resources. Organisms living in fruit production systems often have a number of life history requirements. For example, codling moths overwinter as mature larvae in cocoons on the trunk and major scaffolds of apple and pear. After pupation, the adults may utilize fruit and sugars provided by ground cover plants. Eggs are laid on

Feeding and overwintering sites of some fruit pests and pathogens.

Insect or mite	Feeding site	Overwintering stage and site
Apple and spirea aphids	Foliage - primarily apple	Eggs on smooth twigs
Apple maggot	Fruit - apple, hawthorn, cherry, plum, wild rose	Pupae in the soil
Blueberry maggot	Fruit - blueberry	Pupae in soil under bushes
Cherry fruit fly	Fruit - cherry	Pupae in the soil
Codling moth	Fruit - apple, pear, quince	Mature larvae in cocoon under loose bark scales or in litter
Cranberry fruitworm	Fruit - blueberry, cranberry	Mature larvae in hibernacula in soil under bushes
European red mite	Foliage - many fruit crops and ornamentals	Eggs on small branches and twigs
Grape berry moth	Fruit - grape	Pupae in vineyard and woodlot leaf debris
Grape leafhopper	Foliage - grape	Adults in vineyard floor and surrounding habitats
Japanese beetle	Fruit and foliage - many fruit crops and ornamentals	Grubs in soil, especially under sod
Oribquebanded leafroller	Foliage and fruit - apple, pear, cherry, peach, many wild hosts	Young larvae in hibernacula on tree
Oriental fruit moth	Fruit and foliage - peach, nectarine, apple, plum, cherry, pear, rose	Mature larvae in hibernacula of silk in tree crevices or litter
Peachtree borers	Woody tissues - peach, nectarine, plum, cherry	Larvae in woody tissues
Pear psylla	Fruit - pear	Winter-form adults
Plum curculio	Fruit - apple, cherry, plum, peach, blueberry and others	Adults under leaf litter in woods, fencerows, ditch banks and plantings
Potato leafhopper	Foliage - many fruit crops	Adults in southern United States
Strawberry sap beetle	Fruit - strawberry	Pupae in soil in woods and plantings
Tarnished plant bug	Fruit - peach, strawberry	Nymphs and adults under leaf litter in and around plantings
Tentiform leafminer	Foliage - apple, pear, cherry, prune plum	Pupae in fallen leaves
Twospotted spider mite	Foliage - many weeds, ornamentals, vegetables, field & forage crops, tree fruits, small fruits	Adult females in duff at the base of tree or sheltered sites beneath bark
White apple leafhopper	Foliage - apple, cherry, prune plum	Eggs in newer wood
Disease/Pathogen	Part infected	Overwintering stage and site
Anthraxnose - fruit rot <i>Colletotrichum acutatum</i>	Fruit, twigs - blueberry	Mycelium in infected twigs
Anthraxnose - Elishoe veneta	Primocanes, leaves - raspberry and blackberry	Mycelium and fruiting bodies in diseased canes
Apple scab - <i>Venturia inaequalis</i>	Leaves, fruit - apple	Fruiting bodies in infected leaves on orchard floor and mycelium in infected buds
Bacterial canker - <i>Syringae</i> , <i>Pseudomonas</i> sp.	Tree trunk, branches, leaves, fruit - sweet and tart cherry, plum, prune	Bacterial cells in bark tissue at canker margins, apparently healthy buds and systemically in the vascular system
Black knot- <i>Apiosporina morbosa</i>	Shoots - plum, prune, tart cherry	Mycelium and fruiting bodies in knotty growths on trunks, branches, twigs
Black rot - <i>Guignardia bidwellii</i>	Leaves, fruit, canes - grape	Mycelium and fruiting bodies in mummified berries and infected canes
Brown rot - <i>Monilinia fructicola</i>	Fruit, twigs - all stone fruits	Mycelium in mummified fruit and in cankers
Cedar apple rust - <i>Gymnosporangium juniper-virginianae</i>	Leaves, fruit - apple	Mycelium in galls on eastern red cedar trees
Cherry leaf spot - <i>Blumeriella jaapii</i>	Leaves, fruit - cherry	Mycelium in leaves on the orchard floor
Downy mildew - <i>Plasmopara viticola</i>	Leaves, fruit - grape	Oospores in dead leaves on ground
Fire blight - <i>Erwinia amylovora</i>	Flowers, shoots, roots, fruit - apple and pear	Bacterial cells in bark tissue at canker margins and systemically in the vascular system
Gray mold - <i>Botrytis cinerea</i>	Leaves, flowers, fruit - grape, blueberry, strawberry, brambles	Mycelium and sclerotia in infected plant debris
Leather rot - <i>Phytophthora cactorum</i>	Fruit - strawberry	Oospores in fruit mummies and soil
Mummy berry - <i>Monilinia vaccinii-corymbosi</i>	Young shoots and fruit - blueberry	Pseudosclerotia (fruit mummies) on the ground
Peach rosette mosaic virus	Entire plant - peach, grape	Virus particles in roots and nematode vectors
Phomopsis cane and leaf spot - <i>Phomopsis viticola</i>	Canes, leaves, rachises, fruit - grape	Mycelium and fruiting bodies in infected canes
Powdery mildew - <i>Podosphaera leucotricha</i>	Leaves, shoots, fruit - apple	Mycelium in infected buds
Powdery mildew - <i>Uncinula necator</i>	Leaves, shoots, fruit - grape	Fruiting bodies in crevices in the bark

Adults and larvae generally are adapted to consume different resources. For example, moths have sucking mouthparts and feed on nectar and pollen; as caterpillars they have chewing mouthparts and feed on fruit and foliage. The larvae go through a series of stages, finally transforming into pupae before becoming adults. Pupae are usually inactive and serve as the overwintering stage for many insects. Insects may complete one generation (life cycle) or more per year. In some cases, insects have a constant number of generations, while others vary in the number of generations

depending on the weather within a growing season.

Nematodes

Nematodes are microscopic roundworms that inhabit all ecosystems. They have many roles in fruit production, including making nutrients available to roots, causing infectious diseases and vectoring plant viruses. These nematodes are microscopic and live in soil or decaying organic matter on the surface. Most plant parasitic nematodes feed on root tissue. The root knot, root lesion, ring and dagger nematodes are

pathogens of fruit crops. Root knot nematodes are sedentary, feed internally and cause root galls, whereas root lesion nematodes migrate throughout the root. Ring and dagger nematodes are ectoparasites and feed without entering root tissue. Dagger nematodes vector the tomato ringspot virus, which causes stem pitting of cherry and union necrosis of apple. Peach rosette mosaic virus, which causes a serious disease of grapes, is also vectored by the dagger nematode. The Michigan grape root knot nematode is known to exist only in Michigan and is

Timing is everything

Ecological concept

Each life stage interacts differently with the crop.

Putting it into practice

Knowing pest life cycles helps planning of effective pest control programs.

Some insects, such as codling moth, do little damage in their adult stage to their host plants, but lay eggs directly onto the crop. Later, these eggs hatch, and larvae emerge and feed on the crop. In this case, to optimize control insecticide applications should be targeted to the eggs and

young larvae, which are the most sensitive stages. For insects such as Japanese beetle, where the adult causes most damage, targeting the adult is critical for reducing direct feeding damage to the foliage and fruit, while controlling grubs can reduce the overall population.

The Japanese beetle life cycle consists of egg, larval, pupal and adult stages.



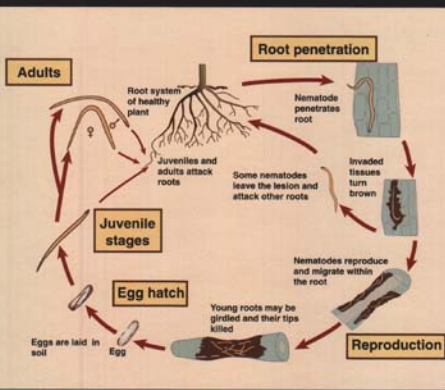
Z. Szendri

R. Isaacs

R. Isaacs



Above left, a plant parasitic nematode (root-feeding) as viewed with an electron microscope. Above right, a light microscope created this photomicrograph that allows us to see inside a nematode and view the stylet used to feed on root tissue.



A nematode life cycle: root lesion nematode.

uniquely adapted to a northern temperate climate.

In the life history of nematodes, females or hermaphrodites produce eggs, which hatch as juveniles. All nematodes have four juvenile stages. Between stages they shed their cuticle (molt) and increase in size. Both nematodes and arthropods have this unique characteristic. In many species, the adults resemble the juvenile stages. Females of

some species, such as the root knot nematode, become swollen and are unable to move. Nematode development is influenced by host, temperature and other ecosystem factors. Nematode life cycles may be as short as 72 hours or as long as several years. Some species have stages that are designed to persist through long periods of adverse environmental conditions.

Plant pathogens

The life histories of **plant pathogens** are varied and often tightly intertwined with host development. In general, plant pathogenic fungi overwinter as fungal threads (mycelium), fruiting bodies or spores in previously infected plant parts or in the soil. In the spring, spores are released and carried by wind or rain to susceptible plant tissues. The fungus penetrates the plant surface (either directly or through wounds or natural openings) and starts to colonize the underlying tissues. In some cases, the fungus grows throughout the entire plant, which is called systemic infection.

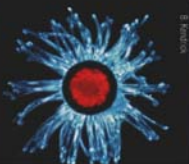
Powdery mildew



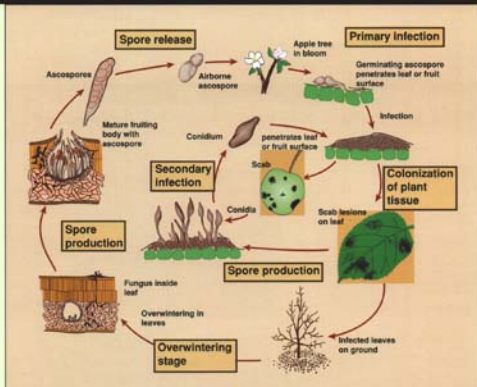
Powdery mildew on grape leaf.



Overwintering fruiting bodies of the powdery mildew fungus.



Close view of overwintering fruiting body.








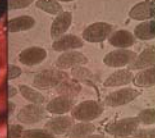
A fungal life cycle: apple scab.




After a certain period, in which symptoms usually become evident, the fungus produces fruiting bodies, which contain spores. These spores can reinfect other plants or parts of the same plant.

Some pathogens obtain most of their nourishment from dead or dying plant material; others depend entirely on a living plant for their growth and reproduction. Weak pathogens cannot usually attack a healthy

plant but can become secondary invaders when a plant has been weakened by another pathogen or environmental stress.

Bacteria tend to overwinter in infected plants, in plant debris on the ground or in soil. In the spring, they get splashed by rain onto susceptible plant tissues. They may first multiply on the plant surface to build adequate numbers for infection and then gain entry through

Bitter rot		
		
Bitter rot of apple.	Fruiting bodies of bitter rot fungus.	Spores of bitter rot fungus.
Leather rot		
		
Leather rot of strawberry.	Masses of sporangia around seed.	Sporangia of the leather rot fungus.

Fire blight

Apple shoot killed by fire blight.

Bacterial ooze on infected apple

Close-up of <i>Erwinia</i> bacterium



wounds or natural openings such as stomates. Once inside the plant, the bacteria start to multiply and destroy plant tissues in the process, after which they ooze out of infected plants. Rain, wind or insects disperse the ooze to other susceptible plant tissues.

Viruses usually overwinter in stem or root cells of infected plants. Once the plant resumes growth in the spring, the virus moves throughout the plant, especially to young growing tissues. The virus tells the plant cell to make more virus particles and, in the process, disrupts the normal cell functions. Sucking or chewing insects, nematodes and certain soilborne fungi move viruses from plant to plant. Viruses can spread via seed, pollen or vegetative propagules, such as bulbs, corms and tubers. They can also be transmitted through plant sap on farm equipment, pruning shears, knives, hands and clothing.

What goes around comes around

Ecological concept

Pathogens survive in plant debris.

Putting it into practice

Remove overwintering inoculum to reduce disease pressure.

Brown rot is an important disease of apricot, peach, nectarine, plum and cherry. The brown rot pathogen infects blossoms, spurs, shoots and fruit. Infected tissues become covered with the fungus and then turn dry and hard by the end of the season. The pathogen



A. Jones

overwinters primarily in the tree in fruit mummies, fruit stems and twig cankers. Brown rot disease pressure can become severe in orchards where fruit remain after harvest. Removing sources of inoculum from the orchard helps reduce disease pressure the following season. Growers must use a more diligent control program if there is a large amount of overwintering inoculum.

Biotic interactions

Individuals in a community are bound together by biotic

interactions such as predation, parasitism, herbivory, competition and mutualism. Because of these interrelationships, each population's activities affect other populations. Herbivores are strongly influenced by interactions with their food plants but also compete with one another for resources. Furthermore, the abundance of herbivores is strongly influenced by the densities of organisms that attack them.

Blueberry shoestring virus



Leaves damaged by blueberry shoestring virus.



Blueberry shoestring virus is vectored by the blueberry aphid.



Blueberry shoestring virus particles.

How pathogens cause disease

Spore lands on leaf surface.



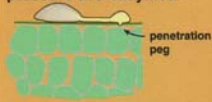
Spore germinates when there is sufficient moisture.



Infection cushion forms.



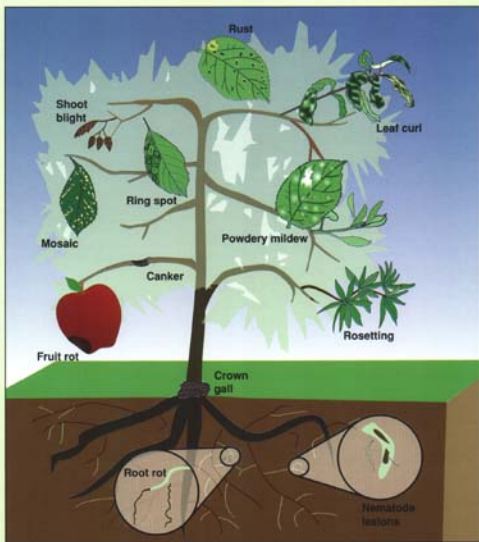
Fungus penetrates the plant surface using pressure and enzymes.



