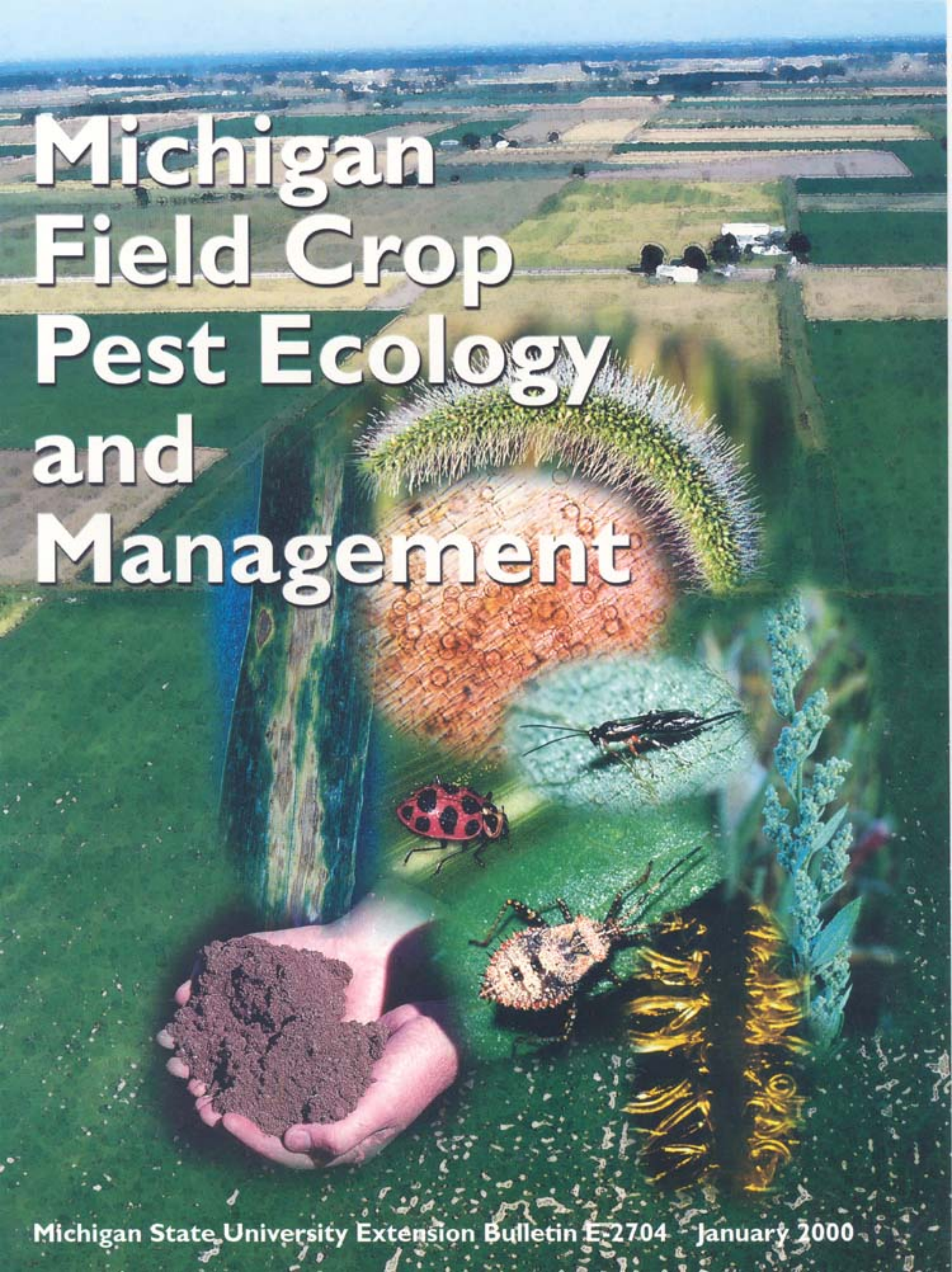
Michigan Field Crop Pest Ecology and Management



Michigan State University Extension Bulletin E-2704 · January 2000

This bulletin is dedicated to Dr. Richard R. Harwood, in honor of his considerable work to further our knowledge of sustainable farming.

Michigan Agricultural Experiment Station
Michigan State University

Project GREEEN

Michigan State University Extension

Michigan Field Crop Pest Ecology and Management

The publication team:

Dale R. Mutch	Team leader
Michel A. Cavigelli	Scientific editor
Steven R. Deming	Graphic design and photography
Leah A. Frost	Word processor and copy editor
Laura K. Probyn	Editor and publication coordinator

Contributing authors:

George W. Bird, Michel A. Cavigelli, L. Patrick Hart, Andrew M. Jarosz, Douglas A. Landis, Fabian D. Menalled, Dale R. Mutch, Laura K. Probyn, Karen A. Renner, Kurt D. Thelen

Thanks to the following for additional input:

Bill Carpenter, Merrill Clark, Chris DiFonzo, Mary Dunckel, Richard R. Harwood, Jim Kells, Bernie Knezek, Gary V. Manley, Larry Olsen, Natalie Rector, Susan Smalley

The following institutions have provided major financial, logistical and scientific support:

- W.K. Kellogg Biological Station
- Michigan Agricultural Experiment Station
- Project GREEEN
- Michigan Groundwater Stewardship Program
- Michigan Agricultural Stewardship Association (MASA)
- The W.K. Kellogg Biological Station Long Term Ecological Research Project (LTER)
- Sustainable Agriculture Research and Education Program (SARE)
- Michigan State University Center for Integrated Plant Systems
- Michigan State University Extension
- U.S. Environmental Protection Agency
- W.K. Kellogg Foundation
- U.S. Department of Agriculture

United States Environmental Protection Agency

Michigan State University — An Integrated Learning Environment — W.K. Kellogg Biological Station

Michigan Groundwater Stewardship Program

Table of contents

Introduction
page IV

Pest Management on Three Michigan Farms
page 1

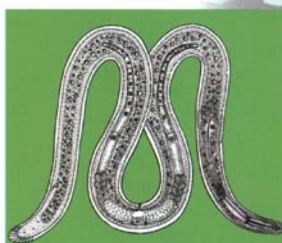
Principles of Field Crop Pest Ecology and Management
page 14

Soil Ecology and Pest Management
page 25

Insect Pest Ecology and Management
page 35

Weed Ecology and Management
page 51

Plant Pathogen Ecology and Management
page 69



Nematodes and Soil Quality
page 84

Putting It All Together
page 95

Photos: Steven R. Deming

Correct Citation: Cavigelli, M.A., S.R. Deming, L.K. Probyn and D.R. Mutch (eds.). 2000. Michigan Field Crop Pest Ecology and Management. Michigan State University Extension Bulletin E-2704, 108 pp.

Taking the next step

Farmers have been managing weeds, insects and diseases as long as there have been crops. Though we've come a long way in learning about how to control the organisms that kill plants and lower crop yields, we still have a long way to go in figuring out how to deal with pests while keeping farms economically and environmentally viable.

Agriculture is in a transition period. There are many challenges surrounding our ability to produce food, including urban sprawl, pesticide residues, genetically engineered crops, pest resistance to pesticides and commodity prices. Just as farmers once learned to rely on synthetic pesticides to manage field crop pests, they are now looking for alternative strategies that will help keep them in business while keeping our country healthy and fed for generations.

As this bulletin's author team sat down to develop a document that would both provide information and highlight the many complexities involved in field crop pest ecology and management, we found we often had more questions than answers. While there is a lot to learn, this bulletin is a step toward creating a more ecological field crop agricultural system.

We hope this bulletin challenges you and raises questions about how we farm and should be farming. We hope you'll use the case studies to visualize how each chapter can be incorporated into field crop farming, that the key points and study questions will help focus your learning and that the management tables will help you see how farming management practices influence pests.

It is important to understand that practical ecological principles can be implemented right now on any farm. It's equally important to realize that there is no "magic bullet" or quick fix to managing pests ecologically. The concepts and strategies presented in this bulletin are only the beginning of a long journey toward a more sustainable agriculture.

We hope our readers will be encouraged to take the next step.

Sincerely,

Dale Mutch
MSUE District Agent,
W.K. Kellogg Biological Station
Hickory Corners, Michigan

Introduction

"If the grower knows why, he will teach himself how."

Liberty Hyde Bailey, 1916
The Principles of Fruit Growing

Liberty Hyde Bailey's perspective is at the heart of this publication. Its predecessor, ***Michigan Field Crop Ecology*** (MSU Extension Bulletin E-2646) introduced producers and educators to the idea of looking at farms as ecosystems, and recognizing that farms are habitats for many organisms other than crops, livestock and pests. These organisms form an integrated web that allows farms to function. That publication's major theme focused on understanding how management practices affect those organisms' food sources and habitats. Producing economically viable crops while preserving and enhancing both the farm fields and the surrounding ecosystems requires understanding a farm's ecology. That bulletin also emphasized that because of the great variability in soils, microclimates and other factors, farmer participation is crucial for developing more sustainable agricultural systems.

The way pests are managed in the United States is changing. A growing emphasis is placed on reducing the reliance on conventional pesticides. Strong public opinion coupled with legislative and executive actions by state and federal governments is driving this change. Farmers, foresters, ranchers, homeowners and others who seek to prevent excessive pest damage are increasingly aware of the short-comings of many conventional approaches to pest control.

Congress of the United States, Office of Technology Assessment. 1995.

Michigan Field Crop Ecology readers have requested more pest management information for field crop ecosystems.

This volume comes in response to that demand. Some insects, disease-causing organisms (pathogens), nematodes and weeds compete with humans for field crop resources. Left unmanaged, these pests reduce crop yield and quality.

In the past 50 years, pesticide use has become the dominant pest management strategy. There is a growing consensus, however, that relying on chemically-based pest management systems is neither desirable nor sustainable. Pesticides may threaten human and environmental health, pests are becoming more resistant to pesticides and legislative action is reducing pesticide options. Alternative pest management strategies are needed. This bulletin will help readers understand the ecological principles that can be used to manage field crop pests in new and more effective ways.

What are field crop pests?

Pests are organisms that cause economic damage to crops. In this bulletin we will look at weed, insect, plant pathogen and nematode pests. Pests exist in both managed and natural ecosystems. Their impacts are often more severe in agricultural systems because humans often create conditions in agricultural systems that favor crop pests but not their natural enemies.

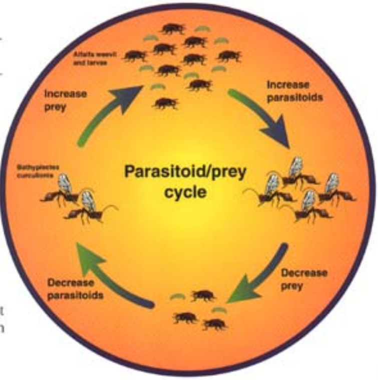
Without benefit of the natural controls that keep pest populations in check, growers become increasingly dependent on chemical pesticides to which many pests may eventually develop resistance. Thus, there is an urgent need for an alternative approach to pest management that can complement and partially replace current chemically based pest management practices.

National Academy of Science, National Research Council. 1996.

What is pest ecology?

Pest ecology is the study of the interactions between pests, their environment and other organisms. All organisms are regulated by both abiotic (non-living) and biotic conditions and other organisms. Abiotic factors that can limit pests include temperature extremes, light and water. Biotic factors controlling pest populations include a pest's natural enemies (predators, pathogens and parasites) and competitors.

In unmanaged or natural ecosystems there is usually balance among organisms. As the population size of a pest organism increases, it becomes an abundant resource for its natural enemies, which then increase in number and drive the pest population size down. As its food becomes scarce, the natural enemy population size also declines, producing an ongoing cycle that results in population regulation. Since organisms in unmanaged or natural ecosystems are often controlled by more than one natural enemy or competitor, the population size of any one species rarely reaches epidemic outbreak proportions.



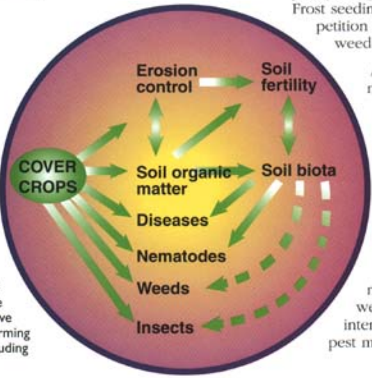
Red clover growing in wheat stubble. Photo: Steven R. Deming

What is field crop pest ecology and management?

Ecologically based pest management makes full use of understanding pest ecology, including farm conditions that the farmer knows best. In field crop ecosystems, we often create situations where pests have excess resources but few, if any, limiting factors. By understanding how pests take advantage of field crop situations, we can work to limit their success. For example, common ragweed is frequently found in wheat stubble where there is plenty of light and moisture and little competition. Frost seeding a legume into wheat increases competition for light and moisture, reducing ragweed population density.

A legume cover crop also provides nitrogen to the succeeding crop, helps prevent soil erosion, increases soil organic matter levels and may help control insect and nematode pests by providing a favorable environment for their natural enemies. Management strategies that provide multiple benefits are a key component of ecologically based pest management.

By explaining ecological interactions among field crop pests, abiotic factors, natural enemies, competitors and crops, we hope this volume will spur readers' interest and ideas for ecologically based pest management strategies.



Cover crops have multiple and interactive effects on farming systems, including pests.

For further reading

National Research Council. 1996. Ecologically Based Pest Management: New Solutions for a New Century. A report of the Committee on Pest and Pathogen Control through Management of Biological Control Agents and Enhanced Cycles and Natural Processes, Board on Agriculture. National Academy Press. Washington, D.C. 146 pp.

U.S. Congress, Office of Technology Assessment. 1995. Biologically Based Technologies for Pest Control. OTA-ENV-636, U.S. Government Printing Office. Washington D.C. 204 pp.

Note: This bulletin is not an identification guide for Michigan field crop pests or a species-by-species manual on control methods. This type of information can be found in a number of Michigan State University and North Central Regional Extension Bulletins:

Common Weed Seedlings of the North Central States, NCR Regional Extension Publication No. 607.
Corn Diseases, MSU Extension Bulletin E1974
Alfalfa Diseases, MSU Extension Bulletin E1976
Wheat Diseases, MSU Extension Bulletin E19778
White Mold of Beans, MSU Extension Bulletin E0892
Phytophthora Root and Stem Rot of Soybeans, MSU Extension Bulletin E1511
Soybean Cyst Nematode, MSU Extension Bulletin E2200
European Corn Borer: Ecology and Management, NCR327
Managing Bean Leaf Beetles in Soybeans, MSU Extension Bulletin E2262
Alfalfa Weevil Management, MSU Extension Bulletin E2271
Managing Black Cutworms in Corn, MSU Extension Bulletin E2273
Managing Soybean Defoliators, MSU Extension Bulletin E2272
Corn Rootworms: Biology, Ecology and Management, MSU Extension Bulletin E2438
Insect Management in Wheat and Other Small Grains, MSU Extension Bulletin E2549

These publications are available through the Extension Bulletin Office, 10-B Agriculture Hall, Michigan State University, East Lansing, MI 48824-1039, or on the World Wide Web (http://www.msue.msu.edu).