Fungus invades underlying tissues.



Tissue breaks down and dies.



Common disease symptoms of fruit plants.

Types of biotic interactions

Predation: When one organism attacks another organism and consumes it.

Parasitism: When an organism gains food or shelter from another organism at the other organism's expense.

Herbivory: When an organism feeds on a plant.

Competition: The negative effects that one organism has upon another by consuming or controlling access to a limited resource.

Mutualism: A beneficial relationship between two or more species that live close to one another and rely on one another for survival.

Competition for resources

Competition occurs when organisms of the same or different species need the same resources, such as food, water, shelter or light. Growers are well aware of some of the potential effects of competition. Fruit trees are planted at certain densities to decrease the effects of competition between trees and to optimize resource use and yield. Growers use weed management to limit competition for water and nutrients between crop species and weeds.

Some herbivores may compete directly for a potentially limiting resource, such as a fruit. An individual cherry is likely to support the development of a single cherry fruit fly larva. To help avoid competition for this resource, female cherry fruit flies mark the fruit with a chemical after depositing an egg. Flies landing on marked fruits detect the chemical and do not lay additional eggs.

Community members commonly compete indirectly through their effects on the habitat. Insect feeding may cause physiological changes in the host plant that alter its nutritional suitability or defensive chemistry. These changes affect other species

occupying the habitat. For example, early season foliage changes caused by the feeding of apple rust mite result in the exclusion of European red mites later in the season. Likewise, a virus-infected plant may be less likely to get a fungal infection because of lower humidity in the canopy due to poor growth. Pest attack on a crop may also create changes in the habitat that facilitate colonization, feeding and reproduction by other species. Large populations of wood-boring pests may develop in trees that have been severely stressed by defoliating pests. These indirect effects are often difficult to see but can have large effects on pest development.

A practical application of competition is to use beneficial microorganisms to manage certain diseases. The adage “first come, first served” also applies in the microbial world. Some microorganisms eat up a food source so fast that other organisms starve. The fungus *Ulocladium* is able to colonize and consume nutrients in dead leaf matter before *Botrytis* (the gray mold fungus) gets to them. The result is a reduction in the *Botrytis* spore load. Another example is use of *Pseudomonas fluorescens* (commercially available as

Blightban A506), which competes for space and nutrients with the fire blight bacterium on stigmas of apple and pear, resulting in biological control of fire blight.

Pest and natural enemy interactions

Integrated pest management emphasizes the importance of interactions between pests and the **natural enemies** that prey upon them. When broad-spectrum insecticides are applied, pest and non-pest species are killed and the



Sometimes microbes use toxic substances to exclude other organisms that are competing for the same space or food source. For instance, the biocontrol agent *Agrobacterium radiobacter* strain K-84 (sold as Galltrol) makes a toxin that prevents infection by the crown gall pathogen, which has infected this raspberry plant.

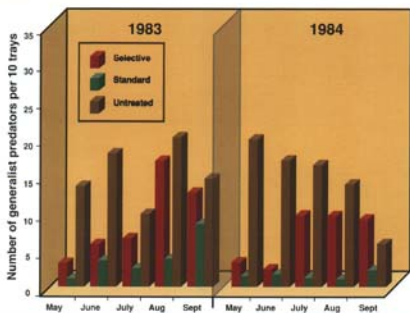
balance of the community is disrupted. For example, pesticide use in pear orchards to control codling moth can also destroy the natural enemies of pear psylla. In the absence of its natural enemies, pear psylla can reach high densities and cause significant damage to the fruit. Natural enemies are divided into two main groups: predators and parasitoids.

Predators

A predator lives by capturing and feeding on another species. Predators are usually

larger and more powerful than their prey. Many of the most common predators in fruit production systems attack a

wide range of pest species and help regulate pest population densities.



Comparison of predator abundance in unsprayed versus sprayed pear.

Keep these killers on the loose

Ecological concept

Natural enemies help keep pest populations in check.

Putting it into practice

Preserve natural enemies.

There is good potential for biological control of several fruit pests if populations of predators and parasitoids are preserved and enhanced. For example, biological control of plant-eating mites is achieved in many fruit production systems by conserving predatory mites, as well as predacious beetles and bugs. To avoid killing natural enemies of mites, pesticides must be selected carefully. Two classes of insecticides that are

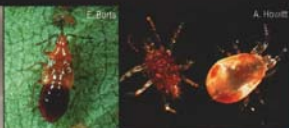
highly toxic to mite predators are the pyrethroids and the carbamates. Biological control of apple leafminers by parasitoids is common in Pacific Northwest orchards and has potential in other areas. To conserve these important allies, avoid using moderately and highly toxic insecticides from mid-June to early July when adult parasitoids are most active.

Use control tactics that are the least harmful to natural enemies. Avoid insecticides that are highly toxic to predators and parasitoids. If one of these materials must be used, spray when natural enemies are least vulnerable. In general, broad-spectrum insecticides applied



A syrphid larva capturing and feeding on an aphid.

early in the growing season, before many natural enemies have become active or moved into the crop, tend to be less disruptive than those applied later in the summer. Use spot treatments or delayed applications when it appears that natural enemies might be able to provide control.



Anthocorid nymphs feeding on pear psylla.

Predatory mites: *Apistemon fleschneri* (left), *Amblyseius fallacis* (right).



Ladybird beetle.

Lacewing



Bigeyed bug adult feeding on a lygus nymph.

Syrphid fly

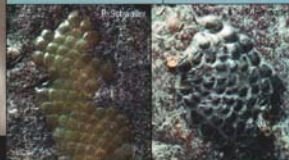


Aphelinid wasps attacking woolly apple aphids



Trichogramma adults attacking leafroller eggs.

Tachinid fly



A normal redbanded leafroller eggmass on the left and a parasitized mass on the right.

Common predators and some of their prey in fruit crops.

Predators	Prey
Amoebae	Soilborne fungi, bacteria
Anthocorid bugs	Spider mites, thrips, aphids, pear psylla, young scale, various insect eggs
Bigeyed bugs	Lygus bugs, aphids, leafhoppers, spider mites
Collembola	Fungi
Ladybird beetles	Aphids, scale insects, pear psylla, mealybugs, other soft-bodied prey
Lacewings	Aphids, scale insects, mealybugs, pear psylla, leafhoppers, thrips, mites
Mirid bugs	Spider mites, aphids, leafhoppers, pear psylla, scale insects
Mycophagous mites	Fungi — e.g., grapevine powdery mildew
Nematodes	Soilborne fungi, bacteria, other nematodes
Predatory mites	Plant-feeding mites
Spiders	Pear psylla, aphids, leafhoppers
Syrphid flies or flower flies	Aphids, scale insects

Common parasites and some of their hosts in fruit crops.

Parasites	Hosts
Aphelinid wasps	Aphids
Tachinid flies	Caterpillars, beetles
Trichogramma wasps	Moth eggs
<i>Bacillus thuringiensis</i> (bacterium)	Butterfly/moth larvae
<i>Pseudomonas fluorescens</i> (bacterium)	Fungi
Polyhedrosis virus	Butterfly/moth larvae
<i>Beauveria bassiana</i> (fungus)	Many insects
<i>Trichoderma harzianum</i> (fungus)	Many fungi
<i>Ampelomyces quisqualis</i> (fungus)	Powdery mildew
<i>Arthrobotris</i> (nematode-trapping fungus)	Nematodes
<i>Steinernema</i> (nematode)	Insect larvae
<i>Pasteuria penetrans</i> (bacterium)	Nematodes

Parasites

A **parasite** lives in, on or with another organism and obtains food and usually shelter at the host's expense. Parasitic insects and microbes are important in the biological control of many pests. Plant pathogens may be considered parasites that cause disease symptoms in plants.

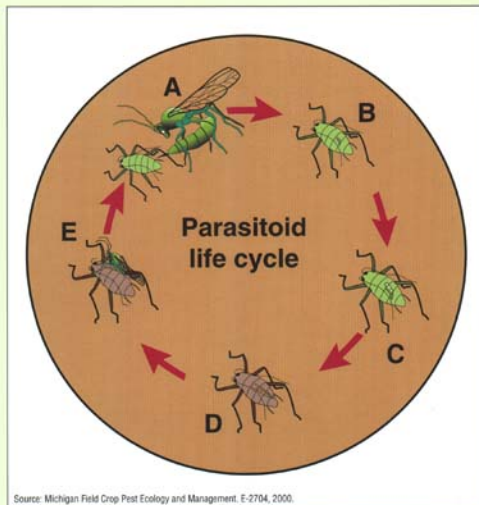
An insect that is parasitic on other insects during its immature stages but is free-living as an adult is called a **parasitoid**. Most parasitoids are small flies or wasps. Parasitoids are often common in flowering plants such as fruit crops and therefore are potentially very beneficial allies of fruit growers. Some parasitoids are specialists, attacking one or a few host species, while a few are generalists and use a wide variety of other insects as hosts. The free-living adults often feed on the nectar provided by flowers. The female parasitoid finds a host and lays eggs. The parasitoid larva develops inside or on the host. At first the larva feeds only on fatty tissues, allowing the host to continue to grow and develop. As the parasitoid nears the end of its development, it consumes the host's vital organs, killing it. The parasitoid larva pupates and later emerges as an adult.

The emerging parasitoid often leaves behind telltale signs of its handiwork. When scouting for pests, also watch for parasitoid pupal cases or emergence holes in insect bodies. Try to choose management strategies that protect parasitoids, such as using selective insecticides.

Parasitic microbes such as fungi, bacteria and viruses can cause diseases of insects. *Bacillus thuringiensis* (Bt) is a

well known bacterium that kills insects with a potent toxin. Bt must be eaten before it can kill its host, so sprays should be timed to coincide with warm periods when the target insect is most likely to be feeding. Once consumed, the Bt toxin destroys the insect's gut. Infected insects become lethargic, stop feeding and die.

Parasites also keep pathogen populations in check. For instance, the fungus



Source: Michigan Field Crop Pest Ecology and Management, E-2704, 2000.

- A.** A wasp lays an egg in a host (in this example, an aphid).
B and C. As the host feeds and grows, so does the wasp larva.
D. The parasitoid kills, then pupates within the dead host.
E. An adult parasitoid emerges from the dead host.

The good, the bad and the ugly



R. Sauer

Ecological concept

Many kinds of organisms inhabit fruit production systems.

Putting it into practice

Monitor both pest and beneficial species.

A good scouting program is key to making ecologically sound pest management decisions. The need for control and the impact of any action are determined by monitoring pest and natural enemy

populations. Sampling provides information on the organisms present, their stages of development, population densities and the ratio of pests to natural enemies. A scout must know how an organism develops because different life stages may be monitored in different ways. For example, you would sample fruit to look for grape berry moth larvae but use pheromone traps to monitor adults. In addition, a single life stage may move to different plant parts as the season progresses. Oriental fruit moth larvae attack terminal shoots early in the season, feed in shoots and fruit in the middle of the summer but infest only fruit late in the season.

Sampling for predators and parasitoids is as important as

monitoring pest populations. Higher pest densities can be tolerated when populations of natural enemies are also high. For example, a mite spray may be warranted in apple when there are two or three mites per leaf if there are no natural enemies, but a grower might wait until there are five or six per leaf if one predator mite per leaf is also present. Monitoring parasitoid populations can be tricky — often it is only the signs of their presence that can be readily detected. For example, aphid parasitoids that feed within their hosts cause the aphids to become puffy or mummified and tan, golden or black. A round hole can be observed where the wasp has cut its way out of the aphid mummy.

Ampelomyces quisqualis parasitizes powdery mildew fungi on several fruit crops. A commercial formulation can be applied to slow disease development by reducing vigor and spore production of the mildew colonies. Also well known are *Trichoderma* species, which parasitize soilborne pathogens such as *Rhizoctonia* and *Pythium*.

Even more interesting are soil-inhabiting fungi that trap and devour nematodes with specialized structures that resemble lollipops and lassos. Bacteria are also known to parasitize nematodes. For example, the bacterium *Pasteuria penetrans* attacks the root knot nematode.

Mutually beneficial relationships

Some parasitic fungi have mutually beneficial relationships with plants. For example, mycorrhizae are fungi that live inside plant roots and generally have a beneficial effect on the plant. They use their extensive threadlike mycelia to absorb nutrients and water from the

W. Yang



Mycorrhizal hyphae (the thin strands coming out of the root) are very important in blueberry, which has no root hairs and relies on these fungi to increase the absorptive capacity of its roots.

soil, passing them on to the plant roots. In return, the plant provides shelter and nourishes the fungus. Mycorrhizae may also protect plant roots against pathogen invasion.



Ants tending aphids to benefit from the aphid-produced honeydew.

Some insects live together to benefit one another, and this can make pest management more challenging. Aphids can often be found living in a mutually beneficial arrangement with colonies of ants. In this case, the aphids produce honeydew and the ants harvest the sugary liquid for food. Worker ants can be seen running between aphid colonies and their nests in the soil. In return, the ants protect aphids from predators and may even carry them to a better habitat if the plant starts to die. This interaction can lead to rapid increases in aphid populations because natural enemies are prevented from regulating the aphids.

Pathogen and vector relationships

Another important interaction among organisms in a fruit crop is the role of insects in spreading diseases. Blueberry aphids, which are pests in their own right, can also vector blueberry shoestring virus, which causes malformation of blueberry shoots and leaves and a decline in vigor and productivity. The mummy berry fungus forms a unique alliance with an insect that visits blueberry flowers daily. Bees are fooled into thinking that the shoots covered with fungal spores are actually flowers by the distinct UV patterns

produced by the diseased tissue. The spores, which are produced in a sweet sticky matrix, easily stick to the bee's body and are delivered to the stigma where infection occurs. Belowground, certain nematodes are also vectors for plant pathogens. The dagger nematode can transmit the tobacco and tomato ringspot viruses to various hosts, including grapes. These viruses cause a slow decline of the grapevine.

Alternative food sources

Some predators and parasitoids use alternative food sources during the growing season. These include prey or hosts other than pests, and nectar-producing plants other than fruit crops. If an alternative host is not available, the predator or parasitoid may not survive or stay long enough in the crop to control pests when needed. Predatory mites often feed on rust mites when their primary prey, spider mites, are absent or in low numbers.