Additional copies of this bulletin, No. E2704, are also available through the bulletin office.

Pest Management on Three Michigan Farms

Laura K. Probyn, Michel A. Cavigelli and Dale R. Mutch

Key Points:

- Pest management is farm specific.
- Pest dynamics change each year.
- Closely monitoring pest population dynamics is a key to reducing pesticide applications.
- Farming without pesticides is economically possible in Michigan.

Study Questions:

- What cultural practices help reduce or eliminate pesticide use on each farm?
- Can you think of ways the farmers can further reduce pesticides use? After reading the ecology chapters, can you think of additional ways of trying to reduce pesticide use?

Editors' note:

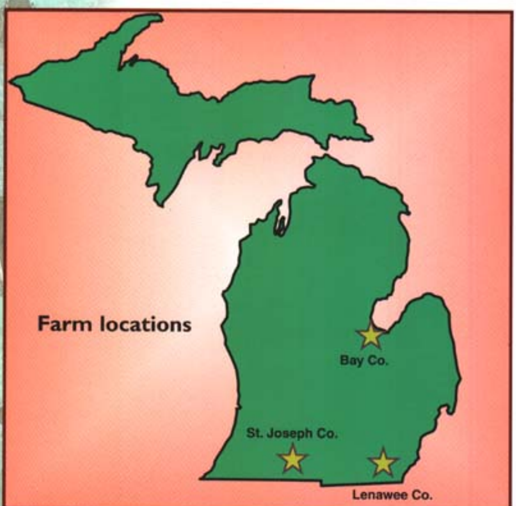
We suggest that the reader carefully review the case studies and study the ecology chapter noting key underlying principles embodied in the case studies. Reread the case studies to understand how these farmers practice pest ecology principles.

Introduction

We introduce the concepts of field crop pest ecology and management by describing three Michigan farms and their pest management approaches. More extensive discussions of major field crop pests (insects, weeds, pathogens and nematodes) follow the case studies. Look for cross-referencing icons throughout the case studies to relate farmer management practices with the principles discussed in the pest ecology chapters.

The three farmers highlighted here share a number of characteristics: they are excellent managers who pay close attention to the ecological processes occurring on their farms; they tend to have diverse crop rotations; they use at least some cover crops; they continuously seek to improve their farms; and they know soil quality plays a crucial role in efficient crop production. Two of the farmers manage 1,250 acres and one manages about 300 acres. The two larger farms use integrated pest management (IPM) techniques extensively. The smaller farm is certified organic, so pest management strategies do not include synthetic pesticides. All three farmers are interested in minimizing their purchased inputs, primarily for economic reasons. One of the larger farmers works full-time off the farm and farms in conjunction with his father while the other two farmers work their farms full-time.

The farms represent three different and important Michigan agricultural regions: the Saginaw Valley sugar beet and dry bean producing region, noted for fine-textured soils; the southwest seed corn production region, noted for sandy soils and a large number of irrigated acres; and the southeast region, with perhaps the state's most productive, loamy soils. While these three farms do not represent the complete diversity of Michigan agriculture – the third most diverse in the nation – the principles illustrated in these case studies apply to other important agricultural regions in this state, the upper Midwest and elsewhere.



These icons are used to cross-reference the following ecology chapters

Icon	Chapter
	**Soil Ecology and Pest Management**
	**Insect Pest Ecology and Management**
	**Weed Ecology and Management**
	**Plant Pathogen Ecology and Management**
	**Nematodes and Soil Quality**

Bay County farm

Background

This farmer began working the current 1,250-acre Bay County operation with his father in 1991. The two make farming decisions together and operate with occasional help from two other family members. Father and son examine their own yield data, talk to elevator consultants about what other farmers are trying, look at what MSU and other researchers are doing and then adjust this information for their situation. Their pest management strategies are strongly dictated by economic cost-benefit analysis.

More than half of their acreage is leased, much of that from relatives. Fields are typically 40-50 acres in size, and the farmer splits a number of 120-acre fields into 40- or 50-acre parcels. Planting more than one crop in the larger fields spreads out income among landlords and minimizes risk by planting all crops on each soil type. Soils are mostly Tappan and Londo loams, with some loamy sands.

Photo: Steven R. Deming

Sugar beets.

Crop rotations

This operation uses three- and five-year crop rotations based on soil type and landowner considerations. The number of dry bean acres is based on contracts.

One three-year rotation is corn, dry beans and sugar beets, a typical rotation for this area. Another three-year rotation includes strip cropping corn and soybeans followed by sugar beets. Corn and soybean strips are rotated for two years before planting the entire field to sugar beets. The farmer began using this system in 1994, after a USDA Natural Resources and Conservation Service agent showed him convincing economic and yield data. The corn and soybean strips are planted after other corn fields are planted, between May 12 and 15. Corn is planted in six 30-inch rows, and soybeans are drilled in seven-inch rows. Two corn varieties are planted in the strips – a shorter variety on outside rows and a taller variety in the middle rows. This pyramid effect is designed to improve yield by increasing sunlight to the center rows. The varieties are usually 95-day hybrids, as the producer has not noticed a yield difference using 100-day hybrids. Corn yields are typically 20-30 bushels per acre higher in strips than in monocropped fields and soybeans typically yield one to two bushels more when planted in strips. Another benefit with this system is that the corn residue protects the soil from wind erosion and surface crusting.

Photo: Steven R. Deming

Strip cropping.

This farmer's five-crop rotation is sugar beets, corn, dry beans (black, small red, cranberry, pinto and navy beans) wheat or soybeans and back to dry beans. In 1998 his total managed acreage was 180 acres sugar beets, 280 acres corn, 380 acres dry beans, 280 acres soybeans and 130 acres wheat.

Field characteristics p 45.

Row spacing p 53 + p 67.

Field preparation

Tillage and plant pathogens p 72 + p 77.

Field preparations are based on soil type and a field's previous crop. When corn follows sugar beets, for example, the farmer subsoils the ground and drags a pipe to level it. The producer field-cultivates the ground once before planting. Soybean ground is worked twice – first using a soil finisher with disk sweeps and finishing baskets in the back, and then with a field cultivator. Dry bean ground is worked three times before June planting. The first tillage is with the soil finishing unit. The second tillage follows early weed germination with preplant herbicides incorporated at the same time. The third tillage takes place the same day as planting. Sugar beet fields are subsoiled with a v-ripper before planting and after harvest.

Alfalfa and wheat strips border a sugar beet field.

Soil fertility and quality

This farmer has reduced phosphorus use over the past five to six years based on soil test results. He has planted some soybean fields without added fertilizer and planted all his 1999 soybean fields this way. In addition, he plants some dry beans with nitrogen as the only added fertilizer (dry beans do not dix sufficient nitrogen for their needs).

Wheat or rye cover crops are used for wind erosion control and organic matter additions on a few fields. Cover crop use depends on fall harvest and weather conditions. Wheat is often planted in a 45-foot border in sugar beet fields for erosion control.

Soil organic matter pp 27-30.

Pest management

IPM scouting methods are used to determine various pest threshold levels. This farmer considers whether to use pesticides very carefully, even lower-cost sprays, since they all require additional time, field passes and equipment.

Sugar beet pests

Insects

Host range p 37.

Cutworms are a spring sugar beet pest problem. This farm did not have a problem with them until 1998, when about 10 acres were treated with an insecticide. The farmer felt the problem was possibly related to neighboring woodlots and Conservation Reserve Program (CRP) ground, where cutworms might have laid eggs on low-growing or rosetted weeds in the spring. The producer decided to spray after scouting the field, a decision supported by the sugar company agronomist.

Spinach leaf miner is another sugar beet pest. This farmer last sprayed for it in 1997 after noticing the pest at or above threshold levels.

Diseases

Cercospora leaf spot is a late summer and early fall problem that was first an issue for this farm in 1998. He was one of the last operators in his area to spray for it. The producer based his decision on charts distributed by a sugar company and MSU Extension. The chart defines a spraying threshold based on the number of spots on each leaf.

Pesticide applications p 82.

Sugar beet cercospora leaf spot.

Photo: MSU Dept. Botany and Plant Pathology

Nematodes

This farmer believes he has a sugar beet cyst nematode problem in some parts of several sugar beet fields. He has not sampled for nematodes, but is managing this pest by expanding from a two-year corn and sugar beet rotation, hoping to put sugar beets in at least a four-year rotation. As noted, he has a five-year rotation in some fields, but he says that, "With the longer rotations we have not yet seen an increase in sugar beet yields."

Crop rotation p 91.

Weeds

The farmer broadcasts and incorporates a preplant broadleaf herbicide. At planting a preemergence herbicide is applied in a 10-inch band behind the seeder. When the beets are at cotyledon stage, the farmer makes his first postemergence herbicide application at a reduced rate in a 10-inch band, followed by another reduced rate application seven to ten days later. He usually cultivates beets three or four times. On the first cultivation, at the second to fourth leaf stage, he uses a beet cultivator with a cutaway disk and shields. On his second cultivation he removes the disks. On the third cultivation, around July 10, he uses a big sweep, which throws soil near the beets. He notes that it is important not to push soil onto the beet crowns where it could cause a *Rhizoctonia* problem. Depending on the weed situation, he may cultivate again at the end of July. In 1998 he cultivated five times because it was a dry summer. The sugar beets grew slowly and weeds emerged after each sporadic rainfall.

Weed competition pp 52-53.

Dry bean pests

Insects

Potato leafhopper (PLH) is the only insect pest problem in this farm's dry bean fields. Pinto and navy beans and one black bean variety are more sensitive to this pest than other dry bean classes or varieties. The producer scouts the headlands and parts of fields. If PLH populations are at or above the threshold level (at least one PLH per trifoliate leaf) he band sprays once with a systemic insecticide at a reduced rate when he cultivates. As the beans get larger, PLH is usually not a problem since it is naturally controlled by a fungus later in the season.

PLH migration and biocontrol p 38 + p 43.

Diseases

This farmer manages white mold using cultural methods. He plants dry beans in 30-inch rows, which keeps the plants drier and less susceptible to fungal diseases than narrow-row plantings. He usually cultivates twice; the second cultivation is less intense and is intended to 1) "bust some branches," again to keep the plants drier, 2) cover any white mold spores that might be present and 3) get some air into the soil to keep it from staying too wet. Though he's not sure, the farmer thinks a longer rotation helps avoid white mold problems. The producer does not spray for white mold because he can't justify the cost of the pesticide and its application, nor the increased soil compaction from extra trips across the field. In addition, timing pesticide applications is difficult because there is only a short window of opportunity for effective spraying.

Root rot and *Anthracnose* (which the farmer believes may be associated with root rot) are concerns on this farm. Root rot is a problem when beans are planted early and soils stay wet. Keeping soil compaction to a minimum reduces root rot problems. The operator does not spray for *Anthracnose* because it is not economical. Instead, he plants resistant varieties and tries not to follow beans with beans.

Row spacing and white mold pp 78-79.
Planting date p 79.
Disease development p 76.
Crop rotation pp 70-71 + p 77.

Photo: Steven R. Darling

Black beans.

Weeds

Dry bean weed control is limited to those herbicides that can be used with sugar beets in the rotation. The farmer uses preplant incorporated (PPI) herbicides. If many weeds emerge before cultivation, he may band a postemergence herbicide at a reduced rate, depending on the field and the species of weeds. He says, "Dry beans are planted late enough in the season (mid-June) that if the ground is worked early, left alone for two to three weeks then worked again, many of the weeds are killed."

Weed emergence p 54 + p 67.

Corn and soybean pests

Rotation and corn rootworm p 47.

Insects

Insecticides haven't been used on this farm's corn since the 1980s. Though Bt corn was used when the seed company suggested that higher corn borer populations were expected, the producer does not think this investment was worthwhile. He did not see the ten bushel yield increase needed to offset the additional seed cost.

Corn rootworm (CRW) has not been a problem in the strip crops yet, though the farmer is concerned that CRW may change behavior and become a pest problem in corn strips. As of the 1999 field season, no CRW egg laying has been detected in Bay County soybean fields.

Diseases

Soybeans are planted at 160,000 seeds/A in the strips and 180,000 seeds/A in other fields. The lower seeding rate helps avoid white mold, which the farmer says he has not seen in the soybeans since he began strip cropping.

Weed adaptations pp 56-57.

Weeds

Broadleaf and grass herbicides are PPI or applied preemergence in corn and soybeans not planted in strips. If the farmer has a perennial weed problem he'll spot spray. Ten to 15 days after corn emergence he cultivates while applying nitrogen, based on preside dress nitrogen test results. Corn and soybeans receive postemergence herbicides for broadleaf weed control. In strips, the farmer applies a grass herbicide preemergence and a broadleaf herbicide postemergence.

Wheat pests

As is common, this farmer has very few wheat pest problems. If winter annual weeds such as shepherd's purse are especially dense, an inexpensive herbicide may be applied. He has sprayed for powdery mildew, though the producer questions whether this is worthwhile economically. At current pesticide and wheat prices, the additional income from the 15 bu/A yield increase provided by the pesticide is offset by its cost.

Summary

This farmer uses many information sources and is very cost-benefit oriented. In addition, he tries to minimize the number of trips across the field to reduce compaction and costs. The producer continually seeks ways to further reduce pesticide applications.

St. Joseph County Farm

Wind break bordering potato field.

Background

This 1,250-acre operation is located in St. Joseph County, a seed corn production center noted for its sandy soils (Oshtemo and Spinks). Once a continuous seed corn operation, this irrigated farm now produces seed corn, snap beans and potatoes.

When the producer began farming full time in 1977, he did what every farmer he knew did to bring in profitable yields – weed and feed. Since he realized that nitrogen management was an important issue on his sandy soils, he began experimenting with decreasing nitrogen fertilizer application rates, incorporating cover crops, diversifying his rotation, and grazing some of his cover crops. After making these changes, he produced 140 bu/A seed corn using only 90-100 lb/A nitrogen fertilizer.

He makes decisions in consultation with his wife and a long-time employee. The operator believes it's good to involve others in decision making, and that by asking questions they stimulate his thinking in new ways. This inclusive decision making process also helped educate the entire family about farming's complexity. As one of the farmer's sons said, he chose to become a medical doctor because, "I'm not smart enough to farm."

Crop rotation

The farm's four-year rotation is seed corn, potatoes, seed corn and snap beans, with the seed corn and snap beans grown under contract. This farmer recently added potatoes to his rotation because they are a high-value crop that can help justify irrigation costs and diversify the rotation. In addition, since they are managed by the potato contractor, they reduce his time requirements. Snap bean plantings are staggered beginning around May 10 and the earliest planted fields are double-cropped. Snap bean harvest starts after July 4 and continues through the end of the second harvest. Potato harvests are also staggered.

Soil fertility and quality

Cover crops p 47.
Natural enemies p 41.

Because of this farm's sandy soil, the producer has instituted a nitrogen management program for his seed corn acreage. He uses a spring pre side-dress nitrogen, summer tissue testing and full stalk nitrate analysis for precise nitrogen level monitoring. Using these tests helps him maximize crop plant nitrogen use and minimize losses to the environment.

Cereal rye, the first week of October.

Cover crops are used on every field. The staggered snap bean and potato harvests provide many cover crop options. The farm is also part of a Michigan State University/W.K. Kellogg Biological Station project evaluating a number of cover crop options for seed corn, which has a more open canopy than field corn.

Oilseed radish and weed control p 65.

In general, cereal rye is planted into seed corn in August or September and on any snap bean or potato ground that is harvested after September 1. When rye precedes a snap bean or potato crop, the rye is chiseled and later disced. On any ground harvested before September 1, the producer plants oats, which reduce springtime field work since they winter kill.

Irrigating seed corn.

He plants cover crops within one week after snap bean or potato harvest. Once the cover crops are established, he rents these acres to a dairy farmer who grazes dry cows and bred heifers. About one-half of the potato and snap bean acres are grazed. These fields are chisel plowed and fitted prior to planting the cover crops. The ungrazed acreage is no-tilled and fields that have been grazed are spring-tilled to reduce soil compaction from animal and tractor traffic. All ungrazed acreage going to seed corn is no-till planted the following year.

Though he initially used cover crops to help prevent wind erosion and add soil organic matter, the producer is also learning to appreciate their role in nutrient cycling and, possibly, pest management. His father always used cover crops (mostly rye) but this operator is gaining a better understanding of their benefits by working with the MSU/KBS Cover Crops Program. He believes that decaying cover crop residues increase soil health and soil biological activity.

Though he used to sample each field each year for basic soil testing, in 1998 the farmer contracted to have a portion of his samples analyzed for additional nutrients. Results showed one field had many areas low in calcium and all but one micronutrient. A few fields had a pH of 6.0 or lower, so he used high-calcium lime to remedy these spots.

Organic matter management p 29.
Soil food web pp 27-30.

Seed corn pests

Because seed corn production is an important part of the local economy, the St. Joseph County MSU Extension office sponsors weekly IPM breakfasts during the growing season. This grower uses pest dynamics information from these meetings to develop management strategies and set pesticide application windows that maximize effectiveness.

Insects

The farm's major seed corn pests are corn rootworm, armyworm, cutworm and European corn borer (ECB). Rotation has provided excellent rootworm control and this farmer does not treat for it. He scouts for armyworms, which cause problems in some years, and sprays when they reach threshold levels. Armyworm problems are more common when no-till seeding into a cereal rye cover. If the cover crop is destroyed early (in April) or if an oat cover is used, armyworms are not a problem.

He does not intend to change his cover cropping practices because of armyworms. Armyworm scouting begins early in the season, when the moths lay eggs in grasses. The farmer says he has to be vigilant at this time and most years treats one or two fields.

ECB is intensely monitored in St. Joseph County and producers treat seed corn when populations reach threshold levels. Since the seed corn company does not let growers know the genetics of the seed corn, this farmer does not know whether he has raised Bt corn.

Photo: Steven R. Deming

European corn borer.

Crop rotation and rootworms p 47.

Diseases

The first Stewart's wilt infestation occurred on this farm seven or eight years ago. The seed corn representatives initially didn't see a need to spray because they thought their hybrids were resistant. Since the bacteria responsible for this disease are transmitted by flea beetles, Stewart's wilt is managed by controlling this insect pest. If the average temperature for each month between December and February adds up to less than 90 degrees, there is little risk that flea beetles will spread the Stewart's wilt bacteria. The seed corn company also tests flea beetles to determine if they are carrying the bacteria. During the past few years, winter temperatures have been relatively mild and flea beetle populations have been above the threshold, so this farmer has sprayed for flea beetles.

The seed corn company also regularly monitors for northern corn leaf spot (*Cochliobolus carbonum*) and rust. Treatment is determined by a damage threshold, but these two diseases have not been big problems on this farm.

Pesticide applications p 82.

Nematodes

Corn needle nematode can be a problem in these sandy soils. The farmer suspects he has had two instances of nematode problems, though he did not test to confirm them. Both these instances occurred when he was growing continuous seed corn.

Crop rotation/soil quality p 93.

Weeds

Prior to diversifying the rotation in 1994, controlling weeds in continuous corn was an annual struggle. Now excellent grass control in the snap beans and potatoes carries over to the seed corn, and there is a lot less weed pressure, though crabgrass is still a challenge. A preemergence grass herbicide is used on tilled fields at corn planting. On ungrazed land, the grower uses two weed control strategies, depending on the cover crop seeded. If the cover crop is cereal rye, he applies a burndown herbicide at the six- to eight-inch stage in early to mid-April.

This is followed by an early preplant grass herbicide application around April 20. On oat-seeded ground, he applies a burndown plus grass herbicide tank mix about April 20. "The key is to plant your seed corn into a field under weed-free conditions," he says. He controls broadleaf weeds in corn with one postemergence application. For his last weed control strategy, he cultivates with a single wide-sweep cultivator when he applies side-dress nitrogen.

The producer suspects that his fall panicum and crabgrass problems may be related to low soil pH (low calcium levels). Crabgrass is his worst weed problem and he has to be diligent in attempting to control it with preemergence herbicides or he'll later find himself cultivating to try to manage it.

When the cattle began grazing Brassica cover crops a significant velvetleaf problem arose where husklage, a diet supplement for heifers, was spread.

Weed emergence p 54.
Crop rotation and weeds p 66.
Weed seed dispersal pp 58-59.

Snap bean pests

Insect feeding pp 39-40.

Insects

PLH is the dominant snap bean pest. Since PLH populations are low early in the season, this farmer scouts the first snap bean crop. If PLH populations build to the damage threshold, which is relatively low in snap beans, the farmer sprays a systemic insecticide. For the second snap bean crop, PLH levels are usually high so he applies a systemic soil insecticide at planting.

Corn borer is also a major snap bean pest, but controlling it is the contractor's responsibility. The normal procedure is to spray the first crop two to three times. By scouting and carefully timing insecticide applications, however, corn borer can often be controlled with just one application. This farmer has worked closely with the contractor, helping reduce the number of insecticide applications.

The disease triangle p 76.

Diseases

White mold is not a problem on the first snap bean crop, but the second crop is closely monitored. The grower usually does not apply preventative pesticides for white mold, since they are expensive. Instead, he keeps records of where white mold has occurred. If there is no history of white mold in a field, he does not worry about it. He always plants snap beans in 30-inch rows, in part because the harvesting machinery works best this way. In addition, he does not over-irrigate, especially two to three weeks before flowering begins. Snap beans are also susceptible to blight and *Fusarium* root rot. He plants western blight-tested seed and combats *Fusarium* root rot using controlled traffic patterns that reduce overall compaction.

Snap bean field.

Weeds

Preemergence grass herbicides are used in snap beans. Pest scouting is used to determine whether a broadleaf herbicide application is necessary. The farmer rarely uses a broadleaf herbicide but may spot spray.

Summary

This farmer emphasizes a strict four-year rotation, extensive cover crop use and careful pest monitoring and irrigation scheduling. These four strategies seem to have reduced his pest problems and his need to apply pesticides. The farmer continues to seek more ways of reducing pesticide use.

Lenawee County farm

Background

When this Lenawee County farmer visited an Ohio organic operation that produced 150-bushel/A corn, he saw his future in organic farming. He began talking to organic growers and found they readily shared ideas and information. He is now in his twelfth year as an Organic Crop Improvement Association (OCIA) certified organic grower.

This producer began farming in 1974 and today farms 52 of his own acres and 254 rented acres. His fields average 40 acres, which he says, "Makes it easier to get things done." The farmer does most of the farm work himself, but occasionally hires people to "walk soybeans" for weed control. He bases management decisions on his and other organic farmers' experience. The operation's primary soil type is Hoytville clay.

A newly planted windbreak in front of organic corn.

Field size and disease p 75.

Field size and insects p 45.

Crop rotation

The rotation – wheat or spelts, corn, food grade soybeans – is a compromise between what the farmer considers ideal and an economically viable rotation. Although the organic market influences his rotation, he tries to maintain one third of his acreage in each primary crop.

Wheat or spelts are drilled in the fall, then frost seeded with either an 80/20 mix of red clover/sweet clover (used as a green manure/cover crop), or a non-dormant alfalfa, which is baled once for horse feed. The farmer also uses cereal rye as a cover crop at one bushel/A following corn. Since organic food grade soybeans currently command such an attractive premium, he plants soybeans following either clover or corn/rye, but never plants soybeans following soybeans.

For ground that is in clover and going to corn or soybeans, the producer chisel plows and offset discs in the fall, then field cultivates twice in the spring. He prepares the seedbed about one week before planting corn in mid-May. When soybeans follow corn/rye, the farmer kills the rye in the spring with a field cultivator or offset disc, depending on the rye's height. Ideally, he kills rye when it is less than 12-inches tall, because it decomposes fastest when young.

Organic clear hilum soybeans and corn.

Soil fertility and quality

If regular soil tests indicate a need, this farmer uses OCIA-approved chicken manure compost on wheat, and fish emulsion starter on corn, though he minimizes use of purchased inputs. He aims to keep crop residue and manure additions in the top five to six inches of soil, so he has eliminated plowing and instead uses an offset disc or chisel plow. He also avoids working the ground when it is wet.

Soil organic matter pp 27-30.

His farm size and desire to limit his purchased inputs gives him flexibility in planning field operations and allows him to spend more time on the farm. His fiscal policy is that, "If I don't spend it, I don't need to make it," although he readily admits that it is "hard to get out of your head the idea that you've got to have an input."

This farmer believes his practices are increasing his soil quality because he sees some soil crusting on newly rented ground, but not on the fields he has managed for a long time. "I wish you could see the difference in my soil from the original soil – it looks more alive, more rich." Five days after a two and one-half inch April rain, this farmer was working his ground while his neighbors needed to wait an additional two or three days. He attributes this difference to soil management practices that have increased his soil organic matter, allowing better drainage in these lake-bottom soils.

Wheat/spelt pests

Rotation and weeds p 66.
Weed seed fate pp 63-64.

Weeds

This farmer has few pest problems in small grains. To manage weeds in the stubble he uses a stubble beater after combining so the clover can get a good start. When clover does not come in well, he may let the field lay fallow through the summer and then plant it to a cereal rye cover crop around September 1.

"It's our whole system that helps us with weed control. I've known farmers that grow organic corn and soybeans in rotation and have tons of weed problems." The small grains in his rotation are winter annuals that help break up the summer annuals' weed cycles.

The clovers and alfalfa also help break weed cycles. The farmer notes that, "We used to have problems with thistle patches. We'd plant the field to hay for three years and the thistle patches would be gone."

Photo: Steven R. Deming

Red clover cover crop growing in spelt stubble.

Corn pests

ECB and soil quality p 44.

Insects

Although European corn borer is present in this farmer's corn fields, it has not caused economic losses. He knows of no other insect, disease or nematode problems in his corn. Although pests are present, he feels they are not economically important because the corn crop is healthier to begin with and can withstand more pest pressure.

Weed emergence p 54 + p 67.

Weeds

This farmer's late planting date (mid-May) is also an important part of his weed control program, allowing greater control of early-germinating weeds and quick corn germination for greater competition with weeds. For weed control in the crop, the farmer likes to make his first pass with the rotary hoe within four days after planting – before the corn emerges. He usually makes another two or more passes with the rotary hoe – depending on growing conditions – when the corn plants are very young. He cultivates with a simple s-tine cultivator on larger corn plants. Since his late-planted corn grows so quickly he often uses this second piece of equipment only once.

Soybean pests

Abiotic factors p 45.

Insects

This farmer feels his management practices may help control insect pests. For example, the summer of 1991 was very dry and spider mites were a significant problem on a neighbor's farm. The mites spread across the road to his fields, but once in his fields they did not spread, even though the dry weather continued and the neighbor's problem continued. The farmer has not had a spider mite problem since.

Diseases

Soybeans planted in 30-inch rows allow easy cultivation, which adds oxygen to the soil, and minimizes white mold incidence. Although late summer and early fall 1998 were very wet, this farm did not have a white mold problem.

The soybeans sometimes develop a white, fuzzy mold inside the pods at maturity. It is not white mold and can be cleaned fairly easily. It is mostly a problem when damp weather occurs during the final development stage.

Row spacing, p 78.

Nematodes

Though the farmer has not seen visual evidence of nematode damage, tests have shown that his farm has low levels of soybean cyst nematodes. The producer attributes this to his frequent use of soybeans in the rotation.

Soil quality pp 88-91.

Weeds

Soybean and corn weed control are very similar in this operation. Many weeds are controlled with tillage prior to the late planting date, and with an initial rotary hoe four to five days after planting. Typically, he uses the rotary hoe three times in soybean fields, then uses an s-tine beet cultivator for weed control. A cutaway disc at the front of the s-tine cuts the soil close to the row and tunnel shields protect small soybean plants from soil clods. These features allow him to drive relatively fast while cultivating. Although his weed control takes more time than using herbicides, the farmer says, "I'd rather be on my tractor than going to town to buy chemicals and filling tanks with water."

His soybean yields are usually about 10 bu/A lower than his conventional neighbors, but the clear hilum varieties he plants have a lower yield potential. During dry years, his soybean yields are more similar to neighbors, which he attributes to his organically managed soils' greater water holding capacity.

Soybean weed problems include Canadian thistle and giant foxtail. The rye cover crop helps suppress giant foxtail in soybeans. Lambsquarters, velvetleaf and quackgrass are former problems, and though they are still present, they do not impact the crop. According to this producer, "I think tillage and maintaining soil quality combat weeds better than chemicals."

Weed dynamics p 34.

Cover crops and weed control pp 65-66.

Summary

Since this farmer is certified organic, he cannot use pesticides. Thus, he is almost completely dependent on cultural ecologically based pest management methods. These include crop rotation, cover crops and innovative cultivation techniques. Although his yields are sometimes lower than his neighbors' and loss to pests may be sometimes higher, he is able to farm less land economically while avoiding pesticide use.

Chapter summary

While these farmers do not use all the principles described in subsequent chapters, by describing actual farms we create a context for some of those principles. The principles may be appropriate in many production agriculture settings. Some of the concepts presented may not have obvious, immediate application, but they provide basic information for making decisions about future pest management strategies. As noted in the introduction, this bulletin is designed around the concept that, "If the farmer knows why, he will teach himself how." This bulletin is a guide to help farmers, Extension agents, researchers and others work together in developing ecologically based pest management practices.

Principles of Field Crop Pest Ecology

Fabián D. Menalled and Douglas A. Landis

Key Points:

- **Living organisms interact with each other and their environment.**
- **Farmers modify the physical environment and the ecological interactions occurring on a farm.**
- **Many pests are regulated by natural enemies.**
- **Several practices may increase the abundance of natural enemies.**

Study Questions:

- **What are the similarities and differences between a natural and a farm ecosystem?**
- **What are the undesired side effects of pesticides?**
- **How are population numbers regulated?**

What is field crop ecology?