Parasitoids may require an alternative host to complete their life cycle. A small parasitic wasp, *Colpoclypeus florus*, can have a major impact on some leafroller populations in apple orchards. However, *C. florus* is often not present in high



Mighty mites

Ecological concept

Predators often need an alternative food source.

Putting it into practice

Manage orchard diversity to sustain predatory mites.

Predatory mites are among the most effective biological control agents in fruit crops. When present at the right time and in sufficient numbers, predatory mites can prevent harmful species of mites from reaching damaging levels. The most economically damaging species of mites in apple are collectively referred to as spider mites, including the twospotted spider mite and the

European red mite. Another kind of mite, the apple rust mite, can become a pest of apple but also plays a beneficial role as an alternative food source for predatory mites. This is a critical component of mite biological control because it allows predatory mites to survive when spider mite densities are low.

Rust mites should be controlled only if densities are too high. Moderate populations of apple rust mite do little damage. Control measures for rust mites as foliage feeders can be withheld until 50 to 100 mites per leaf are detected. Even if populations build to 200 to 300 per leaf in the summer, the benefit of conserving rust mites as an alternative food source may outweigh their potential to russet fruit or reduce yield.

numbers early in the season because none of the leafrollers in the orchard overwinter as late instar larvae, the host size required to complete its

development. Another leafroller host of this parasitic wasp overwinters as a large larva on wild rose, found in wild habitats around orchards. Larvae of the



E. Beers

Zetzellia mali are predatory mites that feed on European red mite.

parasitoid successfully overwinter in this host on rose and complete their development early in the spring. They then emerge and can fly to colonize leafrollers in nearby orchards.

Many natural enemies require more than one kind of food to develop normally and sustain their populations. Syrphid fly adults supplement their diets by gathering and eating pollen from flowering plants. Where natural enemies have access to pollen and nectar, there is often more predation and lower abundance of pests. Similarly, parasitic wasps supplement their diets by feeding on nectar, aphid honeydew and other



Parasitoid larvae of *Colpoclypeus florus* attacking a leafroller.

sources of sugar. For example, *Trichogramma* species are tiny wasps that parasitize the eggs of moths, such as codling moth. Planting a cover crop that includes flowering plants is a good way to provide nectar sources for these beneficial insects, but care must be taken in selecting a cover crop that is not a host for other pests.

Some pathogens also need to find alternative hosts when a fruit host is unavailable. For example, the root knot nematode can also reproduce on dandelions in vineyards. This weed can also serve as a host for viruses that are vectored by the dagger nematode. Weed management is essential to reduce these types of risk. Cover crops that suppress weeds and nematodes have been used in fruit systems and are likely to play an even more important role in the future. *Verticillium albo-atrum*, a soilborne fungus that causes a severe wilt in strawberries, also attacks the roots of many other hosts, especially solanaceous crops such as tomatoes, peppers and potatoes. Growers are advised not to plant strawberries after *Verticillium*-susceptible crops.

Remember rotation

Ecological concept

Rotating crops disrupts pathogen life cycles.

Putting it into practice

Rotate to reduce soilborne diseases of strawberry.

Rotating crops for pest and disease management is not common in perennial fruit production except for strawberries, which are replanted more often. The disease *Verticillium* wilt is difficult to control in strawberries. The best way to get rid of the pathogen is to starve it by rotating to a non-host crop such as oats or wheat. The field should not be planted to strawberries or any other susceptible crops, including tomatoes, peppers or potatoes, for three to five years to bring the pathogen population down to non-damaging levels. For red stele, however, the length of the rotation would need to be much longer because the pathogen may persist in the soil for more than 10 years after a strawberry crop.

A Schilder



J Landis



Management influences on the community

Management practices change the dynamics of the community of pests and natural enemies within the crop. The positive effects, such as reduced pest numbers and increased yields, are obvious. Certain management decisions, however, can have unintended impacts on the community.

Impact of cultural practices

Fire blight of apple and pear was once considered a sporadic disease that usually could be managed by combining cultural and chemical methods. Since the early 1990s, however, fire blight has plagued apple growers to a degree previously unknown. Indeed, modern fire blight epidemics have been an economic disaster.

The "new face" of fire blight has resulted from several changes in the apple crop habitat. Genetic, physical and cultural factors have interacted to create ideal conditions for growth and spread of the fire blight pathogen:

- The number of trees planted per acre has increased dramatically. This means that fire blight can move more easily from tree to tree.
- More acres are being planted to highly susceptible cultivars, including Braeburn, Fuji, Jonathan and Rome.
- Size-controlling rootstocks, many of which are highly susceptible to fire blight, are used to achieve high-density plantings.
- Trees are being pushed to bear earlier, and training systems are being adopted that are very different from the way apple trees grow in nature. These modern orchards have a high density of apple tissues such as flowers and young shoots that are very susceptible to fire blight. Traditional, low-density orchards also have susceptible tissues, but they are interspersed with a lot of older, woody tissues that are much less favorable to the growth of the fire blight pathogen.

New tools are being developed to manage fire blight on susceptible varieties in high-density plantings. For example, there are a few size-controlling rootstocks that are relatively resistant to fire blight. Certain plant growth regulators reduce vigorous shoot growth and thereby reduce shoot susceptibility to fire blight. Also, larger trees planted at lower densities will not have the production potential of the more modern orchard systems, but they will be more likely to survive fire blight long enough to yield a crop.



Fire blight on Honeycrisp.

Pesticide impacts on the community

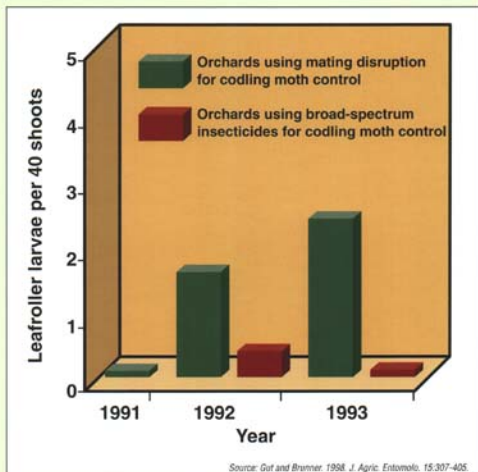
Although pesticide sprays are generally targeted against one or a few pest populations, they often influence other pest and non-pest species. Some insecticides are very toxic to predators and parasitoids. Destroying these natural enemies often results in target pest resurgence or secondary pest outbreaks. Some pesticides have a greater impact on the natural enemies than the target pest. **Target pest resurgence** can result when the unfavorable ratio of pests to natural enemies permits a rapid increase or resurgence of the pest population. For example, biological control of twospotted spider mite by predatory mites is common in many fruit crops. Insecticides that are applied for control of pest mites and insects are often highly toxic to predatory mites. Some pest mites survive the spray, but most predators are killed. The population of twospotted spider mites is able to rebound quickly, reaching economically damaging levels before its natural enemy can recolonize from unsprayed areas.

Preplant fumigation of the soil is often used for control of black root rot in strawberry.

However, if black root rot pathogens are reintroduced in fumigated soil with infected planting material, the disease comes back with a vengeance, presumably because competitive organisms in the soil have been eliminated by the fumigation.

A **secondary pest outbreak** occurs when a pesticide that was applied to control one pest kills the natural enemies that were keeping a second pest population in check. For example, a complex of

predators can be helpful in keeping aphid populations from reaching damaging levels. The broad-spectrum insecticides that are used to control key pests are highly toxic to these predators. As a result, applying one of these insecticides often leads to secondary outbreaks of aphid populations. Pesticide applications can also affect beneficial microbes, leading to increased plant disease problems.



Effects of codling moth control on a secondary pest (leafrollers).

Secondary pest problems are not always associated with the destruction of natural enemies. Control of codling moth by mating disruption entails releasing enough sex pheromone into orchards to interfere with mate location, reducing reproduction and subsequent larval infestations. However, using this highly specific tactic in place of broad-spectrum insecticides can also have a significant impact on other potential pests. In disrupted orchards, leafrollers that were kept at non-damaging levels by broad-spectrum insecticides are now suppressed only by natural enemies. Unless natural controls provide sufficient suppression, leafroller populations will increase, sometimes reaching damaging levels.

In similar fashion, minor diseases that are not normally a problem can become important when major diseases are controlled. Because pathogens often compete for space and nutrients, removing one pathogen with a fungicide may benefit other pathogens that are not affected by that particular fungicide. An example of this is the increase in *Alternaria* infections of blueberry fruit in fields that have been treated with a fungicide against anthracnose fruit rot.

Environmental effects on insects and diseases

Annemiek C. Schilder, Rufus Isaacs, Larry J. Gut, Jeff A. Andresen, Patricia S. McManus and Nikhil Mallampalli



A worker checks weather data and insect traps in a vineyard.

Weather and climate strongly affect how organisms function within an ecosystem. These effects include the rate at which organisms grow and develop and how some insects and pathogens are spread over time and space. Crop managers can use weather data to help predict when insect pests and pathogens will be present and most vulnerable to control measures.

Microclimate

"Microclimate" refers to weather conditions over a distance of less than half a mile. It includes climate effects from the orchard or vineyard down to the microscopic scale. The endless combinations of characteristics such as crop canopy structure, topography and soil type can create unique microclimates. Often microclimates are understood only after years of observation.

Air temperature within crop canopies is not usually uniform but varies with height, depending on the architecture of the crop, time of day and cloud cover. When the sun is shining, the highest temperature occurs in the top of the canopy. Under overcast skies, temperatures tend to be relatively uniform within crop canopies.

Different rates of heating from varying exposures to sunlight can greatly affect temperature in a small area. In a Michigan forest, researchers recorded temperatures inside gypsy moth egg masses placed 3 feet above the ground on four sides of an oak tree. Temperatures were recorded at various times on a clear fall day. Simultaneous temperatures on the same tree varied as much as 40°F because of differences in the amount of sunlight shining on the egg masses.

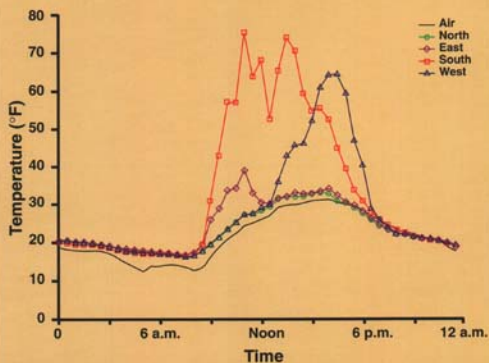
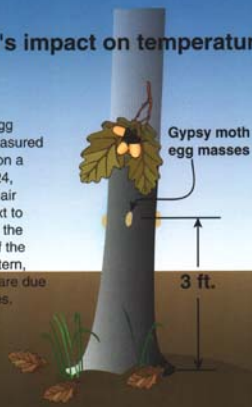
Such differences lead to significant variations in the rate that organisms develop during the growing season. In this case, the date of egg hatch differed as much as three weeks the following spring.

Many pest-plant interactions take place on the plant surface, so it is important to consider that leaf temperature may vary from air temperature because of solar radiation or convective cooling. The surface of a sunlit leaf is commonly 8 to 15°F warmer than the surrounding air. At night under clear skies, leaves can cool to 8 to 15°F lower than the air temperature.

Snow cover can also significantly modify surface or soil temperatures by insulating the ground from extreme cold and fluctuating temperatures. Snow's capacity to insulate overwintering crops depends on its depth, age and density. In a study of vineyard microclimates in Michigan, researchers observed daily maximum and minimum temperatures at various heights above and below the soil surface. The snow pack at the experimental site was approximately 16 inches deep. On a clear February day, the coldest minimum temperatures were observed at the top of the snow pack near the coldest, densest air. Temperatures at the snow surface were 11°F colder than

Sunlight's impact on temperature

Instantaneous gypsy moth egg mass temperatures were measured on four sides of an oak tree on a clear calm day (September 24, 1997) in Augusta, Mich. The air temperature immediately next to the tree was also included in the graph for reference. Some of the large fluctuations on the eastern, southern and western sides are due to shading from tree branches.

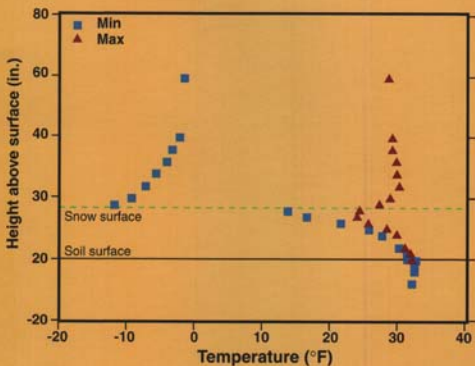
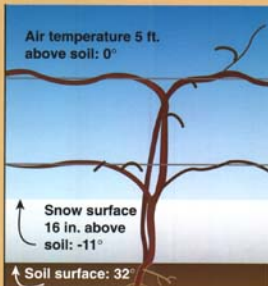


the air temperature at 5 feet above the ground and 43°F colder than the soil surface temperature. This indicates the

importance of snow cover for survival of vegetation and insects that overwinter in or on the soil.

Snow as an insulator

Maximum and minimum temperatures were measured at various heights in a snow-covered vineyard on Feb. 14, 1997, in Mapleton, Mich. The minimum temperature at the snow surface was 11°F colder than the air temperature at 5 feet above the ground and 43°F colder than the soil surface temperature.



Moisture in the crop canopy occurs as humidity (water vapor in the air) or water due to rain or dew. Relative humidity can be significantly different within the canopy and in the air above the crop. During the day, relative humidity in the crop is generally higher because of transpiration by the crop. At night, the differences are

smaller. In a transpiring crop, the water vapor pressure close to the leaf surface where pathogens grow may be close to saturation.

Environmental effects on the community

Although there is usually little we can do to control or manipulate the crop micro-

climate, understanding how environmental factors affect crop pests and pathogens is essential when developing effective control strategies. The physical environment strongly affects the life cycles of pests and pathogens as well as other organisms in the community. The seasonal abundance and activity of organisms are mostly due to changes in climatic conditions.