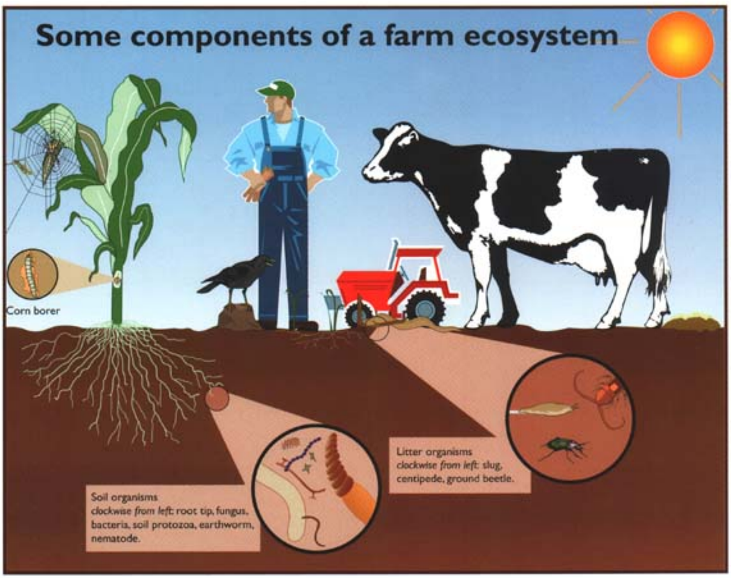
Agriculture is a biologically based enterprise. Its success depends heavily on the activity of many living organisms that interact continuously with each other and their physical environment. Ecology is the study of these interactions and field crop ecology is the application of these principles to field crop systems.

What is field crop pest ecology?

Field crop pest ecology is the study of interactions between the farm's physical environment (soil, water, temperature, etc.), desired animals and plants (livestock and crops, beneficial insects, beneficial nematodes and other soil organisms) and undesired organisms (weeds, plant pathogens, nematodes and insect pests). An understanding of field crop pest ecology will allow farmers to make better management decisions.

Farmers are ecosystem managers

When farmers make management decisions, they influence interactions among crops, livestock, beneficial organisms, pests and the physical environment. Farmers make decisions about the mix of plants and animals, the number of acres planted, when crops are planted, the tillage or herbicide used, the type and timing of fertilizer and pesticide applications. While biological and ecological considerations play a role in these management decisions, so do a number of economic, social and legal considerations. The result of making these management decisions is that farmers create a unique type of managed system: the farm ecosystem. There are almost as many different types of farm ecosystems as there are farmers!

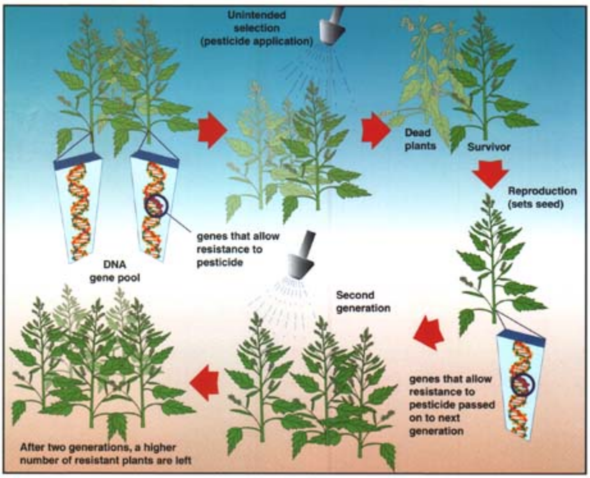


While we may not understand all aspects of each farm ecosystem, the same basic principles apply on all farms, if not in all ecosystems. Knowing more about these ecological principles, then, can help farmers design pest management strategies for their own farms and reduce some of the problems associated with overreliance on synthetic pesticides.

Genes and the environment: natural and artificial selection

Natural selection

Every living organism's physical and behavioral traits are determined by both its genes and its environment. **Genes** are sections of **DNA** (deoxyribonucleic acid) that determine what protein a cell produces. Particular protein combinations determine what an organism looks like and how it behaves. Each organism (except for a clone), has a unique combination of genes. When individuals reproduce, they pass their genetic material to the next generation. Because different environments favor individuals with different traits, individuals reproduce at different rates based in part on their environment. Thus some genes are passed on more often than others. This **differential reproduction** means that the abundance of each gene usually changes with time. The mix of genes in a population is called the **gene pool** Change in the gene pool that is not directed by humans is known as **natural selection**.



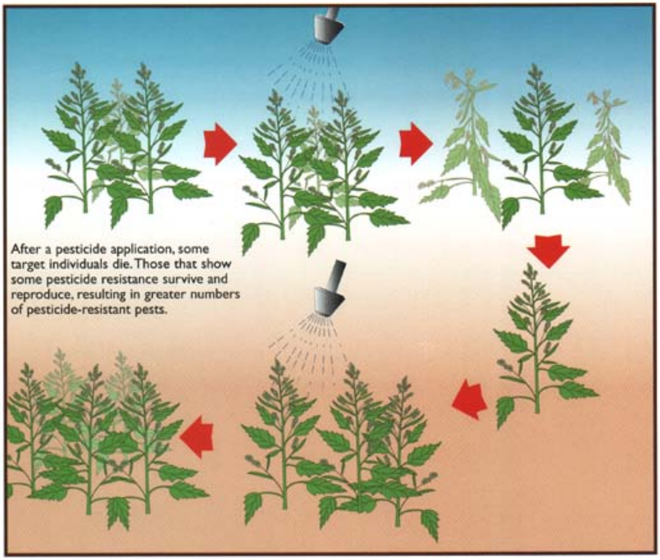
Artificial selection and agricultural productivity

In agriculture, we often manipulate both genes and the environment to influence how organisms look and behave. With the help of plant and animal breeders, farmers have taken advantage of the gene pool's natural variability within and among populations since the dawn of agriculture in the process known as **artificial selection**. After selecting desired traits (like quick growth or hardiness) from wild individuals for many years, farmers and breeders have increased reproduction of desired individuals to produce domesticated plants and animals.

Artificial selection: some unintended but important consequences

Indirect or **unintended selection** occurs when humans impact organisms by controlling their environments. One unfortunate result of this selection is **pesticide resistance** by weed, insect, nematode and pathogen pests. Chemical pesticides foster resistance because they kill the more sensitive individuals, while those that have some pesticide resistance, based on their DNA, survive and reproduce. When this pattern is repeated, pesticides gradually lose their effectiveness. Pesticide resistance is probably the greatest obstacle to long-term reliance on chemical pest control.

To reduce the risk of developing resistance, farmers should not rely on one chemical to control a pest problem. It is also important to design farm ecosystems to avoid pest damage. This means creating farm environments that do not favor pest population outbreaks. Let's look at some basic ecological concepts that will help us do this.



After a pesticide application, some target individuals die. Those that show some pesticide resistance survive and reproduce, resulting in greater numbers of pesticide-resistant pests.

Pesticide resistance

- At least 520 species of insects, mites and spiders have shown some type of pesticide resistance.
- There are more than 60 herbicide-resistant weed species. Lambsquarters, pigweed, common ragweed and common groundsel have all shown resistance to atrazine.
- In some pest species, pesticide resistance has increased as much as 25,000 times.
- Pesticide resistance can have a large economic cost. In Michigan, Colorado potato beetle resistance to insecticides was first detected in 1984. By 1991, control costs were $167/A in areas most heavily affected by resistant beetles but only $14-30/A where resistance was not a problem.

Basic ecology and pest management

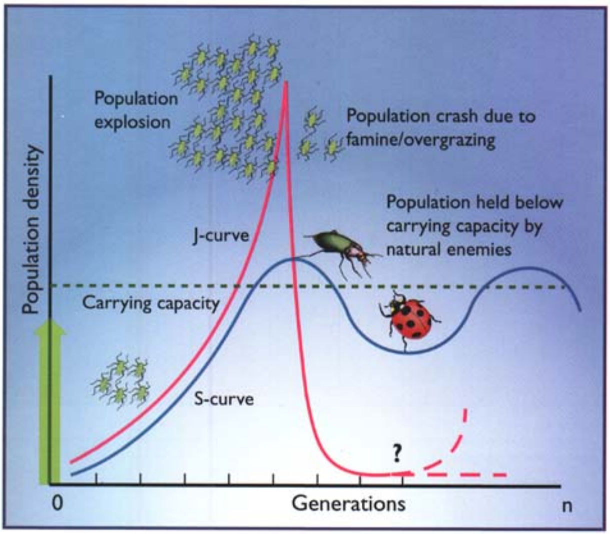
Population growth and regulation

All living organisms require certain amounts of **resources** to live and reproduce successfully. Among these basic needs are space, water, food (for animals), nutrients and sunlight (for plants). Since most individuals have more than one offspring in their lifetime, population density in a resource unlimited environment would increase **exponentially** through time as indicated by the **J-shaped** curve in the diagram below.

In real ecosystems, however, **resources are limited**, meaning that population size is limited by resource availability. The maximum number of individuals of the same species that can be supported indefinitely by these limited resources is called the **carrying capacity**. The carrying capacity is different for each organism in each environment. If a population exceeds its carrying capacity, it will soon crash due to insufficient resources. In most situations, population growth rate decreases as a population nears its carrying capacity. This pattern is represented by the **S-shaped** curve in the diagram below. Population densities of most organisms fluctuate due to such factors as changing resource availability. Since population densities are also regulated by natural enemies, actual population densities are often below carrying capacity. In many agricultural systems, we provide lots of resources for pest species but poor environments for natural enemies. The resulting environments favor pests.

Definitions

- **Species** – Organisms that can reproduce and bear viable and fertile offspring.
- **Population** – Individuals of the same species which can and do freely interbreed.
- **Population density** – the number of individuals of the same species living in a certain area.



Communities and ecosystems

Community

Crop fields seldom contain only one weed, insect, pathogen or nematode species; they contain communities of insects, pathogens, weeds and nematodes. A **community** is a group of populations of different species that live in an area. Individuals in a community are bound together by **biotic interactions** such as predation, parasitism and competition for resources. Because of these linkages, each population's activities may affect other populations. **Species diversity** refers to the number and relative abundance of species living in a community.

Ecosystem

All individuals belonging to a community are supported and affected by **abiotic factors**, the non-living, chemical and physical aspects of their environment. Temperature, humidity, rainfall patterns, wind speed, topography and soil physical and chemical characteristics are examples of abiotic factors that influence the distribution, abundance and type of interactions that occur between organisms in a community. All biotic and abiotic components and interactions make up an **ecosystem**.

Soil food web

Soil-dwelling microrganisms and insects that feed on dead plant and animal materials are called **detritivores**. A large number of soil insects and worms feed upon detritivores. Together these many interactions form the soil food web.

The soil food web is fundamental to all ecosystems since it is responsible for nutrient cycling; decomposition; many aspects of soil quality; supporting general predators; and providing some biological control of field crop pests, including insects, weeds, plant pathogens and nematodes. More details are provided in the following chapter.

Biotic interactions in agricultural ecosystems

Many interactions take place among organisms within and across farm ecosystems. Understanding the factors that influence these interactions is an important part of ecologically managing field crops. Remember that managing to address one aspect of a field crop ecosystem can indirectly or unintentionally influence other aspects. Several types of interactions relevant to agricultural management are discussed below.

Effects of competition between weed and crop plants

Effect of competition	Example
Increased mortality	Many weeds that emerge die due to competition from the crop plant.
Decreased reproductive success	Less seed produced per plant (fewer weed seeds and/or lower grain yield).
Varied individual size and shape	Weeds and crops grow taller and thinner to increase light interception.
Decreased growth rate	Many small weeds or a shorter crop.

Biotic interaction definitions

- **Food web structure** – the combination of all the feeding relationships that exist in an ecosystem.
- **Non trophic interactions** – relationships not included in food web interactions. For example, resource competition between weeds and crops, beneficial interactions between cover crops and cash crops, the association between parasitoids and hosts.

Competition for resources between crops and weeds

Competition between organisms of the same or different species occurs when there is greater resource demand than supply. Weeds and crops compete for moisture, nutrients, light and space. The effects of competition are numerous (see below). Farmers establish crops at a particular density (planting rate) to reduce the effects of **intra-specific competition** (competition between individuals of the same species) and maximize resource use and crop yield. Since crops and weeds require the same resources, one of the major causes of crop losses is **inter-specific competition**, competition between individuals of different species, such as corn and quackgrass. Practices such as crop rotation, cultivation, tillage and herbicide applications change crop-weed interactions and help reduce yield losses. Likewise, soil quality, which favors crop growth, can reduce weed competitiveness.

Weeds and herbicides

- Annual U.S. crop loss due to weeds currently exceeds $4 billion.
- Herbicides are widely used across the United States. They are the most common farm pesticide group.
- Increased herbicide reliance has improved crop productivity and farm labor efficiency, but in many cases has resulted in ground and surface water contamination, and the development of weed resistance to herbicides.
- Farmers, researchers and regulators are seeking new, ecologically based ways to help reduce weed competition in crop fields.

Photo: Steven R. Deming

A crimson clover cover crop.

Beneficial interactions between crops and other plants

Some inter-specific plant interactions are beneficial. **Cover crops,** for example, can suppress weed populations, reduce soil erosion, improve soil structure and fertility, and reduce insect pest populations. Cover crops can sometimes have a negative impact on a succeeding crop by reducing soil moisture availability or serving as an alternate host for a crop pest. This means that during a dry spring it is important to kill a cover crop earlier than during a wet or normal year. It is also important to match cover crop and cash crop characteristics to reduce potential negative interactions between the two. Managing cover crops effectively requires understanding both the positive and negative interactions between cover crop species and varieties and the crop plant.

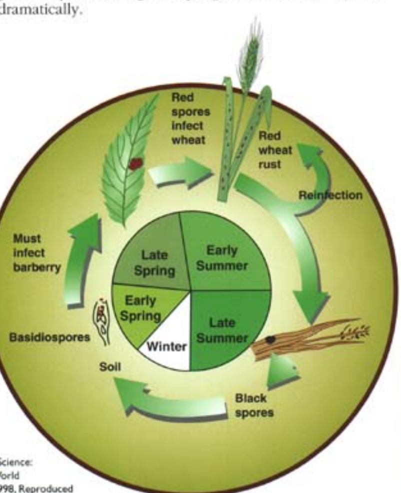
Plant-insect-pathogen interactions

Some biotic interactions are more complex. Weeds bordering fields may harbor aphids that can transmit barley yellow dwarf virus. In this case, a landscape management approach may help reduce pest problems.

Barley yellow dwarf virus.

Plant-pathogen interactions

Since fungi and bacteria may overwinter or complete their life cycles in plant residues, habitat management is a valuable strategy for reducing the risk of pathogen infestations. Wheat rust, for example, is a serious wheat field pest, causing high mortality levels. For part of its life cycle the rust must infect barberry, an alternative host. Eliminating barberry in wheat-growing regions reduces wheat rust problems dramatically.



Source: Nebel/Wright, Environmental Science: The Way The World Works, 6/E, ©1998. Reproduced by permission of Prentice-Hall, Inc., Upper Saddle River, N.J.

Rust on wheat.

Ground or carabid beetle adult.

Plant-insect interactions

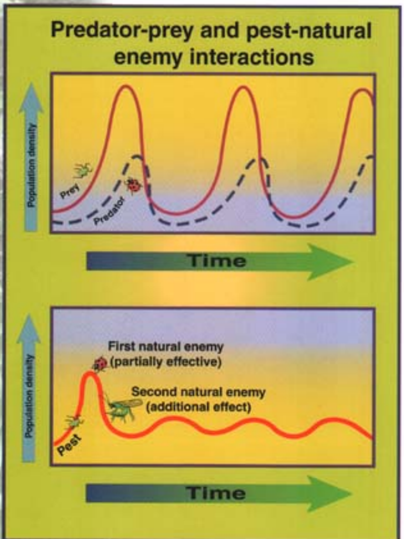
Plants can influence insects. Plant structural and chemical composition influence insect species abundance and diversity. For example, the behavior, reproductive success and amount of food consumed by ground beetles – common beneficial field crop insects – are directly affected by soil humidity and soil temperature. These factors, in turn, are affected by the amount and location of a crop's branches and leaves. Ground or carabid beetles, are more common in fields with cover crops than in recently plowed fields. These beetles also seem to prefer cover crops that form dense mats.

Insects may also influence plants. These influences include herbivory, pollination and seed predation and dispersal. Due to its importance in reducing crop yield, herbivory has perhaps attracted more attention from applied researchers and farmers than have all other forms of plant-insect interaction. Understanding the many insect-plant interactions is essential in managing field crop ecosystems to reduce insect pest impacts.

Crop pest-natural enemy interactions

Natural enemies are organisms that prevent agricultural pests from reaching outbreak levels. Natural enemies may be predators, parasites or parasitoids and include birds, frogs, spiders, lady beetles (also called ladybugs), ground beetles, fungi, bacteria and nematodes.

Researchers have analyzed pest-natural enemy interactions for many species. Many potential pest problems are controlled, largely without our knowledge, by natural enemies. The importance of such interactions becomes evident when pesticide applications kill natural enemies and permit pest outbreaks.



Predators

Predators help control pest population densities as shown in this diagram. For simplicity, let's assume that the number of predators living in a crop field depends only on the prey population size and vice versa. If there is a large number of aphids, a common Michigan field crop pest, then ladybird beetles eat a lot of aphids and have many offspring. If there are no aphids, lady beetles starve and disappear from the system. The number of aphids depends on the number of lady beetles: if there are few predators, most prey survive. Prey are **predator-limited** and predators are **prey-limited**. In an ideal situation, predator and prey population sizes vary through time, but prey never reach pest status.

Often, more than one insect predator is necessary to keep pest population densities below economic threshold levels.

Common Michigan predators

Predator	Pests attacked
Ladybird beetles	Aphids, scale insects, mealy-bugs, whiteflies
Ground beetles	Cutworms, armyworms, weed seeds
Predatory flies	Aphids
Lacewings	Aphids, whiteflies
Minute pirate bugs	European corn borers
Damsel bugs	Bean beetles, alfalfa weevils

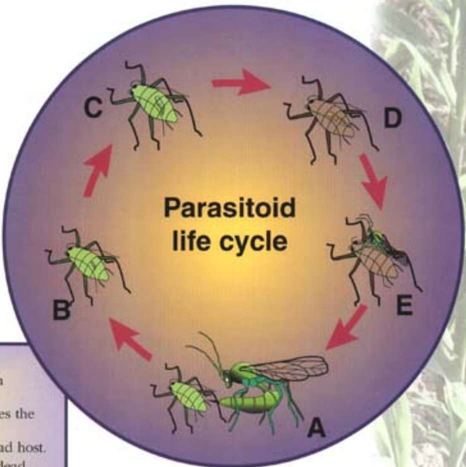
Predaceous stink bug.

Parasitoids

Parasitoids are insects, usually small flies or wasps, that lay eggs in, on or near their hosts. Free-living adult parasitoids often feed on the nectar provided by flowers. The female parasitoid finds a host and lays one or more eggs in or near it. The parasitoid larvae develop inside or near an insect host. The host dies and, eventually, one to many thousand adult parasitoids emerge.

Parasitoids

- Parasitoids are a rich and diverse group. For example, in just two parasitic wasp families there are about 100,000 species!
- Parasitoids are beneficial insects that kill their hosts to control crop pests.



Parasitoid life cycle

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

Common Michigan parasitoids

Parasitoid	Pest attacked
Eriborus terebrans	European corn borer
Meteorus communis	Armyworm
Tetrastichus julis	Cereal leaf beetle
Microctonus aethiopoides	Alfalfa weevil

Photo: Steven R. Deming

The black marks on this armyworm are oviposit stings from *Glyptapanteles Militaris* (Walsh), a parasitoid wasp. The white, cottony structures above the armyworm are the tiny parasitoids' cocoons.

Photo: Steven R. Deming

A border along a field's edge provides habitat for many beneficial insect predators and parasitoids.

Although insect pest predators and parasitoids can help farmers reduce the risk of pest outbreaks, annual crops often provide a harsh environment for them. The lack of food, water and shelter to escape from adverse conditions like a pesticide application, and the absence of hosts limit large natural enemy populations in many field crops. Effective predator and parasitoid communities can be preserved by such practices as planting cover crops, maintaining hedgerows and fencerows and pest scouting with carefully planned pesticide application. Using a combination of these practices may decrease the need for pesticides.

Complex interactions

Many ecological interactions are even more complex than the prior examples suggest. For example, managing soil organic matter seems to have a strong influence on plant parasitic nematode populations. All the interactions involved in this management strategy are not yet fully understood, but are discussed in the following chapters: Soil ecology and pest management and nematodes and soil quality.

Summary

Farmers play a major role in controlling interactions occurring among a field's many components. It is important to remember that anything we do to increase crop productivity, reduce weed, plant pathogen, nematode and insect pest outbreaks, and raise healthy livestock impacts the farm's biological and ecological communities.

Designing an economically viable, sustainable and productive modern agriculture requires clearly understanding the environmental, biological and economic framework where these activities take place. As with IPM, the ecologically based pest management principles discussed in this bulletin also depend on monitoring, identifying and understanding pest life cycles, pest damage thresholds, economic injury thresholds and action levels. Ecologically based pest management, however, takes the next step by deliberately designing field crop ecosystems and landscapes to reduce pest population sizes by increasing natural enemies' effectiveness and making the abiotic environment less favorable to pest species.

Soil Ecology and Pest Management

Michel A. Cavigelli

Key Points:

- Many field crop pests live at least a portion of their lives in soil.
- Most soil organisms are not pests and many help keep pest populations low.
- Soil organisms include many diverse groups. Some of their many interactions are described using soil food webs.
- Organic matter is the ultimate energy source for soil organisms.
- The amount, type and timing of organic matter additions to soil, as well as other management practices, influence the soil food web and may have some important effects on field crop pests.

Study Questions:

- How can soil fertility influence insect pest dynamics?
- How might soil organic matter influence plant pathogens and plant parasitic nematodes?
- How do weeds and the soil food web interact?

Soil - What's it good for?

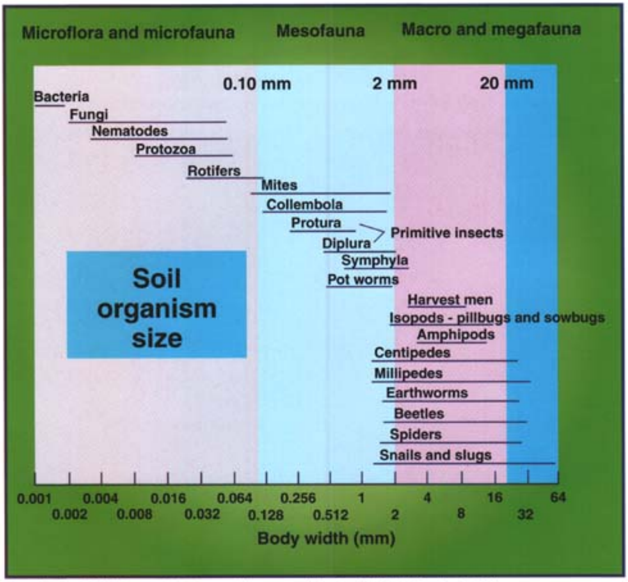
Soil filters water, recycles wastes and nutrients and provides an environment for plant growth. It is also an important habitat for many organisms. The interaction between beneficial organisms and the agricultural pests they eat, parasitize, infect and compete with, keeps many potential pests from becoming economically important pests.

Some farmers have long talked about soil health's importance to plant health and pest management. As scientists begin addressing these links, they are finding some interesting and, perhaps, surprising connections between belowground ecology and aboveground plant health and pest dynamics. Some of these findings are described in this chapter, along with soil food webs and how farm management impacts them.

Soil organisms

All weeds and most field crop nematode pests live in soil. Many insect pests, all soilborne plant pathogens and some foliar pathogens rely on soil for at least a part of their life cycle. These potential pest species, however, comprise a tiny proportion of the total soil community. The vast majority of soil organisms are either beneficial or not harmful to field crops.

One useful way of categorizing soil organisms is by their size, as shown below. Note: These organisms are so small that they are difficult to describe in English units like inches; their size is noted in millimeters (mm).



Source: Swift et al. 1979. Decomposition in terrestrial ecosystems. University of California Press, Berkeley, CA.

Microflora and microfauna

The smallest soil organisms, bacteria and fungi, are called the microflora. The microfauna, many of which eat microflora, are the smallest soil animals and include nematodes, protozoa and rotifers. Microflora are responsible for chemically decomposing many plant and animal residues and converting them to soil organic matter. When microfauna prey on microflora, decomposition and nutrient cycling rates and soil food web dynamics increase.

Microflora and fauna live in the thin films of water surrounding soil particles and are very sensitive to soil moisture. Many have resting stages or forms that allow them to survive during unfavorable conditions. Microflora and microfauna are often grouped together and referred to as soil microbial biomass.

Mesofauna

The next biggest group, the mesofauna, includes organisms that are between 0.1 and 2 mm in size. These organisms live in the air-filled portions of soil pores and are not as sensitive to dry conditions. Because they are larger, they can move greater distances. Most of these organisms are arthropods that eat smaller organisms and soil organic matter. The mesofauna are important in breaking up plant and animal residues and increasing decomposition and nutrient release rates.

Macro and megafauna

The macrofauna are 2 to 20 mm in size and the megafauna are greater than 20 mm. These organisms are large enough to create their own soil pore spaces. This activity affects the microhabitat of smaller organisms. These large organisms also affect smaller organisms when they feed, since they ingest thousands of organisms as they consume decomposing organic matter and pass soil particles through their guts.

More specific functions of many of the microflora, microfauna, mesofauna, macrofauna and megafauna are described in ***Michigan Field Crop Ecology***.

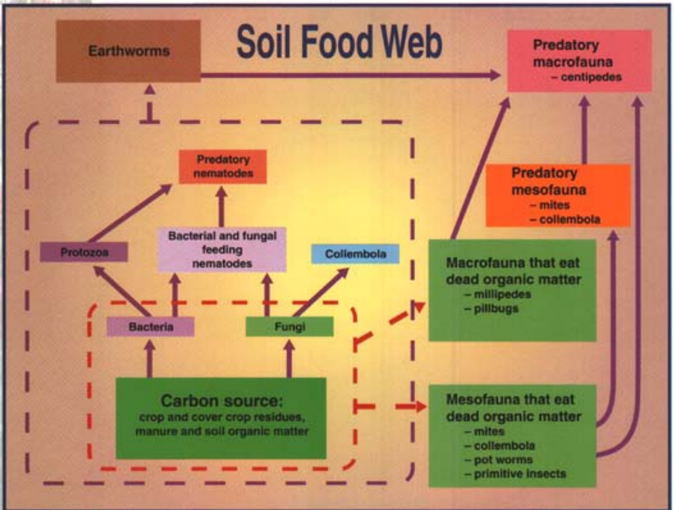
Soil food web

Many important soil organism groups and their interactions are shown in the diagram on the next page. This "who eats whom" diagram is called a food web. In most cases, larger soil organisms eat smaller ones. It is this feeding that breaks down organic matter (crop residues, manures, cover crops and soil organic matter), converting it to soil organic matter during decomposition. As shown in this diagram, one group of organisms, such as nematodes, may play many different roles in the soil food web. Additionally, more than one group of organisms may play similar roles. For example, mites, collembola and potworms each feed on microbial biomass as they consume dead organic matter. Also, notice that the entire food web is dependent on organic matter inputs.

Since measuring soil life is very time consuming, only a few studies have compared how the biomass or numbers of the various soil food web groups respond to farm management practices. One group of scientists in the Netherlands counted or measured soil organisms every six weeks in winter wheat managed under two systems: a conventional and an integrated system. The integrated system incorporated more organic matter (crop residues, manure and compost) into the soil and reduced the need for synthetic nitrogen fertilizers and pesticides, especially nematicides, compared to the conventionally managed system. Many of the management differences between these two systems are listed in the table on the following page.

> "Integrated farming involves a shift from directly feeding the plant with mineral nutrients to feeding the soil organisms with organic matter, thereby indirectly feeding the plant through nutrient mineralization by soil organisms."

Source: Bloem et al. 1997. Modern Soil Microbiology, Marcel Dekker Inc., New York, pp 245-278.



Source: Wardle, D.A. 1995. Advances in Ecological Research 26:105-185.

Soil food web

The arrows indicate who eats whom. The dashed lines indicate the groups of organisms that are consumed together by larger organisms.

Summary of management practices and crop yields in conventional and integrated farming systems in the Netherlands. All numerical values are averages for four years of a winter wheat, sugar beet, spring barley and potato rotation.

Practice	Conventional	Integrated
Cover crops	Following small grains	Following barley
Tillage depth	8 inches	4 inches
Organic matter additions - sources	Crop residues, cover crops	Crop residues, cover crops, animal manures and mushroom compost
Organic matter additions - amount	2,900 lb/A/yr	5,100 lb/A/yr
Nitrogen fertilizer applied	150 - 250% of integrated	40 - 65% of conventional
Total N inputs (including organic sources)	175 lb N/A/yr	138 lb N/A/yr
Nitrogen mineralization rate	70 lb N/A/yr	98 lb/A/yr
Weed management	Herbicides	Cultivation + herbicides
Nematicides	Following wheat	none
Fungicides	For potatoes, wheat and barley	For potatoes
Insecticides	For potatoes, wheat and beets	For wheat
Crop yields	110% of integrated	90% of conventional

Source: Lebbink, G. et al. 1994. Agriculture, Ecosystems and Environment 51:7-20.