Temperature is the most important environmental factor for insects because it determines their rate of growth. Daily light and dark cycles regulate the timing of flight and other activities, and the long-term changes in day length through the seasons serve as a signal for some insects to start or end dormancy. Typically, insects will enter dormancy as the day length shortens in the fall by developing an overwintering stage able to withstand cold temperatures. The insect will emerge in the spring as the temperature rises.

The environment can have either a direct effect on pathogens or an indirect effect by influencing the health and growth of the crop. For foliar pathogens, the microclimate of the plant surface plays a dominant role, while the physical and chemical nature of the soil is important for

soilborne pathogens. Moisture, temperature, wind and light affect pathogens throughout most phases of the disease cycle.

Temperature

Microbes, whether fungi or bacteria, have minimum, maximum and optimum temperatures for growth, infection and sporulation. These requirements differ for each organism, although most are not active below 40°F or above 95°F. Sometimes diseases develop when temperatures are less favorable for plants than for pathogens, thereby giving the pathogens an advantage.

Some pathogens need a chilling period, just like their hosts, to break dormancy. The mummy berry fungus likely needs at least 1,200 hours of temperatures below 45°F for the mummies to germinate in northern climates. This fungus is able to synchronize its germination with blueberry bud break to an uncanny degree.

Most insects will grow and develop when a minimum temperature is met. This critical temperature is different for each insect species and may vary for different life stages of the same species. Dormancy is broken and growth begins in the spring when temperatures



Spores of the *Eutypa* dieback fungus are able to infect pruning wounds at temperatures just above freezing when the grapevine is dormant and wound healing is slow. *Eutypa* dieback symptoms are visible in these Concord grape leaves.

increase above the minimum temperature threshold. Growth is faster on hot days than on cold days, and so insect life cycles are accelerated during the summer compared with the cooler spring and fall. This results in rapid multiplication of insect pests during warm periods, especially in aphids, which can reproduce asexually. Some very high temperatures

can stop development, but these conditions are rare in the Midwest region of the United States.

Insect feeding activity is also greater on warm days, so insecticides that need to be eaten by larvae (such as Bt's or growth regulators) are most effective when temperatures remain above 70°F. Pollination, mating and flight are also dependent on temperature. This environmental factor is important for insect-related aspects of pest management. As the weather cools in the fall, development slows and generations take longer to develop.

Moisture

Moisture is a key factor for fungal and bacterial pathogens and beneficials because they are mostly unprotected in air and on plant surfaces and can easily dry out. Most require high humidity and need free water for a certain length of time to germinate or infect. Grape downy mildew spores can germinate only in free water, making infection most likely after dew or rain. In contrast, powdery mildew can be a problem even in areas of low rainfall because its spores may germinate in low to moderate relative humidity. Bacteria also need a film of

Adapted Mills Table^a

Approximate wetting period required for primary apple scab infection at various air temperatures and time required for conidia to develop.

Average air temperature		Wetting period (hr) ^b			Incubation period ^c (days)
		Light infection	Moderate infection	Heavy infection	
°F	°C				
78	25.6	13	17	26	—
77	25.0	11	14	21	—
76	24.4	9.5	12	19	—
63-75	17.2-23	9	12	18	9
62	16.7	9	12	18	10
61	16.1	9	13	20	10
60	15.6	9.5	13	20	11
59	15.0	10	13	21	12
58	14.4	10	14	21	12
57	13.9	10	14	22	13
56	13.3	11	15	22	13
55	12.8	11	16	24	14
54	12.2	11.5	16	24	14
53	11.7	12	17	25	15
52	11.1	12	18	26	15
51	10.6	13	18	27	16
50	10.0	14	19	29	16
49	9.4	14.5	20	30	17
48	8.9	15	20	30	17
47	8.3	15	23	35	—
46	7.8	16	24	37	—
45	7.2	17	26	40	—
44	6.6	19	28	43	—
43	6.1	21	30	47	—
42	5.5	23	33	50	—
41	5.0	26	37	53	—
40	4.4	29	41	56	—
39	3.9	33	45	60	—
38	3.3	37	50	64	—
37	2.7	41	55	68	—
33 - 36	0.5 - 2.2	48	72	96	—

^a Adapted from Mills, 1944; modified by A.L. Jones.

^b The infection period starts when rain begins.

^c Approximate number of days required for conidial development after the start of the infection period.

water on the plant surface to enter natural plant openings.

Wetness requirements vary by fungus and temperature. The closer to the optimum temperature for fungal growth, the shorter the period of leaf wetness needed for infection to take place. At 70°F, the apple scab fungus needs 9 hours of wetness to cause infection, whereas at 40°F, 29 hours of wetness are needed. The Mills Table describes the minimum environmental requirements for apple scab infection.

Moisture is also important for fungal sporulation and bacterial multiplication. Leaf-infecting fungi require high relative humidity for sporulation, although powdery mildew can sporulate under widely varying humidity levels. For those fungi that require free water for sporulation, the duration needed is often longer than that for infection. Intermittent dry periods often enhance sporulation.

Moisture is rarely a limiting factor for insects in humid regions. Larvae and adult

A. Schläpfer



The causal agent of leather rot needs only a half hour of wetness to infect strawberry fruit.

insects can gain water by eating plant tissue or sucking plant sap, and adult moths might suck water from dewdrops. If there is a prolonged drought, insects such as Japanese beetle grubs that live underground and need moisture for part of their life might be affected. Fruit fly emergence is impeded by dry weather and activated by rain. Growers can use weather predictions and trap counts to predict the risk of attack by these flies in blueberry, cherry and apple plantings.

Using cultural methods to reduce moisture in the crop canopy helps avoid disease outbreaks. Relative humidity and wetness duration are generally higher when airflow

is restricted, such as in dense canopies and behind wind-breaks. Airflow can be increased by pruning, canopy management, wider plant spacing, proper training systems and avoiding over-fertilization. Good weed control can also reduce the humidity within a crop.

Light

Light and darkness are important in regulating sporulation in fungi so that

spores are released at an optimal time. The *Phomopsis* fungus in grapes needs light to produce fruiting bodies, so they tend to occur on plant surfaces where spores are likely to be dispersed. *Alternaria* species need a period of light followed by darkness to produce spores. This ensures that the spores are mature in the morning and ready to be dispersed when the wind picks up during midday. Apothecia of the blueberry mummy berry

Humid hideout

Ecological concept

Reduce humidity to reduce disease.

Putting it into practice

Midseason leaf removal reduces *Botrytis* bunch rot in grapes.

The fungus that causes *Botrytis* bunch rot of grapes thrives in humid environments. Disease is more severe in lush canopies. Removing the leaves around grape clusters exposes them to airflow and reduces the humidity, slowing disease development. Leaf removal has other benefits, including even ripening from increased sun exposure and improved coverage by pesticides.



A. Schläpfer

fungus grow toward the light, which helps them emerge from soil and dead leaf layers on the ground. Light, unfortunately, is difficult to manipulate, except in greenhouses.

Insects are affected by light in two ways. The daily light and dark cycles determine when insects are flying, feeding and mating. Many moths are nocturnal, while bees and other insects are most active during the day and rest at night.

Insects also use day length as a signal to begin dormancy. As day length shortens in the fall, pupae that develop at this time of year are adapted to survive through the cold winter months.

Pest dispersal

Most adult insects move in search of food and sites for reproduction. They are most likely to fly at particular wind speeds and temperatures that allow successful dispersal, but they are inhibited by rain. Pathogens tend to be more passive, depending mostly on wind or rain to get from plant to plant or from field to field. Exceptions are nematodes, which can swim, and soil-borne pathogens such as *Phytophthora* and *Pythium*, which produce swimming spores. However, these can move only short distances even when there is enough soil

P. Wharton



Two swimming spores of the downy mildew fungus inside a sporangium.

moisture. Flooding and surface runoff are important in dispersing these soilborne organisms over larger areas.

There are three phases of pathogen dispersal: release (active or passive), travel (by

air or water) and deposition (by gravity, impaction or rain). Some fungi have active release mechanisms. The fungus that causes brown rot of stone fruit forcefully ejects ascospores, sometimes up to an inch, from its apothecia. Active release is frequently triggered by changes in humidity, temperature or light.

Wind can also remove spores by blowing them from plant surfaces or by shaking foliage and flowers. Wind speeds tend to be lower within the crop canopy, so gusts are thought to be important in getting spores into the air layers above the crop for dispersal over greater distances. Mummy berry shoot strikes in blueberries caused

P. Wharton

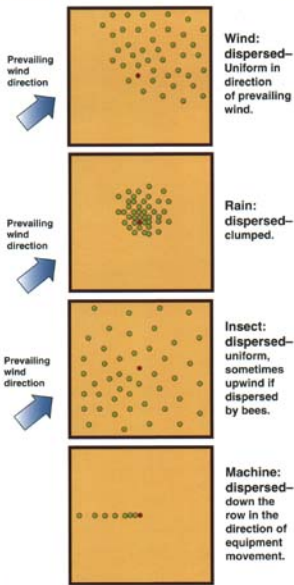


Blueberry mummyberry apothecia disperse spores by puffing them into the air.

by ascospores are typically more numerous downwind from a source. Fruit infection caused by bee-dispersed conidia tends to be more severe upwind, because bees tend to fly upwind while foraging. In some cases, soilborne pathogens can be dispersed by wind-blown soil.

Rain or overhead irrigation can splash fungal spores and bacteria from plant surfaces or wash them off in runoff water. Splash droplets can be thrown more than a meter from the point of splash, but most travel only a few centimeters. Soilborne pathogens are often dispersed by water flowing through soil.

Dispersal distances are usually smaller for rain splash-dispersed pathogens than for windborne pathogens, except in the case of wind-driven rain or splash droplets that form aerosols in the wind. Rain-dispersed pathogens also tend to spread more readily along the rows than across rows because the



How pathogens are dispersed. Disease distribution in a field varies with method of pathogen dispersal from a diseased source plant. Above, red dots indicate location of source plant; green dots indicate locations of infected plants.



After Phytoph. Soc.

distances between plants are smaller. Some pathogens use both tactics. The grape black rot fungus uses windborne ascospores produced on fruit mummies to get from the ground into the canopy. Then conidia produced on leaf lesions are splashed by rain to the developing fruit. The dispersal mechanisms of insects are similar to those of pathogens, but wind has greater impact and rain has less.

Pathogens can also be dispersed by farm equipment. For example, blueberry mechanical harvesting machines have been shown to move the blueberry aphid and the shoestring virus it transmits from infected to uninfected plants down the row. Washing the harvester between fields is a simple way to reduce transfer of this virus from field to field.

This aerial view of a blueberry field indicates that machinery spread blueberry shoestring virus down the rows.

Using weather and climate information to predict pests and diseases

We can forecast pest development using mathematical models because pest development is closely linked to weather conditions. Because of the close relationship between temperature and insect growth, crop managers can predict when many insects will be active by recording temperature data. Sometimes more than one environmental variable is needed to create an effective model. When predicting fungal infection periods, temperature, humidity and leaf wetness need to be considered. Models are designed to be simple to use but accurate at predicting pest events under most environmental conditions.

Growing degree-day models for insect information

Because insects are cold-blooded, the growth of adults, larvae and eggs is driven by temperature. As the temperature fluctuates within these limits, development speed changes, with faster growth typically occurring at warmer temperatures. For all insect pests, diseases and their

R. Isaacs



A laptop computer downloads weather data collected at a fruit farm for pest monitoring.

natural enemies, there are also low and high temperature thresholds for development.

Because temperatures may vary widely from year to year, pest management strategies may not be effective if control measures are based on calendar dates rather than on insect development. Often the stage of insect development can be tied to the growth stage of the crop because plant growth is also driven by temperature. A widely used tool for predicting insect growth is the **growing degree-day** (GDD) model. These models calculate the number of GDDs or heat units that are accumulated between the minimum (base) temperature threshold and the upper threshold. At the end of every

day, the GDD total for that day is added to the previous total to create a cumulative number of GDDs. Pest managers can use the GDD total to predict emergence, egg laying and other important events based on the amount of heat accumulated in the vineyard, field, bed or orchard.

Models have been developed that link GDDs to the stage of development of some key pests and, to a lesser extent, beneficial insects. Using a maximum-minimum thermometer, preferably placed in or near the crop, growers can track the development of insects on their farm. One degree-day is accumulated when the average temperature for a day is one degree over the lower limit (base temperature) needed for development. A base temperature for each organism is used in the calculation because very little growth occurs below the base temperature. Growth rates also are reduced when temperatures exceed the upper threshold, and so the maximum is set to this value if temperatures become hotter.

There are many sophisticated methods for estimating GDDs based on more than maximum and minimum temperatures. For example, computer programs can be used to keep

track of GDD accumulation based on hourly temperature data. However, for most uses, the method below provides sufficient ability to predict major events in insect development.

The start point for accumulating GDDs can be decided in two ways. Either GDDs are counted from a set date, such as March 1, or they are

counted from a specific biological event, called a **biofix** — the date when the first adult is captured in a pheromone or other trap, provided additional adults are captured on two successive trapping dates. This may be called the first sustained capture. Using a biofix is usually more accurate and means that the GDDs have to be counted for a shorter

period. Often optimal timing for an insecticide application is during egg hatch because this is when the insect is most vulnerable. At a set number of GDDs after biofix, sprays aimed at the pest can be applied to target the appropriate stage of the insect. For many of the apple and cherry pest insects, the number of GDDs from first

How to calculate growing degree days

To calculate the number of GDDs accumulated per day, you need to know:

- 1) The upper threshold temperature (T_{high}) and lower threshold (T_{low}) for development of the organism you are interested in.
- 2) The minimum daily temperature.
- 3) The maximum daily temperature.

The method below enables easy tracking of GDDs with a simple max-min thermometer.

The following examples are for an insect with a lower threshold of 42 and an upper threshold of 86. When this method is used for other insects, their threshold values should be used in the equations.

Growing degree days (GDD) = $(T_{max} + T_{min})/2 - T_{low}$

Where **T_{max}** is maximum daily temperature and is set to the upper threshold when temperatures exceed it. **T_{min}** is the minimum daily temperature and is set to **T_{low}** when temperatures fall below this value. **T_{low}** is the base temperature for the insect.