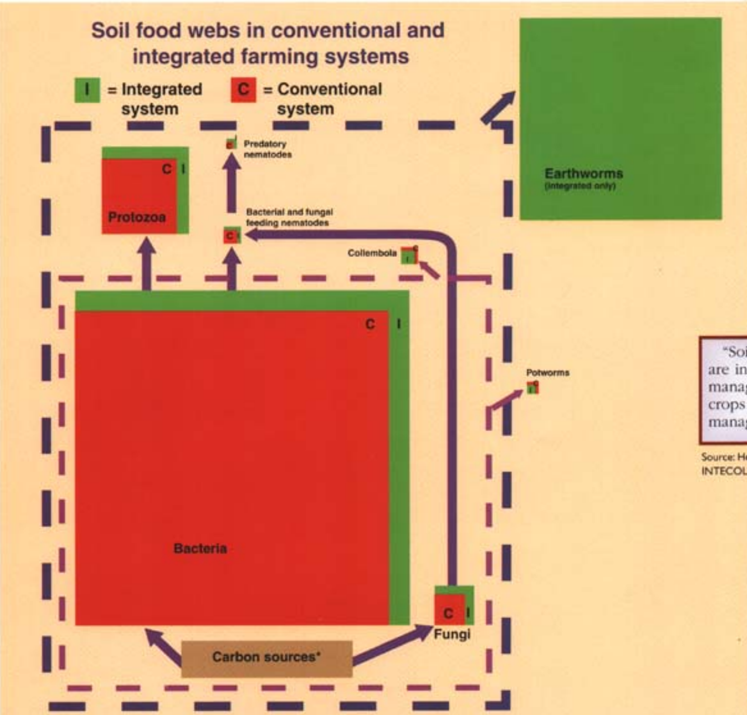
Management effects on soil food webs

How do these different management systems affect soil organisms?

This figure shows a portion of the soil food webs in the conventional and integrated farming systems (compare with the previous diagram). The size of each box represents the biomass of than soil organism group, indicating how farm management practices affect the soil food web.

The carbon source box, however, is not drawn to scale. Since soil microbial biomass is almost always less that five percent of total organic carbon in soils, this box would be more than two feet long on each side if drawn to scale!

The largest difference between these two soil food webs is the lack of earthworms in the conventional system. In addition all other groups except potworms and collembola, had more biomass in the integrated system than in the conventional system.

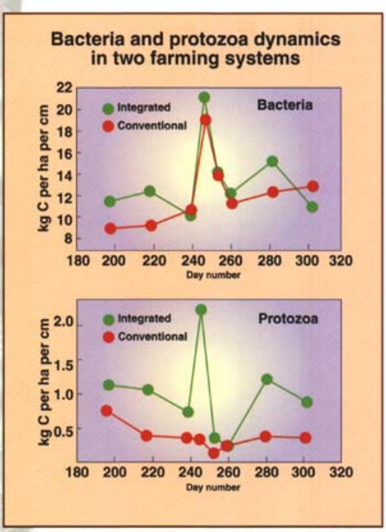


*Note: carbon source box size not to scale.

Source: Diagram from Wardle, D.A. 1995. Advances in Ecological Research 26:105-185, box sizes derived from web values in conventional and integrated systems as given by Lebbink et al. 1994. Agriculture, Ecosystems and Environment 51:7-20.

> "Soil organisms are inadvertently managed when crops and soils are managed."

Source: Hendrix et al. 1987. INTECOL bulletin 15:59-63.



Source: Zwart et al. 1994. Agriculture, Ecosystems and Environment 51:187-198.

Soil food webs are influenced by farm management practices. There is greater soil activity in systems that increase the amount or quality of soil organic matter. It is important to note, however, that conventional farming does not "kill the life in the soil," as suggested by some. Instead, farm management impacts on soil food webs are more subtle, though they may have greater influence on farm function than we currently understand.

For example, in these two systems, since the researchers measured soil food web organisms every six weeks, we can learn something about food web dynamics, or how population sizes change during a growing season. One set of patterns is shown in the graphs at left. In these systems, harvest, tillage and fumigation or compost application occurred between days 227 and 236.

Although bacterial and protozoan dynamics were often similar in both systems at other times of the year, protozoa but not bacteria, responded to harvest-associated management differently in the two systems.

Seasonal population dynamics of other soil organism groups were different in the integrated and conventional systems as noted in the table below.

These patterns can significantly affect how soils function. Nitrogen cycling rates, for example, often increase when the number of organisms that eat bacteria and fungi increases. In this study, protozoa and nematode biomass and nitrogen mineralization rates were greater in the integrated farming system. As we will see later, increased nitrogen mineralization can influence aboveground insect pest behavior.

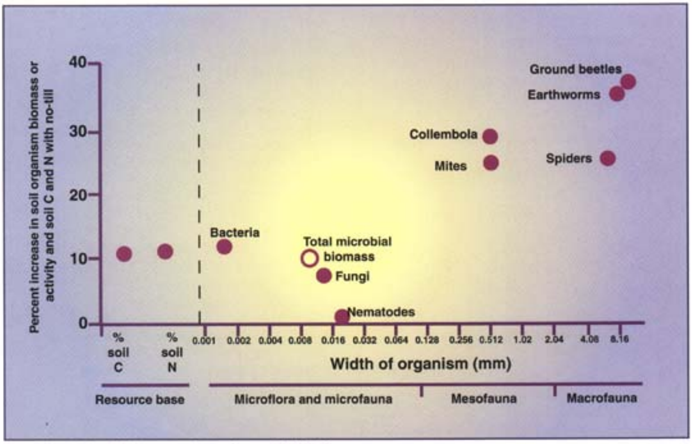
Soil organism dynamics in a conventional system versus an integrated system

Organism group	Seasonal population dynamics (conventional and integrated systems compared)	Organism group	Seasonal population dynamics (conventional and integrated systems compared)
Bacteria	Similar	Collembola	
Fungi	Similar	Predators	Different
Protozoa		Omnivores	Different
Amoebae	Similar	Mites	
Flagellates	Similar	Predators	Similar
Nematodes		Nematode eating	Different
Bacterivores	Similar	Cryptostigmatic	Different
Fungivores	Different	Bacterivores	Different
Predators	Different	Other	Different
Plant parasitic	Different	Pot worms	Different
		Earthworms	Different

Source: Zwart et al. 1994. Agriculture, Ecosystems and Environment 51: 187-198.

Tillage effects on soil food webs

Tillage may affect many soil food web groups. In this graph, the y-axis represents the percent increase in soil food web resources (soil carbon and nitrogen and organisms under no-till compared to conventional tillage. In general, eliminating tillage tends to favor the macrofauna and some of the mesofauna, while having only small effects on microflora and fauna.



Source: Wardle, D.A. 1995. Advances in Ecological Research 26: 105-185.

Photo: Steven R. Deming

Soil insects - collembola.

Soil food web activity is influenced by weather

Most, if not all, soil organisms are particularly sensitive to soil moisture and temperature. Soil organism activity is generally low when soils are dry, very wet, cold (less than 50 degrees F) or hot (greater than 90 degrees F). Activity is highest in warm, moist soils when food is available. In Michigan, this means soil organism activity is often highest in late spring and early fall, except during droughts. In addition, since soil organic matter can help retain soil moisture, a soil's organic matter level (and its texture) can strongly influence soil food web activity.

Mycorrhizae – an important group of soil microorganisms

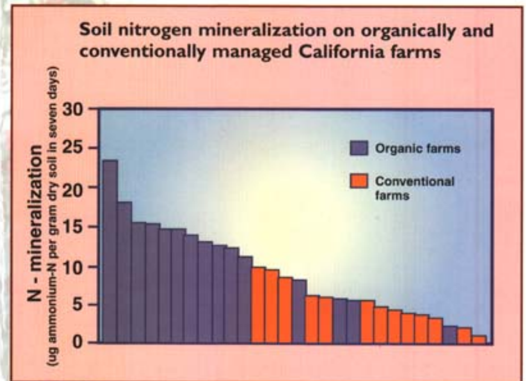
Mycorrhizae are fungi that form a symbiotic relationship with plants. Most plants form these relationships. Mycorrhizae have been shown or suspected of providing many benefits to crop plants, including:

- increased water use efficiency
- increased nutrient uptake, especially phosphorus and zinc
- increased plant vigor
- decreased fungal root pathogen susceptibility
- decreased plant parasitic nematode susceptibility

In addition, mycorrhizae may be important in soil aggregate formation and nutrient cycling. These processes are more fully described in ***Michigan Field Crop Ecology***.

Soil food webs and pests

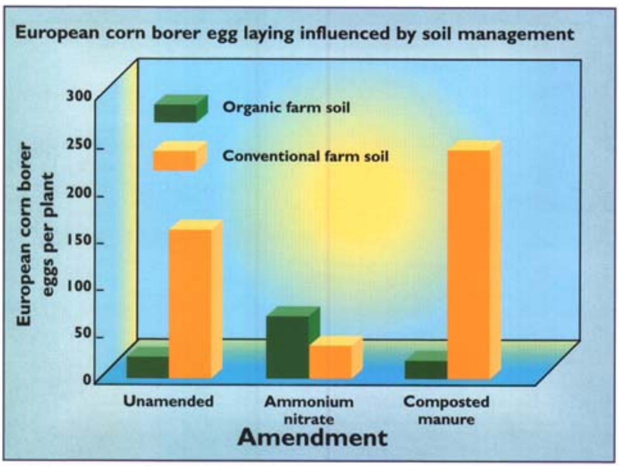
The pests that live in the soil are part of the soil food web. Their interactions with non-pest organisms affect their survival, population densities and how they impact field crops. How soil food web dynamics impact pest dynamics is beginning to be given serious consideration. Some recent examples are discussed below.



Source: Drinkwater, L. et al. 1995. Ecological Applications 5:1098-1112.

Soil ecology and insect pest dynamics

Increased nitrogen mineralization rates are commonly found in farming systems that focus on increasing the amount or quality of soil organic matter. These differences in plant nitrogen nutrition may be related to insect pest population dynamics. In one study, when corn was grown in a greenhouse in two soils – one that had been managed conventionally and one that had been managed organically – European corn borer (ECB) preferred the corn growing in the conventionally managed soil. In addition, the form of nitrogen fertilizer applied to the corn influenced the ECB preference differently in each soil. The researchers think this pattern may be related to the higher nitrogen content of corn growing in the conventionally managed soil.

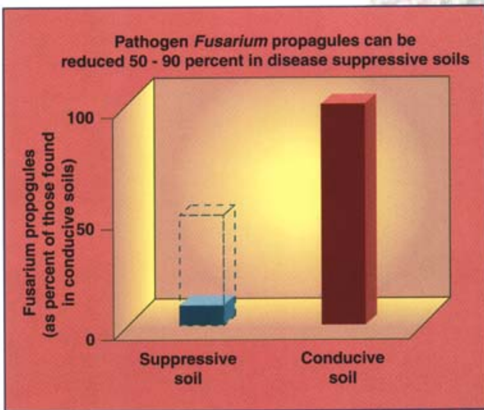


Source: Phelan, P.L. et al. 1996. Environmental Entomology 25:1329-1336.

Soil ecology and plant pathogen dynamics

In natural ecosystems, soilborne disease outbreaks are relatively rare compared to agricultural ecosystems. Some cultivated soils may suppress some diseases. Susceptible crops growing in these disease suppressive soils do not show disease symptoms even when the disease-causing pathogen is present.

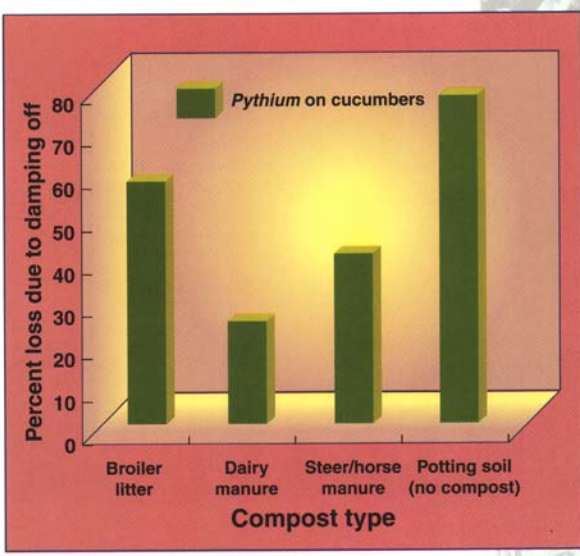
Why this suppression occurs is not always known, but in some cases it involves **microbiostasis** – suppression of a disease-causing organism by other, sometimes closely related, soil food web organisms. Disease suppressiveness can sometimes be induced with management but may also be an inherent part of a particular soil. Disease-suppressive soils are well known in California, the Pacific Northwest and Australia, but there are no documented examples in Michigan. The fact that field crop diseases are not more common is probably due to the constant competition, predation and other interactions between plant pathogens and other soil food web organisms.



Source: Alabouvette, et al. Soil-Borne Plant Pathogens, pp 165-182, 1979, by permission of the publisher Academic Press.

Some types of compost have been shown to suppress some important plant diseases and are currently used in the bedding plant and horticultural industries.

Some believe that this same principle may be at work in organically managed field crops or in some high organic matter soils, but we do not yet know if this is the case. Though we have not yet learned which management practices consistently favor non-pest species at the expense of disease-causing organisms, soil organic matter management will likely be involved in future plant pathogen management options that reduce the risk of soilborne diseases.



Source: Ringer, et al. 1997. Compost Science and Utilization 5:6-14.

Soil ecology and nematode community dynamics

Managing the soil food web by managing the resource base – soil organic matter – clearly affects plant parasitic nematodes. As organic matter inputs to soil increase, there is often a decrease in the ratio of plant parasitic nematodes to other nematodes. This effect may be due to competition between other soil food web organisms and the plant pathogenic nematodes.

Soil organic matter additions affect nematode ratios

Soil fertility program	Bacterial-feeding nematodes / Plant parasitic nematodes
Conventional soil fertility[1]	0.34
Alternative soil fertility[2]	8.63

[1] 2 T/A dolomitic lime; 250 lb/A 0-06-0; 300 lb/A 20-10-10; 223 lb/A 45-0-0.
[2] 2 T/A flour of lime; 5 T/A composted cow manure; 0.5 T/A canola meal.

Source: Berney, M.F. and G.W. Bird. 1998.

Soil ecology and weed dynamics

Weeds and the soil food web influence each other. Allowing economically acceptable weed levels may provide some soil food web advantages, possibly by providing live roots around which soil organisms are particularly active. It is important that weeds not be allowed to set seed and contribute to the soil weed seed bank. In addition, weeds that are alternate hosts for diseases should be managed with this in mind.

Some soil food web organisms help reduce the soil weed seed bank size, but we do not know by what proportion. Researchers are studying how management practices that keep the soil surface moist by maintaining living or dead plant materials on the soil's surface, might increase weed seed decomposition and predation.

Soil and water conservation practices increase weed seed-eating insect populations. When ground beetle species were counted in Michigan switchgrass waterways and alfalfa and soybean fields, the waterways contained 38 ground beetle species, while the alfalfa and soybean fields harbored 29 and 25 ground beetle species, respectively. The ground beetles in the waterways ate 84 percent of foxtail seeds offered them in one week, while the beetles in the soybean field ate only 17 percent of these weed seeds.

Summary

Farming methods that focus on creating biologically balanced soil food webs rely on ecosystem self-regulation and can reduce the need for synthetic fertilizer and pesticide inputs. The extent to which we can rely on ecosystem self-regulation in field crop pest management is not always clear, but we are probably just beginning to see the potential of this strategy.

Photo: Steven R. Deming

Farmers and researchers evaluate soil organic matter in field trials at the W.K. Kellogg Biological Station.

Insect Pest Ecology and Management

Douglas A. Landis

Key Points:

- Most field crop insect species are either beneficial or not harmful.
- Natural factors (weather, predators, parasites and disease) control most insect pest populations.
- Successful pest species are often good invaders with high reproduction rates.
- Management practices that increase natural pest controls can reduce pest insects.
- Consider factors outside fields for effective insect management systems.

Study Questions:

- Why are imported insect species often more of a pest problem than native species?
- How does crop uniformity favor many pest species?
- How can we manage crops to favor natural controls (abiotic and biotic)?

What are insect pests?

Every Michigan field contains a great variety of insects. An alfalfa field may harbor more than 500 insect species and a soybean field more than 400 species. Given this level of diversity, it is remarkable how few insects significantly damage crops. For example, only two insects are consistently pests in Michigan corn fields, two in alfalfa fields and none in soybean fields.

Why do some insects become pests while most do not? Do insect pests share common characteristics? This chapter focuses on insect, crop and crop field attributes that allow some species to become field crop pests. By understanding these factors, producers can better develop new methods for managing field crop ecosystems, reducing insect pest abundance and damage and insecticide applications.

An alfalfa field can be home to more than 500 different insects. Only two species, potato leaf hopper and alfalfa weevil (far left) are major pests.

Alfalfa weevil larva.

Why are some insects pests?

Insect pest adaptations to field crop ecosystems

To survive and be successful, all organisms must cope with the physical environment, find food, avoid enemies and reproduce. Michigan field crop ecosystems share many attributes: crops are usually present for about five months, they have only one dominant plant species and they usually cover large areas. Understanding insect pest adaptations to these ecosystems is one key to discovering new insect pest management methods.

Host range

An insect's host range – the number of different plants it can feed on – helps determine if it will be a pest.

Generalists

Some insects are general feeders, consuming a wide variety of plants. Black cutworms, European corn borers (ECB) and potato leafhoppers (PLH), each feed on more than 100 plant species, including many crop plants. Generalists easily find plants they can eat, but much of that food may not support rapid growth and reproduction. While PLH can eat grasses, for example, they will not produce eggs unless they find a more favored host, such as alfalfa or dry beans. Because generalists feed on so many plants, they cannot adapt to the toxins that some plants (such as cabbage or potato) produce. So, they typically favor plants with less sophisticated defenses.

Moderate specialists

Other insects are moderately specialized, favoring certain plant groups. For example, alfalfa caterpillars prefer legumes (beans, peas, etc.), the potato flea beetle like solanaceous plants (potatoes, tomatoes, etc.) and the imported cabbageworm prefer cole crops (cabbage, broccoli, etc.). Insects often adapt to one plant group because related plants share similar chemical defenses. By overcoming one plant species' defense, the insect may also be able to eat the other members of that plant's group.

Specialists

At the far extreme are the specialists, which feed on only a few, or in some cases, only one host plant species. Specialization has advantages, as it allows the insect to develop sophisticated ways for finding and utilizing its particular host plant. One disadvantage is that the insect cannot survive if the host plant becomes rare or disappears. There are very few specialist field crop insect pests.

PLH (inset) is a general plant feeder. Corn, alfalfa, soybeans and snap beans are all potential food sources.

Armyworms (inset) feed on members of the grass family including corn, wheat, quackgrass and perennial ryegrass.

Potato leafhopper migration

Entomologists have known since the early 20th century that PLH overwinter in the southern U.S. and migrate north each spring. The combination of a high-pressure system centered to Michigan's southeast and a low-pressure system centered to the state's southwest create the right conditions for PLH migration to northern states. These weather fronts stimulate a "nocturnal air jet" that travels about a mile above the earth's surface. This air current helps the migrating PLH fly hundreds of miles a day.

Scientists once believed PLH only survived winters by feeding on legumes along the Gulf Coast. By combining information on weather patterns and overwintering habitats in computer models to track PLH migration, scientists learned that PLH also live on southern pines, as far north as southern Missouri and Virginia. PLH travel to legumes each February, producing the generation that then migrates northward. This 1994 discovery greatly expanded the known PLH overwintering range and now entomologists can better predict the potential for the insect's Michigan arrival.

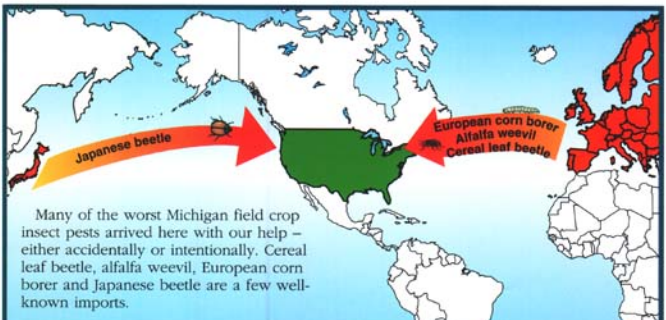
Host-finding

Many Michigan insect pests do not spend the winter in crop fields, so they must disperse to find host plants.

Field crop pests can travel from a few hundred yards to many miles. Some insects migrate very long distances. PLH, black cutworm, armyworm and corn earworm moths migrate hundreds of miles each year between their winter habitats in the southern U.S. and their summer range in Michigan.

Where do Michigan field crop pest and beneficial insects overwinter?

Insect	Overwintering site
	Outside Michigan
Potato leafhopper adults	Pine trees in Southern U.S.
Black cutworm larvae/pupae	In soil, migrates north in spring
Armyworm larvae/pupae	In soil, migrates north in spring
Corn earworm pupae	In soil, migrates north in summer
	Outside crop fields
Alfalfa weevil adults	Field borders, woodlots
Spider mite adults	Sheltered locations in field borders
Spotted ladybird beetle adults	Under plant debris in woodlots and fencerows
Bird-cherry oat aphid	Eggs on cherry trees
Ground beetle adults (some)	Under plant debris in woodlots and fencerows
	In crop fields
European corn borer mature larvae	Corn stubble
Sugar beet root aphid	Lambsquarters roots and culled beets
Corn rootworm eggs	Corn field soils (variant in soybean field soils too)
Ground beetle eggs and larvae	In soil



Many of the worst Michigan field crop insect pests arrived here with our help – either accidentally or intentionally. Cereal leaf beetle, alfalfa weevil, European corn borer and Japanese beetle are a few well-known imports.

Once in or near a crop field, insects must locate their host plants. Many plant-eating insects use visual cues to find their hosts. Yellow is particularly attractive to many of them, which is why pest scouts use yellow sticky traps to capture insects. Aphids use the contrast between the soil and green plants to trigger landing after migrating. Using mulch materials that reflect the sky can greatly reduce aphid landing rates and subsequent population build-up or disease transmission. While mulching materials may not directly apply to field crop situations, this strategy suggests a biologically based way to avoid aphid damage by reducing aphids host-finding ability. Perhaps an intercropped cover crop might also reduce aphid landing, but this idea has not been tested.

Odor is another vital host-finding cue. Some insects detect their hosts' odor with their antennae and fly toward the scent. Seedcorn maggot flies are attracted to the odor produced by bacterial decay of organic matter. Planting corn too soon after plowing down green plant material can result in seedcorn maggot infestations. A general rule is to delay planting for 14 days allowing decomposition to occur.

Photo: Steven R. Deming

Workshop participants identify insects on a yellow sticky trap.

Once on the plant, insects check plant foliage texture using sensory hairs on their bodies and legs. They then use mouthparts, ovipositors or taste organs on their feet (alfalfa butterfly) to accept or reject a plant.

Feeding niches and damage

Field crop insect pests have adapted to use almost all plant parts, meaning they can reduce yield and crop quality from planting time until a crop leaves the farm. Depending on the crop and its intended use, some types of insect damage are harmless while others can cause severe economic loss. Distinguishing between the two types of damage is important in managing insect pests.

Plant parts and examples of field crop insects that attack them

Plant part	Damaging insects
Seeds beneath soil	Seedcorn beetle
Seedlings (below ground, e.g. hypocotyl)	Seedcorn maggot
Seedlings (above ground, e.g. cotyledons)	Flea beetles, Collembola
Roots	White grubs (larvae of May and June beetles)
Root crown	Clover root curculio
Stem	European corn borer, Common stalk borer
Leaves	Grasshoppers, Alfalfa weevil
Leaf epidermal cells	Two-spotted spider mite
Mesophyll (area between leaf surfaces)	Spinach leafminer, Alfalfa blotch leafminer
Phloem tissue	Aphids
Leaf buds	Alfalfa weevil
Flowers	Bean leaf beetle
Developing seeds	Tarnished plant bug
Mature seeds	Indian meal moth

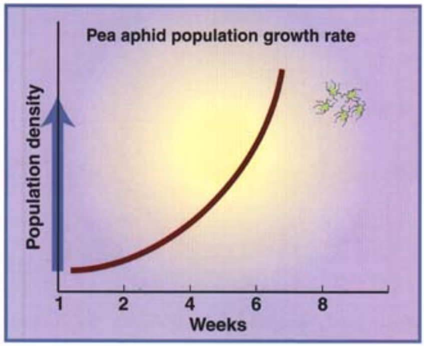
Insect damage: left – spider mite-damaged soybean field (indirect); right – alfalfa damaged by PLH (direct).

Most insect feeding affects yield indirectly by weakening or killing a plant. Examples of indirect pest damage include spider mites on soybean leaves and spinach leafminer damage to sugar beets.

In contrast, other insects directly attack the harvested commodity. PLH feeding on alfalfa foliage and tarnished plant bug damage (stings) to dry bean seeds are two examples of direct pest damage. Direct feeders can be difficult to manage since their attack is concentrated on the valuable plant part, leaving little room for damage tolerance.

Reproduction and population growth

Damage by a few insect pests might be easily overlooked, but many field crop insect pest populations increase very quickly. A single female pea aphid, for example, can give birth to as many as 10-12 offspring per day. Because all of her offspring are typically female and reach sexual maturity in as little as six days, the population grows very rapidly.



Life histories

Entomologists often look at an insect's life history and reproductive strategy for clues on managing it. For instance, insects living in harsh, unpredictable or unstable environments such as annual crop fields tend to produce many offspring early in life. This applies to common field crop insect pests such as aphids, spider mites and leafhoppers. Insects that live in more predictable and stable habitats, such as perennial crops, may reproduce later, have longer generation times and produce fewer young. These insects are relatively uncommon field crop pests.

Life history influences the success of biological control. Natural enemies are often effective in perennial crops such as alfalfa, but less effective in annual crop habitats like corn.

Two lady beetles mate. After finding an aphid-rich site the female will lay eggs (oviposit) and her offspring will help control the aphid population.

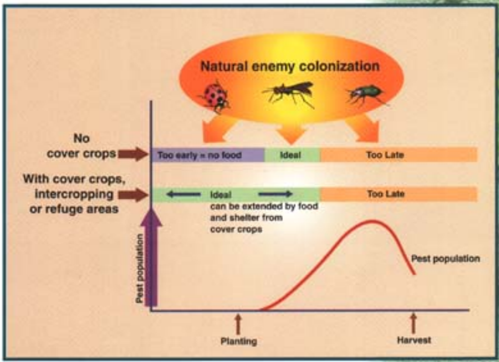
The role of natural enemies and abiotic factors

All insect pests have natural enemies, including predators, parasites and pathogens. These natural enemies often keep the pest population below economic thresholds. For example, while aphids are almost always present in wheat, they very seldom require treatment because there are many naturally occurring predators and parasites that keep them in check. In some cases humans have successfully introduced beneficial insects that effectively control insect pests. For example, after a parasitic wasp (*Tetrastichus julis*) was imported and established in the 1960s, the cereal leaf beetle ceased to be a serious Michigan small grain pest.

Other pests aren't controlled very well by natural enemies. This may be due to the nature of annual crop ecosystems, which can be difficult habitats for natural enemies to colonize.

Natural enemy colonization

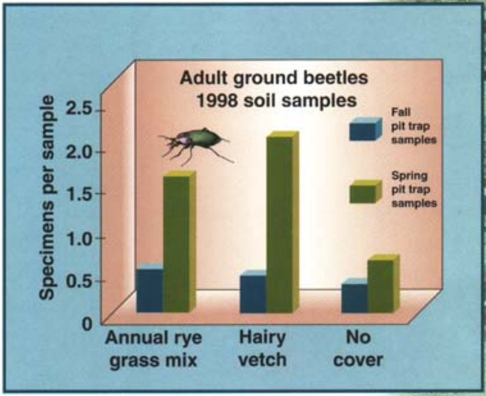
One reason that natural enemies may not do well in annual crop ecosystems is that the habitat exists for a relatively short period. Because a crop is replanted each year, natural enemies must also recolonize crop fields every year. If natural enemies arrive too early, they won't find enough prey and they may leave or die. If they arrive too late, they may not reproduce and provide sufficient pest control before harvest.



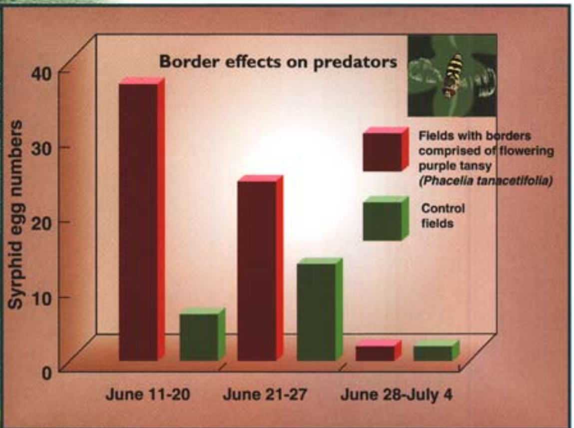
Microclimate effects

Sometimes a field crop habitat is too harsh for a natural enemy. Some predators, such as adult ground beetles, need plant cover for protection through the winter. Fall plowing removes this protection and forces them to look for other shelter. Adding cover crops to a rotation provides shelter for these beneficial insects.

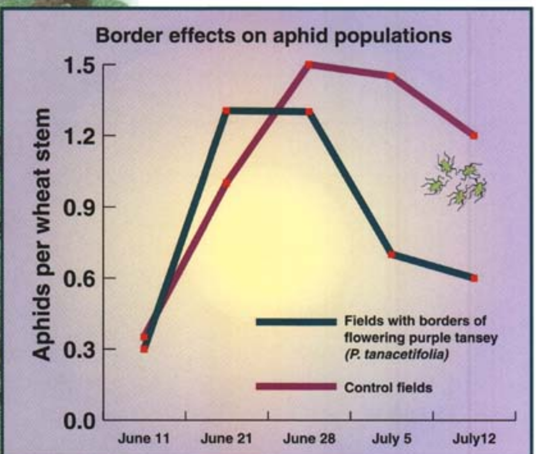
Eriborus terebrans, a wasp that parasitizes ECB, finds it too hot and dry in corn fields prior to canopy closure. It must move back and forth from a sheltered fencerow or woodlot into the field each morning to find hosts. ECB larvae close to wooded edges are thus parasitized at higher rates than those in the middle of the field.