1. Temperatures within insect's development thresholds.

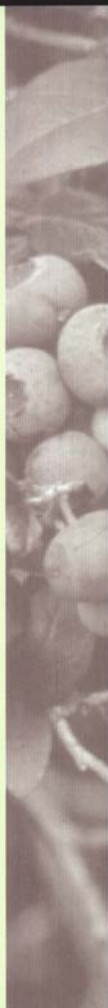
A day with a low of 50° and a high of 78°: $(78+50)/2 - 42 = 22$ GDD

2. Temperature drops below insect's lower threshold.

A day with a low of 30° and a high of 70°: $(70+42)/2 - 42 = 14$ GDD

3. Temperature goes outside both the higher and lower thresholds.

A day with a low of 28° and a high of 88°: $(86+42)/2 - 42 = 22$ GDD



sustained catch to egg hatch is well known. Keeping track of the number of GDDs after biofix makes it possible to determine the optimal timing for control measures. It is therefore important to check traps often near the start of adult emergence.

Above all, remember that degree-day accumulations should be used only as a guide for making management decisions. Ultimate decisions should also be based heavily on frequent scouting of the crop for the presence of insects or insect damage.

Disease prediction models

Disease prediction models usually predict one or more critical phases in epidemic development, such as the presence of primary or secondary inoculum or an infection period. **Infection periods** are times when the minimum environmental conditions have been met for infection to take place. Environmental data such as temperature, relative humidity and leaf wetness are typically needed to run disease prediction models. Research in Michigan

GDDs are better than a Ph.D. for controlling this pest

Ecological concept

Temperature is a major driver of insect growth.

Putting it into practice

Use a degree-day model to time codling moth sprays.

The codling moth is the key pest of pome fruits in most parts of the world. For over 15 years, a degree-day model based on maximum and minimum temperatures has been used to help time insecticide sprays for this pest. The lower and upper thresholds for codling moth are 50°F and 88°F. The codling moth degree-day model begins with the first consistent catch of moths in pheromone traps (biofix). The degree-day total is set to zero at this time. Control sprays are applied in accordance with biological events that are predicted by the model. Broad-spectrum contact insecticides are timed for control of young larvae as they hatch from eggs and before they enter the fruit. So, the first spray is applied at the predicted start of egg hatch, which is 250 GDDs after biofix. Egg hatch for the second generation of codling



ARS, USDA

moth is predicted to occur around 1200 to 1250 GDDs after biofix. The model predicts many other key biological

events, such as the end of first and second generation activity, which are expected at 1000 and 2100 GDD, respectively.

Use of a degree-day model can substantially improve the timing of insecticides for codling moth control. Researchers at Washington State University compared the accuracy of the degree-day model and a calendar approach for predicting first egg hatch or fruit entry in apple. In each of 10 years, the degree-day model predicted larval entry within two days of the actual event. In contrast, the calendar approach predicted egg hatch on average a week early, and in three of 10 years, it was off by two weeks. Applying an insecticide well before egg hatch can result in poor codling moth control and increase the number of sprays required for season-long protection.

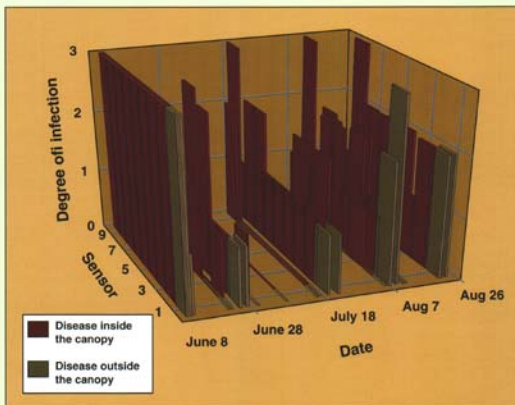
indicates that leaf wetness can vary significantly over short distances and heights in a crop, especially late in the growing season when the canopy is most dense. The use of models, such as for apple scab, that predict disease severity on the basis of leaf wetness may be complicated by the variations in microclimate. For models that predict infection periods, fungicides are generally applied "after the fact," which means that growers have to use curative, systemic fungicides. Models and curative fungicides are not available for all diseases. Most models are based on current or past weather data but can also be run using predicted weather data. Those based on predictions, however, are less accurate.

Predicting apple scab infection periods

Springtime means scab season for apple growers in moist, temperate climates. Researchers have developed several apple scab prediction models that help growers use fungicides more efficiently. These models are focused on two key events in the life cycle of the scab pathogen: maturation and discharge of ascospores, and infection by ascospores and conidia.

Because temperature primarily determines when ascospores mature, models rely on the accumulation of GDDs. The counting of GDDs for apple scab prediction generally starts at the green-tip stage of apple fruit bud development because the first mature ascospores and bud break happen at about the same time. Ascospore maturation usually peaks just prior to bloom. Of course, mature ascospores are a threat only if they are discharged, and this requires rain. Heavy dew can trigger discharge but not as effectively as rain.

In practice, most apple scab prediction systems assume that inoculum is present in the orchard and focus on predicting infection. The leaf microclimate — in particular, temperature and duration of wetness — is monitored. If the temperature and wetness conditions required for infection are met, an "infection period" has occurred. Following an infection period, a grower can prevent further fungal growth and disease development by applying a curative fungicide with postinfection or "kickback" activity.



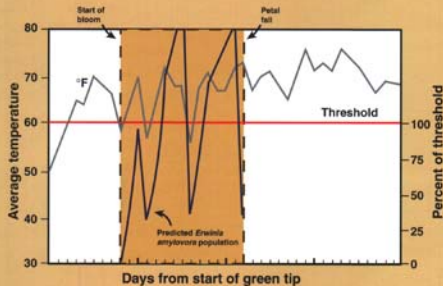
Predicted degree of apple scab infection at nine locations within a Benton Harbor, Mich., apple orchard (2000 growing season). Disease predictions were calculated from leaf wetness measurements using the Mills table as modified by Jones (see page 66).

Predicting fire blight infection

Several fire blight prediction models have been developed to help apple and pear growers manage this potentially catastrophic disease. None of the models actually involves trapping and counting the fire blight pathogen, *Erwinia amylovora*, in the manner done for insect pest models. Instead, the population is estimated from cumulative heat units: degree-hours and degree-days. Growth of the pathogen on flowers and subsequent infection that leads to blossom blight are key stages in the disease cycle. Even if blossom blight causes little direct damage or yield loss, it allows the pathogen to become established in apple and pear trees.

How could long-term climate change affect pest management?

The climate across the Great Lakes region during the next several decades is projected to become warmer and wetter, so scientists are beginning to explore what this means for pest management. While potential direct impacts of climate change on crop yield and carbon dioxide enrichment have been explored, few studies have addressed the indirect impacts such as



In the MARYBLYT predictive model for fire blight, the risk of blossom infection is based on the occurrence of high pathogen populations on plant surfaces during bloom when rain or dew is sufficient to facilitate infection. In the accompanying graph, the horizontal red line represents the threshold above which there is a risk of infection. The golden-shaded zone marks the risk period, beginning with first bloom and ending with petal fall. The gray line shows the average daily temperature. The blue line represents the predicted population of *E. amylovora* on the basis of cumulative degree-hours and degree-days. The dramatic spikes and dips reflect the explosive growth of the pathogen during warm weather and stalled growth in cool weather. Blossom infections are predicted when the gray line and the blue line are above threshold and there is rain or dew. (Figure adapted from MARYBLYT user's manual.)

changes in pest pressure that could be of equal or greater importance to crop performance and management options.

One study has examined the potential impacts of a warmer climate on Great Lakes apple production by looking at codling moth data. In this research, the life cycle of the pest and the apple crop were simulated using seasonal

growing degree-day totals and daily temperature data under historical and projected conditions. Temperature data for the decade 2090-99 were taken from a model that predicts future climate conditions. In the table, the results are given at five locations across the region comparing differences between the recent and future decades. Seasonal GDD

accumulations were predicted to increase as much as 648 units over past totals, an increase of 25 percent. The warmer seasonal conditions would result in an increased number of codling moth generations at most locations. Under this future scenario, new management strategies to control the third generation of codling moth close to harvest would need to be available.

Influence of surrounding landscapes on pest management

Rufus Isaacs, Nikhil Mallampalli, Larry J. Gut, Annemiek C. Schilder, Patricia S. McManus

In referring to fruit crops, we often speak of the orchard, vineyard, bed or field. Management decisions are

commonly based on the area inside these crop borders. However, fruit crops exist within larger ecosystems that can be described as local, regional, continental or global. These ecological units can significantly affect the productivity of the crops within them. Of the larger ecological scales, the immediate landscape and the region are the most relevant for planning pest management strategies. In this context, one can think of the landscape as

Potential climate change effects on codling moth

Simulated impacts of climate change on the number of codling moth generations for historical (1960-89) and projected future (2090-99) periods. The future conditions were generated using a general circulation model, the UKMO/Hadley Centre Model. The changes are expressed as differences between the projected future climate and historical conditions.

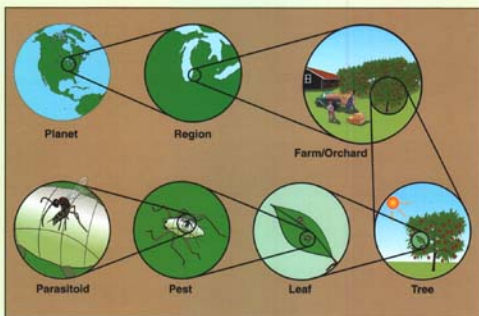
Parameter	Scenario	Sturgeon Bay, Wisconsin	E. Jordan, Michigan	Eau Claire, Michigan	Harrow, Ontario	Fredonia, New York
Seasonal GDD accumulation ¹	1960-89	2176	2162	2786	2644	2561
	2090-99	2622	2659	3241	3260	3209
GDD increase		+446	+497	+455	+616	+648
Number of generations per season	1960-89	2	2	3	3	2
	2090-99	2.5	3	3	3	3
Increase in generations		+0.5	+1	+0	+0	+1

¹Seasonal GDD totals were calculated using the Baskerville-Emin methodology for base and upper threshold temperatures of 50°F and 88°F, respectively, and accumulated each year from March 1 through the simulated beginning of insect diapause during the following fall.

being the area immediately surrounding the crop. By understanding the influence of landscape-level and regional effects on the community of organisms within fruit crops, growers can tailor pest management decisions to the ecology of the larger system.

insects, such as Japanese beetle on sassafras, that then move to the fruit crop. Weed seeds can be carried into the crop from surrounding habitats by wind and animals. Neighboring woods and windbreaks may promote disease development by

predatory insects and mites. Predatory animals such as foxes and hawks may gain shelter in woods and can help to keep vertebrate pests under control. Living hedgerow barriers can reduce immigration of pests into orchards. Recent studies in Michigan peach and apple production systems revealed that barriers around the orchard perimeter reduced the number of aphids and moths moving into orchards. In addition, treating the outside hedgerow barrier with repellents or low rates of insecticides may repel or irritate many pest species that frequently invade orchards from outside sources. The challenge for guardians of rural lands is to



Positive and negative effects

Surrounding landscapes have both positive and negative impacts on pest management in crops. Negative impacts may involve a disease or insect pest moving into a crop from wild hosts in surrounding woods. For example, chokecherries in surrounding woods can harbor X-disease, which can be brought into a peach or cherry orchard by various species of leafhoppers. Some plants may also be attractive hosts for

reducing airflow and increasing humidity in the crop or by creating shade that promotes leaf wetness. Vertebrate pests such as deer, raccoons and fruit-feeding birds can seek shelter in woods.

On the positive side, surrounding habitats can shelter crops from wind, greatly reducing the risk of crop damage during storms. They can act as refuges for predators, pollinators and parasites, and may provide pollen that acts as a nutritional resource for some



This strawberry field flourishes beside some pines.

balance these positive and negative impacts of surrounding habitats on their fruit production while maintaining a profitable business.

Managing local landscape effects

The overall ecology of fruit crop systems is most often affected by what happens within the landscape nearest the crop. Many landscape effects happen at predictable times in the growing season and so are more manageable for the fruit grower. Some pest insects and diseases develop on weed hosts early in the season and then move into the crop as it matures. Such interactions can be managed by enhancing biological control activity in the weed host habitats, by removing weed hosts where possible and by planting appropriate cover crops. In addition, pest movement into the crop from wild habitats can often be predicted, and appropriate controls can be planned to target their most susceptible stage if they do move into the crop.

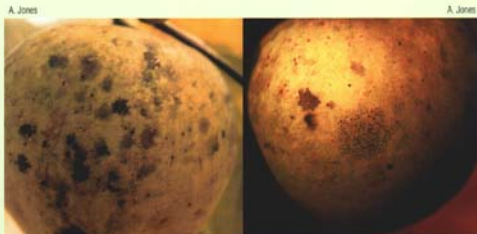
Flyspeck and sooty blotch are two diseases that often occur together on commercial apple and pear fruit. The fungus that causes flyspeck and the multiple fungi that cause sooty

blotch inhabit diverse woody plants, especially brambles. During spring rains, spores are blown into orchards from adjacent forests, woodlots and hedgerows. Growers who use protectant fungicides in early cover spray programs to manage scab will also reduce primary infection by the flyspeck/sooty blotch pathogens. However, if primary infections are not controlled, disease pressure will increase from inoculum in wild reservoirs and within the orchard in mid-to late summer. It is not practical to destroy all wild hosts of flyspeck/sooty blotch, but it would be wise to remove bramble species adjacent to commercial apple and pear plantings to reduce the risk of flyspeck problems.

Enhancing biological control through habitat management

Biological control, also called biocontrol, can be a powerful tool that growers can harness to keep pests from reaching economic thresholds. As Carl Huffaker, one of the founders of insect biocontrol studies, once said, "When we kill off the natural enemies of a pest, we inherit their work."

Maintaining an active population of beneficial organisms in a fruit crop requires some planning because broad-spectrum insecticides and fungicides are generally quite toxic to them. Choosing pesticides with more selective modes of action is a first step, but biocontrol agents will be more effective if overwintering habitat is also provided. Placing appropriate host plants near a crop for parasitoid overwintering means



The fungi that cause sooty blotch and flyspeck on apples inhabit brambles and other woody plants.

Waifs from the woods

Ecology Concept

Pests move from native hosts to agricultural crops.

Putting it into Practice

Target controls only to areas where pest is present.

Wild grape plants are common in woods throughout eastern North America and are the only wild host for grape berry moths. Vineyards planted near woods are at high risk from this pest, and damage is usually greatest at the vineyard edge next to woods.

To combat this pest and to determine whether vines are most at risk at the edge, grape growers can monitor for grape berry moths using pheromone traps and by sampling fruit during key times in July and August. This information can be used to decide whether management is necessary and if spraying only the vineyard border is possible. Determining that damage is limited to the border rows can help save on the cost and time of treating the whole vineyard. Targeted spraying can also have a positive effect on the activity of natural enemies that attack grape berry moth larvae.



R. Isaacs

more wasp and fly parasitoids will be available in the spring to decrease pest populations. These alternative habitats need to be close to the crop for maximum benefit because most parasitoids are not strong fliers.

A well documented example is that of parasitic wasps that attack the grape leafhopper in California vineyards. These wasps overwinter in prune trees, which are often not present near vineyards. Planting vineyard borders with French prune trees improved

overwintering success of these natural enemies, increasing early-season parasitism of leafhopper eggs.

Planting appropriate ground cover in or around a fruit crop can also enhance natural enemy abundance and success. For example, in apple orchards, using buckwheat or faba bean as a ground cover has been shown to increase the number of parasitoids attacking leafrollers. In other orchard studies, border plantings of flowering cover crops such as barley, rye and common vetch provided additional nectar, allowing beneficial insects such as ladybird beetles, lacewings and syrphid flies to flourish near fruit crops throughout the growing season.

Some benefits of cover crops

Planting cover crops provides many benefits to a fruit grower if they are used appropriately. Fertilizer costs can be reduced, fewer pesticides may be needed, and the health of the soil can be improved. The lower levels of soil erosion compared with bare ground and the improvement in moisture retention under cover crops can help minimize the impact of fruit production on the ecosystem. Cover crops can help reduce pests by creating



In the foreground, a ground cover of white and red clover, alfalfa and rye surrounds tart cherry trees.

an unfavorable habitat, such as marigolds for nematode suppression, or by increasing the activity of natural enemies with flowering plants. Many insect natural enemies require pollen or nectar to survive, and this resource can be scarce in some crop monocultures.

Providing a ground cover that supplies these resources means that natural enemies can survive periods when pests are scarce so that pests can be attacked when they are present.

The suitability of a cover crop for the field and crop needs to be determined before planting. For example, some plant species are tolerant of acid soils or shade, while others will not establish in these conditions. Some cover crops may enhance the habitat for pests, but this can be offset by increased abundance and diversity of natural enemies. We are only beginning to understand how to integrate cover crops into fruit

production systems. Current research conducted in Michigan cherry, apple and blueberry plantings aims to better understand the complex

effects of ground cover management on pest and beneficial insects and the productivity of fruit systems.

Long-range insect and pathogen movement

Most insects can fly short to medium distances, but some pests travel hundreds or even thousands of miles on strong winds. Much less is known about the long-range transport of beneficials, although they have been found at great heights. Winds generally increase in strength with height in the atmosphere, and most long-range transport occurs at heights above 3,000 feet.

A fix for what's bugging you

Ecological concept

Non-crop habitats influence pest abundance.

Putting it into practice

Manipulate ground cover to reduce tarnished plant bug numbers.

The tarnished plant bug is a general feeder found on many herbaceous plants. Among the preferred hosts are mullein, alfalfa, clover, vetch, chickweed and dandelion. Only adults are found on fruit crops, attacking buds, flowers and fruit. Because of the intimate link with alternate



A. Howell

hosts in the orchard floor, adult activity and fruit injury within the tree are often influenced by ground cover management.

High populations of tarnished plant bug usually occur in orchards where flowering broadleaf weeds are abundant. Eliminating these hosts through good weed control is an effective tactic for minimizing this pest's abundance and damage. Careful selection of an orchard ground cover can aid in reducing tarnished plant bug problems. Choose grasses that are highly competitive and minimize the establishment of broadleaf weeds.

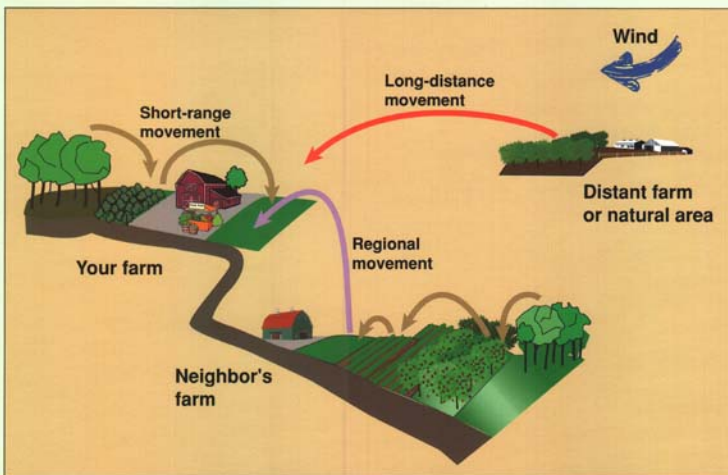
Insects may reach the higher, stronger winds through flight or be lifted by turbulent winds during daytime hours. Viruses may hitch a ride with vector insects that travel on prevailing winds. Fungal spores of some species have been detected in the atmosphere at heights of 1,500 to 3,000 feet and also have the potential to be dispersed over long distances.

The likelihood of long-range transport increases with turbulence and the frequency of frontal passages. Precipitation can pull the organisms out

of the atmosphere and back to the ground. Otherwise, they return to the surface by choice (as when detecting a potential host species on the ground), by gravity or by fatigue.

A well studied example of long-range movement of insects is the potato leafhopper, a pest of most fruit crops in the Midwest. In spring, it develops on pines and then on legumes in the southern states. When sufficient energy reserves are built up, large populations can take flight on winds headed north. The leafhoppers are

carried northward up the Mississippi Valley, and when the winds decrease or precipitation knocks the leafhoppers from the air, they are deposited onto the ground. These storms can lead to a sudden increase in the number of leafhoppers in fruit and other crops. The potato leafhopper damages plants as it feeds, creating "hopper-burn" from the toxins in its saliva. It can also transmit virus diseases of fruit crops.



Pests and beneficial organisms can arrive at a farm by moving from nearby or distant fields and natural areas. Understanding how movement of various pests is influenced by weather conditions enables growers to plan appropriate monitoring and management.

Frequent fliers

Ecological concept

Insects can migrate over long distances.

Putting it into practice

Monitor for potato leafhopper when spring weather conditions are appropriate for their arrival.

By regularly monitoring susceptible fruit crops after spring storms, growers can determine when potato leafhopper has arrived. From then on, frequent monitoring and pest management tactics can be directed toward maintaining the population below an economic threshold.



Cloudbursts such as the one pictured can deposit huge numbers of leafhoppers and other airborne pests onto fruit crops.

Chapter 3. The human setting

Chapter questions

- How can ecological management offer fruit growers special marketing opportunities?
- How can non-farm neighbors become valued customers and allies of farming?
- How can a grower attract and retain the skilled workers needed for ecological fruit management?

Fruit growers operate within a human setting that affects their production choices as much as the natural setting. The human setting begins with the grower

and extends to the families and employees on whom growers rely, the communities where fruit is grown, distributors and processors who establish intermediate markets, the consumers who buy the fruit and the diners who eat it. The human setting also includes the organizations that research and advise on all these stages from farm to table, as well as the government agencies that regulate various aspects of growing and processing fruit. To fruit growers interested in ecological management, this setting offers special challenges as well as special opportunities.

Production and marketing strategy: How best to grow fruit depends upon who will buy it

Scott Swinton, Michelle Worosz, Craig Harris, Vera Bitsch, James Nugent and Larry Mawby

In the supermarket produce department, large, perfect, individual apples sell for double the price of the medium-sized bagged apples across the aisle. Organic apples sell for even more. The first price difference arises because most consumers prefer large, good-looking fruit to smaller, less striking fruit. The organic apples attract a still higher premium from consumers who perceive them as a healthier choice.

The growers who produce the three classes of apples follow different marketing strategies. The bagged apples are a **commodity** and cost the least to produce. To make a profit,

A. Schäfer



their growers keep costs as low as possible while meeting grade standards. The large, perfect apples are a **broad market value-added** product that requires more effort and cost to produce. Their growers' strategy is to attract a higher price by offering extra features that certain consumers desire. The organic apples are a **niche market value-added** product that appeals to consumers with distinct preferences. Organic growers aim to earn a higher price by catering to those preferences.

The same marketing strategies are open to fruit growers who produce for the processed

market. Many value-added features are added in processing, but some originate on the farm. Labels and brands provide a way for value-added producers to make sure consumers perceive benefits that might otherwise be invisible. The accompanying table illustrates a spectrum of farmer marketing strategies for fresh and processed fruits.

Think about fruit consumers. Some care most about health while others focus more on feeding a big group for as little money as possible. Market researchers have identified the traits that most consumers care about in food. They include:

- Health and nutrition.
- Convenience.
- Flavor and texture.
- Appearance.
- Cost.

Notice the first four traits are all perceived benefits. Although various customers view benefits differently, cost matters to almost everyone. How a consumer views "value" is a balance between perceived benefits and cost:

$$\text{Consumer Value} = \frac{\text{Perceived Benefits}}{\text{Cost}}$$

There are two ways to increase consumer value. Producers who follow a value-added

Examples of fruit marketing strategies

Level of processing	Commodity	Value-added		
		Broad market		Niche market
		On-farm value	Off-farm value	
Fresh	Bagged fruit Tray pack fruit in bulk display Best-seller varieties Food service fruit (e.g., for school lunches)	Gift baskets Eco-label fruit	Supermarket fresh-cut fruit	Farm & farmers' markets Organic-labeled fruit U-pick orchards "Agritainment" Heritage varieties
Processed	Juices and sauces: • Supermarket brand • Processor brand Slices for industrial canning, freezing and baking	IPM-label canned fruit Estate-bottled wine Baked goods Jams and jellies	"Nutraceutical" pills Recognized brands Fruit-filled baked goods	Organic dried and canned fruits and juices Farm-processed for farm market sale Canned baby food Kosher products Family-farm-produced

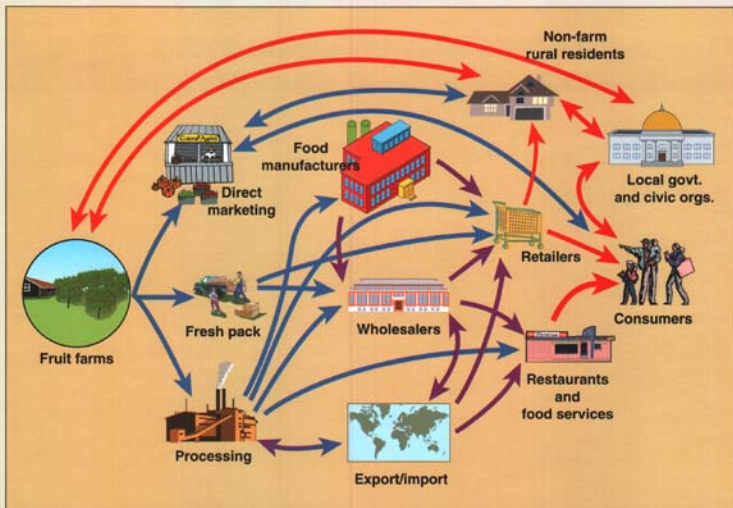
strategy will focus on increasing the perceived benefits. Those who follow a commodity strategy will focus on reducing cost.

Most growers who want to make ecological management pay will want to follow a value-added strategy. Who are the kinds of consumers who appreciate fruit grown under ecological management? Where do they buy food? How does a grower reach them and make sure they perceive the benefits that the grower is offering? Will they pay extra for fruit that costs more to grow?

Consumers buy fruit in various ways. The diagram below illustrates the channels by which fruit products flow to consumers, as well as other important links in the human ecology of the fruit system. In 1997, U.S. consumers purchased more than 98 percent of fresh produce from retail stores, restaurants or institutional food services. Only 2 percent was directly marketed from farmer to consumer. Consumers who care about family farming or lower pesticide residues are more likely to buy at direct markets, food co-ops and

vegetarian restaurants than are other types of consumers. But even the "green" consumers do the majority of their shopping at supermarkets. Many supermarkets now designate and publicize fruit that has been produced in environmentally friendly ways.

A striking change from the mid-1900s is that consumers now spend more on food bought through institutional channels such as food services and restaurants than from retail stores such as supermarkets. Yet these institutions rarely buy fruit directly from growers.



Linkages in fruit distribution and social networks.

A 1997 Food Marketing Institute study of U.S. food consumers found that more than half are "environmentally concerned," but fewer than 10 percent would pay extra for environmentally friendly food. Although "green" consumers still represent a niche in the overall food market, this is changing rapidly. In the decade since the 1990 Organic Foods Production Act, retail sales of organic foods and beverages in the United States rose at a compounded annual growth rate of 23 percent. More than 40 percent of the organic foods market is fresh produce. Juices and processed fruits further expand that share of the market. Just as pizza moved from an urban niche market 40 years ago to a broad market food today, so could fruit produced under ecologically based management, including organic.

Growers who want to market ecologically produced fruit must find a way to reach the consumers who care to buy it. Apart from direct marketing, other strategies include direct contracting for seasonal sales with supermarket or restaurant outlets or sales to specialty processors and food manufacturers. Though costly and far from easily done, farmer cooperatives have



successfully established national brands to win recognition of their value-added products. Some have even arranged with producers in other areas to provide a year-round supply of fruit to supermarket clients.

New demands are emerging for ecologically produced fruit marketed through packers and supermarket chain buyers. Particularly in Europe, supermarkets are increasingly requiring "traceability." Traceability refers to the ability to trace a fruit back to the field or orchard where it was grown and to certify how it was grown and handled. Ecological fruit farmers use the right production practices to reach these markets. But ecological practices alone are not enough. Buyers also make stringent demands for computerized record keeping that ensures traceability for each fruit. Developing such an information system can represent a major investment.

First, growers need to be certified, indicating that their production practices meet the requirements for a special label, sometimes referred to as an eco-label or green label. These labels may certify that integrated pest management practices were followed, or that the fruit was produced on a family farm. As of 2002, a major new certification label is "USDA Organic". Market research on apples has shown that consumers recognize the organic label more readily than any other eco-label.



To display the USDA seal, organically produced products must have been produced and handled by operations certified by a USDA-accredited certifying agent.

Participating in an eco-label program has the advantage that a third-party organization does the certifying, so the grower does not need to invest in establishing a brand. Being certified does not assure higher prices for the fruit, but it sometimes opens doors to retailers who demand eco-labels. For both fresh and processed fruit products, an eco-label may offer a useful way of distinguishing fruit grown under special management practices.

The right marketing strategy is a key part of making ecologically based fruit production work, but consumers and food marketers are not the only important parts of the human setting. Just as the natural ecology of an orchard, vineyard or field depends on the local community, so does the human ecology.

Community relations: Getting along with the neighbors

Michelle Worosz, Scott Swinton, Vera Bitsch, Craig Harris, James Nugent and Larry Mawby

Non-farm neighbors are becoming the norm for most fruit growers. Farm households now make up less than 2 percent of the U.S. population. Even in rural areas, farm families now account for only 9 percent of the people. Living cheek-by-jowl with non-farm neighbors, ecologically oriented fruit growers may be better placed than conventional growers to develop friendly ties.

The same Great Lakes waters that moderate the climate for fruit production also attract people seeking recreation and natural beauty. Many tourists and neighbors find fruit production picturesque. They like to see rolling orchards in bloom or heavy with colorful fruit. They enjoy access to U-pick operations, on-farm stores and stands, and wine tasting rooms. Many who enjoy vacationing eventually buy a piece of land, increasing land prices and becoming permanent neighbors of local farmers.

Tourists and non-agricultural neighbors may also be concerned about growers' production practices. They worry about noise late at night or early in the morning from air blast sprayers. They see pesticide applications and wonder about the possibility of drift and environmental contamination. They may worry about transient migrants being attracted to the community as laborers. Ecologically oriented fruit producers can turn what may look like a lemon into lemonade by finding productive ways to engage their non-farm neighbors.



Lake Michigan is appealing to both these homeowners and the cherry grower whose orchard borders their homes.

Working with local governments and other community groups

Many concerns about farming practices get played out in local and county governments. Getting involved in local government can make a difference. Although local governments may have no official authority over agricultural production practices, their decisions about zoning, road maintenance and similar issues may directly affect the welfare of fruit producers.

Both through their participation in local governance and through their involvement in non-government activities, fruit growers contribute to shaping the development of their communities. Religious groups, community groups and schools create opportunities for fruit growers and their employees to share ideas with other rural residents about values, community and education. Growers can also meet with one another to discuss innovative solutions to problems.

Grower outreach

Many sources of friction between non-farm residents and fruit farmers occur when neighbors know little about farming. They may not grasp

how a farm family views property rights or how some farm operations are carried out. Ecologically oriented fruit farmers have a reassuring message for non-farmers, so connecting with them is important.

The most direct way to reach out to non-farmers is to bring them to the farm. Roadside stands or U-pick operations are in a good position to fill this need. One of the keys to

successful outreach is to make it fun, packaging education into "agritainment." Farms engaged in community-supported agriculture (CSA) are especially well placed for outreach because they often have community members contributing labor to the farm as well as paying in advance for shares of the harvest.

Fruit growers who produce only for the wholesale market can also find ways to teach others

C. Edison



R. Isaacs



Many people are curious about farming and can appreciate principled efforts to manage farms ecologically. To grasp how a fruit farm fits into the local ecosystem may come as a pleasant surprise. Many non-farmers are learning that ecosystem services from fruit farms stretch far beyond bees and pollination. There is a whole new world of habitat for beneficial insects and ways to reinforce crops' natural defenses against plant diseases. Above left, a hawk house is installed to encourage hawks that will deter small, fruit-eating birds. At right, a lady beetle searches for prey on a pear bloom.

about agricultural production. One grower produced a video that was shown to local service organizations; others offer school tours and speak to various groups about farming. Working together, growers can use brochures, Web sites and other resources developed by farm organizations and commodity groups to educate the public about how farms work.

Farmland protection

Another stress on community relations occurs when an influx of non-farm residents causes land values to rise. Higher land values often mean higher taxes, which can overwhelm a farmer's budget. This pressure is less acute in states with laws that tax agricultural land based on the agricultural value.

Rising land values can endanger fruit farms, but they also create opportunities. Higher prices raise the value of the land asset on a farmer's balance sheet. This increase creates new borrowing capacity, which can facilitate new investments. New investments

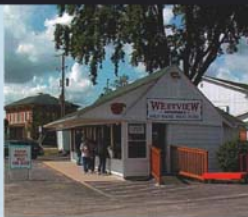
Farming and marketing on the urban fringe

Until the late 1990s, there were nine fruit farms along Van Dyke Road in Romeo, Michigan, just north of the metro Detroit area. By 2001, there were six. One of those remaining is Westview Orchards, which has been operated continuously by one family since 1813. Keeping Westview viable has called for savvy marketing, consumer education and political activism.

Current owner-operators Abby Jacobson and her sister, Katrina Schumacher, have succeeded by parrying the threats and seizing the opportunities of farming on the urban fringe. Amid expanding suburbs, Westview Orchards is in closer and closer contact with non-farm neighbors. These neighbors are sometimes uncomfortable with farming practices, but they are potential customers, political supporters and friends.

Direct marketing

"We are not just growers, we're marketers," Abby says. "I love to work with the customers; my favorite spot is in the market." The farm market that Westview Orchards opened in 1930 is now open nearly every day from July to the end of March. Besides fruits and vegetables, it sells a variety of value-added products



J. Landis

including pies, apple bread, cherry-apple and peach-apple cider, and donuts, all of them advertised on its Web site.

"Agritainment," however, has become central to the marketing operation — "It's the only way we can make it in this area." Visitors are treated to a wide variety of activities designed to create what Westview's Web site calls "Fond Family Memories." Westview has a U-pick operation that starts early in the summer with cherries, moves on to peaches, plums, pears and vegetables, and ends with apples and pumpkins in the fall. The new cider mill is in full swing from Labor Day through the end of October. During the late summer and early fall, children can enjoy a wide variety of activities including hayrides, a play area, a farm animal petting zoo, a corn maze and a restored 1869 schoolhouse.

Farming and marketing on the urban fringe (cont.)

Direct farm marketing is not easy. "It's a challenge...and growers must be sensitive to needs and concerns of the consumer about their food." Abby observes customer buying habits and notes that they see the size and color of the produce first; next they inspect it for blemishes and firmness. For produce to look attractive, Westview must keep insect and disease damage at bay.

Ensuring that fruit and vegetables look attractive is a challenge, and it is doubly difficult as consumer tastes move away from some of the more disease-resistant fruit varieties. Westview Orchards uses ecological pest management methods that include responsible use of pesticides. Abby notes, "Customers do ask about pesticides, and they need to be taken seriously."

Educating consumers and neighbors

To consumer inquiries about pesticide use, neighbors add concerns about pesticide drift and early morning spraying. Abby finds that many customers and neighbors know little about farming and may doubt farmers' commitment to responsible



The restored Sikes School takes visitors back to the early 1900s with authentic school desks, slate boards, old school books and antique items commonly found on early 20th century farms and homes. Westview Orchards' "school marm" greets school children and talks about modern orchard operations.

environmental stewardship. "It's important that they understand what it takes to produce a high quality product. We must take care of the environment, that's how we make our living. Otherwise it's not going to take care of us, or future generations." To communicate this message, Westview provides school and group tours to teach people about scientific farming practices, including ecological pest management. They show visitors that fewer and fewer pesticides are being used and those pesticides that they must use are safer products. The goal

is to find fun ways to educate both students and the public about the relationship between growing food and consuming it.

But faced with rapid suburbanization, the family believes that education alone is not enough to protect the future of Westview Orchards.

Political engagement

Abby has served on the local planning board for two decades and has attended the board of review, which assesses property taxes. Being politically involved gives her opportunities both to explain farming and to learn early about other residents' concerns about it.

Political engagement does not end at the township line. As a grower, Abby has served on the Michigan Apple Committee and the Michigan Apple Research Committee. She currently serves on the boards of the Michigan Agricultural Cooperative Marketing Association and the Michigan State Horticultural Society. Working with these groups has shown her how the larger industry operates, letting her learn from other growers as she helps to shape the future of the industry.

could be on the farm, perhaps to try out an ecological management practice or to plant a new crop or variety, capitalizing on a potentially favorable market niche. Or the investments could be off the farm, in cooperatively owned processing facilities or establishing a brand for ecological management. Where land is rapidly being

transformed to non-farm uses, fruit growers have successfully partnered with non-farm neighbors who also care to protect farmland. Such alliances led to the purchase of development rights in Old Mission Peninsula of northwestern Michigan, an approach that has been repeated elsewhere.

Several non-profit organizations also work toward land trusts and conservation easements, all of which curtail development and help to preserve farmland. The accompanying table identifies successful producer strategies for addressing a variety of concerns from the non-farming public.

Public concerns about fruit production

Public concerns	Relevance to fruit production	Conflict reduction strategies	Comments
Pesticide residue on fruit or contamination of the environment	<ul style="list-style-type: none"> • Pesticides are often needed to meet quality standards • Legislation restricting pesticide use may increase 	<ul style="list-style-type: none"> • Production demonstrations • Participation in environmental stewardship programs 	<p>The average consumer is unaware of:</p> <ul style="list-style-type: none"> • Basic production practices • Regulations that growers follow • Production costs in relationship to market prices
Roadside pesticide warning signs	Increase public awareness and possibly concerns about pesticide use	Few options — the law requires worker protection signage	Signs aim to limit <i>worker</i> exposure to pesticides rather than protect the general public
Night noise	Use of sprayers at night reduces pesticide drift	<ul style="list-style-type: none"> • IPM tours • Lectures • Production videos 	Neighbors may not realize that night spraying minimizes pesticide drift
Retaining rustic agricultural view	Grower access to suitable fruit-producing sites	Participation in land use community organizations	Cooperation with non-farm residents can protect their views and growers' access to land

Human resources: You can't raise fruit alone

*Vera Bitsch, Scott Swinton,
Michelle Worosz, Craig Harris,
James Nugent and
Larry Mawby*

Farm employees and consultants form another important part of the community setting. These people contribute the added labor and skills a farmer needs to produce good fruit. Ecologically based fruit management calls for special skills. Finding and retaining good employees is key to any business. Turning a farm business into an attractive place to work requires getting the whole human system working in harmony — very much like the ecological management of an orchard, field or vineyard. A farm known in its community and that of its employees as an extraordinary workplace is likely to have local support, including a secure workforce for the future.

Few fruit farmers today can completely rely on the local workforce, especially those growers who have a short period to harvest a large and

delicate crop. Most temporary fruit workers travel from outside county lines. Because they are away from home, many of these workers need housing, which must comply with state and national regulations.

Cultural backgrounds of these fruit farm workers are changing. Growing shares of them are Spanish speakers. Farmers may view these workers as different because of their culture or language. But on farms that successfully attract the same employees year after year, the managers recognize that respect and fair

treatment matter as much as appropriate compensation.

Employees want to be proud of their place of work. When they wear their farm's cap into town, they like to see people nod with approval. Their employer's good reputation makes a difference. It is likely that they will talk about their positive experience and will return next year.



S. Deming



A. Schlier

Employees in the orchards and neighbors all around

Ann and Don Gregory live in the center of Cherry Bay Orchards, surrounded by 800 acres of tart cherries, 200 acres of sweet cherries, 400 acres of apples and another 350 acres of non-bearing trees. With that much fruit,

they rely heavily on farm employees. Amid the surging population of northwestern Michigan, they also come into contact with plenty of neighbors and tourists. So people are a big part of keeping Cherry Bay Orchards a commercial success.

Keeping satisfied employees

Cherry Bay Orchards employs 13 workers year-round and about 50 temporary workers for summer harvest. Their key employees have been on staff for more than 10 years. Don Gregory explains: "We view ourselves as a team.... We don't tell them how to do their job. We tell them what



has to be done. Then we help them find an efficient way to do it."

The Gregorys' guiding principles are to be sincere, to communicate and to be flexible. Both full-time and temporary workers are involved in regular staff meetings. Flexibility is important to many employees, and the Gregorys seek to accommodate needs for childcare, attending school functions and recreation. One area in which they are not flexible is safety. "The one good reason for firing someone," Don says, "is a safety violation." Safety bonuses paid in cash reward careful employees.

Cherry Bay Orchards offers an employee stock ownership plan (ESOP) for all year-round employees and some temporary staff. "An ownership attitude is the key to success in farming," Don observes. "The

ESOP is a big motivator, giving employees a sense that 'what I do makes a difference.'" It works like a retirement plan, but the funds accrued can also be used for major life expenses such as a down payment on a house. As "owners," the ESOP members are expected to attend and participate in regular meetings. Apart from the ESOP, employees also receive year-end bonuses, profit sharing and basic healthcare coverage.

Cherry Bay Orchards also views employee training and development as part of its mission. It supports training for pesticide applicator certification and English language proficiency.

Employees in the orchards and neighbors all around (cont.)

Like many fruit farmers, the Gregorys still find they must work hard to attract temporary workers, manage housing and keep up with legal requirements. In fact, one reason for adding the apple acreage to their tart cherries was to offer more work to migrant families. Favorable word of mouth from past employees has helped to attract workers. The Gregorys pay particular attention to understanding the priorities of their temporary workers, which includes finding work for each family member who wants it. Each year they host a barbecue where they wait on their employees.

Getting along with neighbors

More than 200 neighbors about the more than 100 blocks of orchards managed by Cherry

Bay Orchards. Here again, the key to keeping satisfied neighbors is being sympathetic and responsive. The Gregorys allow neighbors and tourists to use their land

S. Deming

in considerate ways. Walkers, horseback riders and children at play are welcome in the orchards, as well as hunters who have obtained a permit.

After 27 years of living in the same community, the family has strong ties that reduce doubt about how they run their operation. Community members have also come to realize that viable fruit orchards are one key to preserving the open landscape they so prize.



Communication and education are as important with neighbors as with employees. Although the mandatory use of pesticide application warning signs has raised concerns among their neighbors, it has also offered a chance to discuss why plant protection is important. Cherry Bay Orchards' insect traps (such as this yellow sticky trap) and hawk boxes have elicited neighbor interest and highlighted the farm's interest in ecological pest management.



Scouts and consultants join growers in discussions at an on-farm update session.

Occupational health and safety are important to any employee. In fruit operations, some pesticides are a known source of risk from exposure. The law requires compliance with pesticide labels that specify safety requirements, such as proper protective clothing and reentry intervals. Fruit growers who follow ecological management principles will usually be able to reduce the employee risks associated with agricultural chemicals.

Ecological fruit management requires growers to build a different knowledge base than practices such as calendar-based pesticide spraying require. Moving to ecological management with the same workforce will likely require that

employees get special training. When possible, training should be scheduled well ahead of the actual need for the skills so that employees can develop and practice what they have learned without too much pressure. Once trained, highly skilled employees can be harder to keep on the farm. Aside from pay raises, employees appreciate knowing how they are doing and how much value is placed on their willingness to learn, to change and to contribute to the farm. Listening to employees' suggestions and involving them in decisions on future changes can win their loyalty.

Where skilled employees are hard to find or the farm is not big enough for specialized full-

time employees, more and more fruit growers rely on professional scouts and consultants. Consultants and scouts invest in their expertise, keeping up with new developments during the off-season. As farming becomes more knowledge intensive, consultants are increasingly important for many farmers.

Overall, human ecology plays a key role in how humans manage the fruit system. Marketing strategies and government regulations dictate the quality standards that shape production practices. Neighbors and employees shape what practices are acceptable and which bring special satisfaction. The challenge of ecological fruit management is to unite the principles of production ecology with the principles of effective business management. Ecologically oriented fruit growers who can fit these pieces together will be able to capitalize on the new opportunities created by consumers who care about what they are eating and also how it was grown.

Chapter 4. Where do we go from here?

Richard H. Lehnert, Joy N. Landis, Jose E. Sanchez and Larry Mawby

The preceding chapters described the main elements that drive fruit ecosystems for sustainable production. It's important to understand the natural, managed and socioeconomic environments and how these interrelated pieces change and influence the fruit enterprise's goals, objectives and outcomes. The successful fruit grower manages the dynamic balance of the fruit ecosystem; changes elements after careful consideration of the present state of the system and the desired goal of the proposed change; observes effects before undertaking another round of change; and modifies production systems by a series of incremental changes.

Farming requires a holistic approach. Consider these guidelines for designing, managing and evaluating an ecologically based production system:

- **Design a fruit production system in harmony with the larger landscape.** A healthy farm benefits the larger community.
- **Increase biodiversity to improve system health.** Biodiversity can be managed to improve nutrient cycling and soil quality and to provide habitat for beneficial organisms. Pest outbreaks may become less frequent.
- **Watch for changes in the community of pests and natural enemies** resulting from changes in management practices.
- **Monitor weather and geographical factors** that affect crop and pest development.
- **When making changes, balance the old and the new.** Trying to change too much too quickly may be counter productive.
- **Constantly build your knowledge base.** Ecologically based management requires processing more information than using approaches such as calendar-based pesticide spraying. Read, visit farm demonstrations and attend workshops.
- **Remember your employees, neighbors and customers.** Fruit growers operate within a human setting that affects their production choices as much as the natural setting.
- **Strong communities are always better prepared to face challenges.** Join others to share ideas and find answers to mutual concerns.

A. Schilder



A. Schilder



How will fruit producers who adopt ecologically based management principles be better equipped to survive and prosper in the fruit business? Many issues challenge fruit production today. Using ecologically based management is not a silver bullet, but it does offer sustainable options.

Apple producers, for example, currently face poor prospects because of worldwide overproduction and low prices. In addition to weak markets, they have suffered weather-related disasters such as windstorms, drought and fire blight epidemics. They need lower costs if they are to continue as commercial commodity producers. Management strategies that control insects or diseases with fewer pesticide applications can lower costs.

Some growers believe that adopting ecologically based fruit management can pay off by directing their fruit toward more profitable markets. The optimistic producers talk about marketing strategies as well as production techniques.

Apple grower Kevin Winkel saved his orchard during the Michigan fire blight outbreak of 2000. He used information from his own weather station plus disease development information from a computer model. Winkel's orchards were sprayed when a critical combination of open blossoms, warm temperatures, free water and threshold levels of bacteria coincided. "We saved the orchards, but it took time, effort and money," he said.

Winkel had limited plantings of the newest varieties, such as Gala, Fuji and Jonagold, which are most susceptible to fire blight. He grows mostly Red and Golden Delicious, which

are less susceptible. He maintains a 1.5-acre test orchard on his farm and is evaluating 150 new varieties that are more resistant to fire blight and apple scab. While some evidence suggests that consumers are looking for novel tastes in apples, history says it takes years to establish a market for a new apple.

Winkel continues to use ecologically based principles. He spent years establishing a good environment for predatory mites—seeking them out and transporting them from abandoned orchards to his own. Since 1999, he has used no miticides, not even dormant oil. He uses his weather station and information on growing degree day accumulations, his own scouting and reports on regional trap catches to time sprays accurately.

R. Isaacs



R. Perry



R. Perry



But the future of the commercial market is a big concern to him. Can Winkel's farm survive in the new world market in which new countries suddenly emerge as major producers?

Grower Jim Koan sees similar challenges. He is changing some of his 100 acres of apples over to vegetables and other fruits such as peaches, plums and raspberries, switching from wholesale to retail sales through his Al-Mar Orchards farm store, and shifting to organic production methods.

"I was a commercial grower who cursed the roadside stand and all its problems," he said. "But that's now the road I'm taking."

His strategy is to sell retail at a higher price, diversify what he grows and sells, and develop other products that complement the retail program. He intends to sell fermented apple juice ("hard cider") and

possibly brandies distilled from fermented fruit, much as the Europeans have done for centuries.

Consumers are unwilling to accept blemishes on fresh fruit, Koan said. But organic consumers are willing to pay a premium for both fresh and processed fruit. Lower pack-out rates on organic fruit are offset by a better market for juices and sauces.

He's remaking his orchard. "Do I use fewer chemicals? No, I use more, but they're different. I use mild materials that have subtle effects. Instead of curing problems, I need to keep problems from happening." That means spending more time monitoring fields and orchards and concentrating on broader issues, such as basic soil health. He's increasing biodiversity, shifting some acres from apples to vegetables and to crops he calls "predator food"—meadows, sunflowers and buckwheat.

Todd DeKryger from Gerber Products Company works with growers to help them produce organically grown fruit for baby foods. "Our goal," he said, "is to continue to work with our long-standing growers by helping them change production methods." The organic market is growing. For producers to share in this growth, they must comply with the standards of Gerber's certifier. Gerber provides support of university research with organic apples and pears, including MSU's new variety trials at the Clarksville Agricultural Experiment Station.

"Pears seem to be the best candidate for organic production in Michigan," DeKryger said. He works with several fruit growers, including Gene Garthe, who is making the transition to organic production in his orchards. Garthe uses organically approved chemicals, parasitic wasps, and mating disruption that affects codling moths and

C. Edson



R. Isaacs



K. Stepritz



some other insect pests. One product, called Surround, made from kaolin clay, provides a protective layer of film that discourages insects.

DeKryger says the processing market offers potential for growers to use disease-resistant varieties. Several pear varieties bred at the Harrow research station in Ontario are fire blight-resistant. "We have tested and can use some of these varieties," he said.

Similarly, several scab-resistant apple varieties bred in the Purdue-Rutgers-Illinois cooperative program process well.

New varieties should also have fresh market potential, he said. Growers who do not have the option of roadside marketing want varieties that are broadly acceptable in the commercial fresh or processing markets.

"The most critical part of the fruit business is marketing," says winemaker Larry Mawby.

"It seems to me, growers are affected by many forces compelling change. Society demands that we perform under tough rules about how we treat labor, the environment, our neighbors, and how much risk to present to consumers. If growers can't produce cheaply within the rules, American consumers will buy from somewhere else—perhaps someplace where our rules don't apply."

Mawby, who was a pioneer in using integrated pest management, estimates he spends 70 percent of his time on marketing, 20 percent on making wine and just 10 percent growing grapes that generate most of the sparkling wine he produces and sells.

"It all comes down to marketing, and growers must find their own opportunities," he said. "They just can't do what most have been doing in the past. The shortest road to ruin in agriculture is to grow a commodity."

Part of the challenge for growers is to change production methods. Mawby's family began growing fruit more than 100 years ago, when growers produced many kinds of fruit, vegetables and berries to spread the workload and reduce risk. They had to devote some land to growing grain and hay for their horses. Biodiversity came naturally.

Over the years, the forces of mechanization and specialization resulted in a monoculture that changed orchard biology and required more pesticides. "Growers changed in what seemed to be sensible ways, like using calendar-based spraying based on expert advice rather than their own information and experience. We ended up going too far down a road that was not sustainable, and now we need to get back," he said.

"At our vineyards, we have not yet learned how to grow fruit without pesticides. I do things now that I feel are not

A. Schilder



R. Isaacs



C. Edson



sustainable, but they are the best things I know now. I'm aware of the things I don't like and I work to change them."

Larry works with a broker to sell some of his wine in Europe. There are lessons to be learned there, he says. European winemakers compete for markets by selling the uniqueness of their product.

Mawby likes Koan's idea of selling complementary products. "If I were an apple grower, I'd try a similar strategy. I would try marketing fermented hard cider or sparkling apple juice, something with a unique flavor spectrum." That might allow use of disease-resistant varieties that don't sell well in the more demanding fresh market.

In addition to agronomics and marketing issues, collaboration among members of the agricultural community is a positive step toward facing

future challenges. For example, the Integrated Fruit Systems (IFS) Think Tank is a group of innovative fruit growers, consultants, horticultural researchers and MSU Extension personnel located near Traverse City, Michigan. They look at what local horticultural industries are doing, what they could be doing and how they might change to become more sustainable in their production practices.

The IFS Think Tank meets periodically to discuss critical production and pest management issues and how best to make progress. Fruit growers have already made significant strides in improving the management of many key pests through the implementation of sound IPM strategies. These strategies require a basic philosophical shift that emphasizes decisions based on real-time information and an extensive knowledge about pest and beneficial populations, their habitats, life cycles and economic thresholds.

A key to the success of the IFS Think Tank is that its participants come from a broad range of disciplines. This venue for interaction helps redefine paradigms that will serve the fruit industry in the future. University personnel benefit from the group's identification of critical research and extension needs. Through their experience with this group, growers become better innovators on their farms. Such community efforts will speed development and adoption of sustainable fruit production practices.

A final thought: This publication is not intended to provide recipes to solve specific problems. Instead, it explains ecological principles driving fruit production systems and provides some tools for managing the ecology of a fruit farm. Growers need to determine how to apply these tools to their unique situations and needs.

R. Isaacs



S. Deming



R. Isaacs



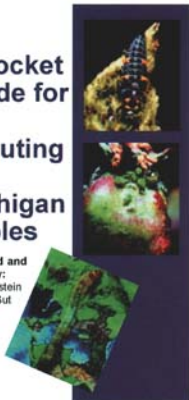
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A Pocket Guide for IPM Scouting in Michigan Apples

Compiled and edited by:
David Epstein
Larry J. Gut



A Pocket Guide for IPM Scouting in Stone Fruits

Compiled and edited by:
David Epstein,
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Alan L. Jones,
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To view sample pages from the guides, visit the publication section of the MSU IPM Program website at: www.msue.msu.edu/ipm/

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the 1990s, the number of people in the UK who are aged 65 and over has increased from 10.5 million to 13.5 million, and the number of people aged 75 and over has increased from 4.5 million to 6.5 million (Office for National Statistics 2000).

There is a growing awareness of the need to address the needs of older people, and the UK Government has set out a strategy for the 21st century in the White Paper on *Ageing Better: Our Future as a Nation* (Department of Health 2000). This strategy is based on the principle of 'active ageing', which is defined as 'the process of optimising opportunities for health, participation in society and security in old age' (Department of Health 2000, p. 1).

The White Paper sets out a number of key objectives for the 21st century, including: 'to ensure that older people are able to live independently and actively in their own homes for as long as possible'; 'to ensure that older people are able to participate fully in society'; and 'to ensure that older people are able to live in security and comfort' (Department of Health 2000, p. 1).

The White Paper also sets out a number of key actions to be taken to achieve these objectives, including: 'to improve the health and well-being of older people'; 'to improve the social and economic conditions of older people'; and 'to improve the services available to older people' (Department of Health 2000, p. 1).

The White Paper also sets out a number of key indicators to be used to measure progress towards these objectives, including: 'the number of older people who are able to live independently in their own homes'; 'the number of older people who are able to participate fully in society'; and 'the number of older people who are able to live in security and comfort' (Department of Health 2000, p. 1).

The White Paper also sets out a number of key challenges to be faced in the 21st century, including: 'the increasing number of older people'; 'the increasing number of older people who are living alone'; and 'the increasing number of older people who are living in poverty' (Department of Health 2000, p. 1).

The White Paper also sets out a number of key opportunities to be seized in the 21st century, including: 'the increasing number of older people who are able to live independently in their own homes'; 'the increasing number of older people who are able to participate fully in society'; and 'the increasing number of older people who are able to live in security and comfort' (Department of Health 2000, p. 1).

The White Paper also sets out a number of key messages to be taken forward, including: 'older people are a valuable resource'; 'older people should be able to live independently and actively in their own homes for as long as possible'; 'older people should be able to participate fully in society'; and 'older people should be able to live in security and comfort' (Department of Health 2000, p. 1).

The White Paper also sets out a number of key conclusions to be drawn, including: 'the need to improve the health and well-being of older people'; 'the need to improve the social and economic conditions of older people'; and 'the need to improve the services available to older people' (Department of Health 2000, p. 1).