Source: Gary V. Manley. 1998. Unpublished data.



Source: Hickman and Wratten. 1996. Journal of Economic Entomology 89:832-840.



Source: Hickman and Wratten. 1996. Journal of Economic Entomology 89:832-840.

Alternate food

Some insect pest predators and parasites use alternate hosts during some seasons. If an alternate host is not available, the predator or parasite may not control pests when needed. Early in the season one armyworm parasite (*Meteorus communis*) preys on caterpillars that live on trees and shrubs. These parasites are more common where wooded habitats and cropland are intermixed.

Similarly, many natural enemies require more than one food source. Syrphid fly adults supplement their diets by gathering and eating pollen from flowering plants. They lay their eggs on these plants, and the larvae hatch to feed on aphids. Many studies have shown that where natural enemies have easy access to pollen and nectar, there is more predation and we find fewer pests.

Using natural enemies more effectively means designing annual crop field ecosystems to better accommodate them. Strategies include leaving or introducing appropriate habitat and food sources. Using plants resistant to pest damage is also an important method of managing insect pests.

Crop and field characteristics

Uniform genetics

Conventional crop breeding programs and hybrid crop plants have resulted in tremendous crop productivity and yield increases. These uniform, high-producing crops, however, are often prone to pest outbreaks. When all crop plants in a field have an identical genetic background, a single genetic change in the insect can make the entire crop susceptible to attack. The Hessian fly is an excellent example. As plant breeders selected for Hessian fly-resistant wheat varieties, they found that a change in one gene in the insect's DNA allowed it to successfully adapt to the formerly resistant wheat variety. Increasing the diversity of crop genetics would slow this adaptation and help preserve plant resistance. Producers sometimes do this themselves by planting more than one variety in a field.

Loss of defensive chemicals

In domesticating crop plants, humans have sometimes selected varieties that are more susceptible to insect attack. Plant chemicals that protected wild plants from insect damage can be lost through breeding. These traits can occasionally be recovered. For example, some corn breeders are examining wild maize (corn) varieties to restore native resistance factors against ECB that have been lost during domestication.

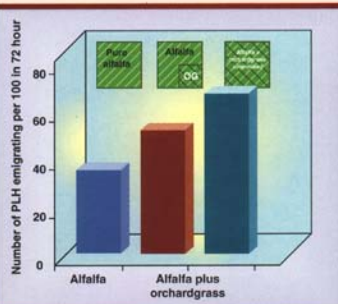
A woodpecker can't reach the European corn borer burrowed deep within a large corn stalk.

Change in plant physical characteristics

Changing a plant's physical characteristics can also affect insects. For example, corn breeders have selected for large stalk diameter to support increased ear size and reduce lodging. This may also make the stalk a more favorable habitat for ECB overwintering and may keep predators, like crows and woodpeckers, from easily reaching the overwintering larvae in the stalk. Chopping stalks kills some of these larvae directly and makes others more accessible to predators.

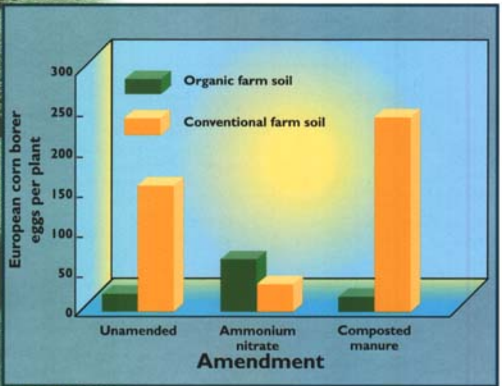
Crop mixtures to control PLH

PLH is a formidable pest, but it has one weakness: it can't tell junk food from the good stuff! Based on farmer observations, researchers began closely examining PLH feeding behavior. They found that adults tried to feed on forage grasses for long periods, even though these grasses do not provide PLH with adequate nutrition to develop eggs. After feeding on grass for five to eight minutes, the PLH moves on and tries another plant. But, if it keeps finding grass, it eventually flies away looking for a better food source. In mixed alfalfa and grass stands, PLH has a good chance of landing on a grass stem instead of alfalfa. Based on the odds alone, some of these insects encounter grass so often they eventually fly away. Michigan researchers found a good correlation between grass density and PLH emigration. In addition, the time spent on grasses is time not spent feeding on alfalfa. This combination of diverted feeding and increased chance for dispersal contributed to about a 30 percent reduction in PLH numbers in alfalfa/orchardgrass mixtures compared to pure alfalfa stands.



Source: Roda, A. et al. 1997. Environmental Entomology 26:745-753.

It may be possible to use the same principle to reduce PLH damage in other crops. The grass does not need to be alive and it may not even need to be grass. Researchers found that PLH spent an average of five minutes trying to feed on glass rods used to mimic grass stems. They believe that any vertical object may have the same effect. Crops planted into standing wheat stubble or herbicide-killed oats may provide an early advantage over PLH. Since PLH populations are usually controlled later in the season by a naturally occurring fungus, such a strategy may reduce PLH damage below threshold levels.



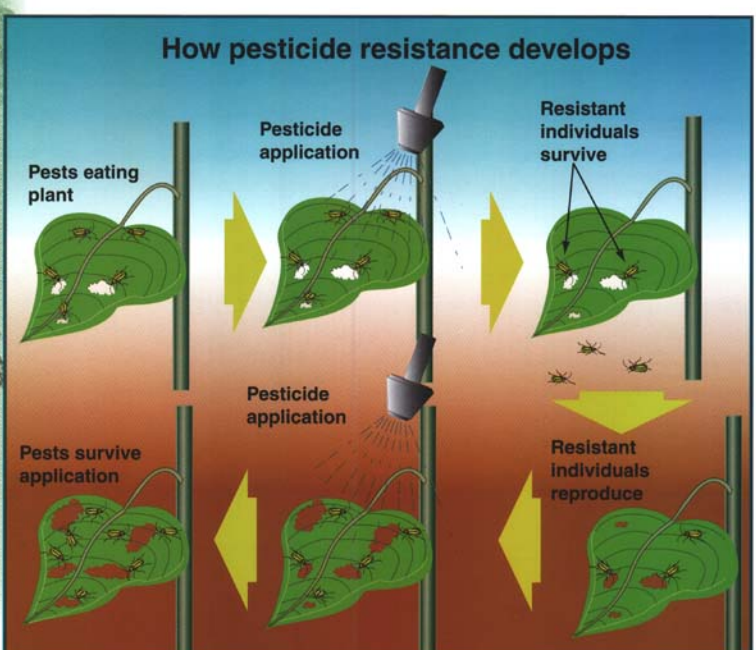
Source: Phelan, P.L. et al. 1996. Environmental Entomology 25:1329-1336.

High food quality

Plant physical or chemical characteristics are also affected by farm-level management decisions. Crops under different fertility and moisture regimes may be more or less attractive to certain insects. A recent Ohio experiment found that corn plants with particular soil/fertilizer combinations were more attractive to egg-laying ECB. By reducing variation in mineral availability, organically managed soils may change plant mineral balance in a way that reduces susceptibility to certain insects.

Disruption by pesticides

Pesticide use can disrupt crop ecosystems and favor certain insect pests. Insecticides almost always kill beneficial insects such that controlling one insect pest often causes the outbreak of a second pest by killing the natural enemies that were previously suppressing it. This is referred to as a secondary pest outbreak. Fungicides can also result in secondary pest outbreaks by suppressing beneficial fungi that attack insect pests.



Pesticides also affect natural enemies indirectly. For example, when insecticides reduce a pest population, the surviving natural enemies may be left without a food source and leave or die. Alternatively, some herbicides irritate certain beneficial insects, increasing their movement and reducing their effectiveness.

Pesticides can alter the crop environment making it less favorable to natural enemies. Herbicides do this when they remove pollen and nectar sources within fields and along field edges. The resulting open canopy is less favorable to some natural enemies.

Crop field characteristics

When many individuals of one plant species occur together in nature, certain insects, often specialists, are more abundant in these patches. In contrast, where the same plants are mixed with other species, specialist insects are less abundant. Since we almost always grow only one field crop species in a large area, this species is particularly vulnerable to attack. Strip cropping and intercropping can help reduce some insect pest attack.

While crop breeding has sometimes resulted in increased crop susceptibility to insect pests, it is also a very important tool for developing plants resistant to insect damage. Hessian fly resistance in wheat is the best Michigan-based example.

Abiotic factors

Temperature, moisture, light, air flow and fertility are some abiotic or non-living factors that influence pests both directly or indirectly. Because living organisms develop in direct relation to temperature, the number of degree days is useful for predicting and managing pests. Cropping practices that leave plant residue on the soil surface (like reduced tillage) or cause earlier canopy closure (such as narrow row soybeans) can reduce soil degree day accumulations and slow soil insect growth and development.

Moisture also affects insects and how they impact crops. Irrigation can partially offset corn rootworm larval damage by providing adequate soil moisture for plant growth and root regeneration.

Airflow patterns (local or regional weather patterns) can influence infestations by spider mites, PLH or other small insects that travel on the wind.

Degree days required for initiating events for common Michigan field crop insect pests

Insect pest growth stage	Base 50 degree days since March 1
Cereal leaf beetle first adults	60-90
Alfalfa weevil first larvae	100-340
Flea beetle first adults	160-340
Cereal leaf beetle first larvae	250-580
Seedcorn maggot larvae	280-880
Armyworm first larvae	500-790
European corn borer first eggs	550-700
European corn borer first larvae	580-870
European corn borer large larvae	810-1440
Variegated cutworm first small larvae	910-1310
Corn rootworm first adults	1010-1440
Corn rootworm peak adults	1410-1840
European corn borer second generation eggs	1510-1740
European corn borer second peak	1710-1990

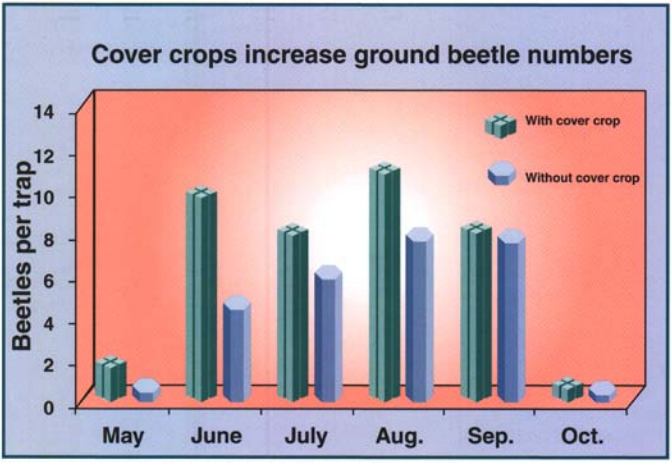
Source: Michigan State University CAT Alert, April 22, 1992.

Reduced tillage helps natural enemies control black cutworm

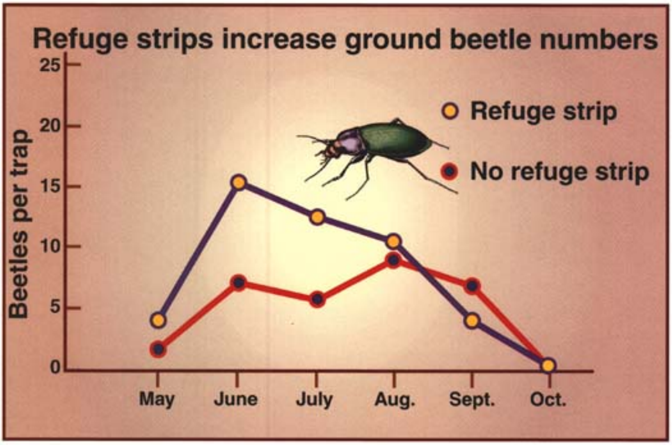
Black cutworm is a pest in several Michigan field crops. Anyone who has experienced it can explain the frustration of watching a "nice stand" reduced to a "re-plant decision." Cutworm eggs are laid on plants close to the ground and the larvae live in the soil. This is the domain of ground beetles, also called carabid beetles – a diverse group of beneficial insects.

Most ground beetles do best in minimal tillage systems when plant residue is left on the soil surface. No-till fields have consistently higher ground beetle populations. When plots were artificially infested with cutworms, there was little damage in no-till plots, while nearby conventionally tilled plots had many cut plants. When second-year corn plots were treated with a soil insecticide to control corn rootworm, cutworm damage was even higher. Whether cover crops also help decrease cutworm damage by favoring ground beetles is not yet known, but we know that cover crops do favor ground beetles. Ground beetles also favor filter or refuge strips.

Source: Brust, E.G., B.R. Stinner and D.A. McCartney. 1985. Journal of Economic Entomology 78:1389-92.



Source: Carmona, D.M. and D.A. Landis, 1999. Environmental Entomology. 28: In Press.



Source: Carmona, D.M. and D.A. Landis, 1999. Environmental Entomology. 28: In Press.

Management influences on insect pest ecology

Crop rotation

Crop rotation generally decreases field crop insect pest damage. Corn rootworm problems are generally avoided when corn is rotated with any other crop. Some rotations can increase certain pests. Crops following a sod or set aside are more likely to be attacked by corn wireworms.

Tillage

Tillage can help reduce some pests overwintering stages. Moldboard plowing helps lower ECB survival, but it may also may disrupt some beneficial insect populations such as ground beetles, which are favored by no-till. Spring tillage is generally preferred over fall tillage to maximize the benefits of beneficial insects feeding on crop pests in the fall and early spring.

Cover crops

Cover crops increase overwintering habitat for beneficial insects, particularly predators like ground beetles and rove beetles. They may also provide cover and food early in the spring, allowing beneficials to get a head start on pests. Some pests can be stimulated by certain cover crops. Armyworms may lay eggs in dense stands of small grain covers in the spring, then attack crops as they mature. Odors given off by covers that have been plowed down too soon before planting can stimulate egg laying by seedcorn maggot. Wait at least two weeks after incorporating covers to plant maggot-sensitive crops like corn and soybeans.

Planting date

Early planting into cold, wet soils can delay germination or slow early season growth and make crops more susceptible to certain soil insect pests such as wireworms, cutworms and seedcorn maggot. Planting corn very early can result in lower insecticide effectiveness prior to the hatch of corn rootworm eggs. While early planted corn tends to be more attractive to ECB, it is less attractive to second-generations borers. Some producers use this knowledge to help make variety selection or scouting decisions.

Harvest

Harvesting alfalfa can be a very effective way to manage both alfalfa weevil and PLH. Timing first harvest to remove alfalfa before the weevil larvae enter the most damaging stage (typically in late May) can maximize forage yield and quality. If PLH numbers begin increasing, cutting the forage can effectively suppress their numbers without insecticide use.

Residue management

Cropping practices that leave plant residue on the soil surface can affect insect pests and beneficials. Increased crop residue from no-till may allow greater ECB overwintering survival and contribute to the following year's first-generation moth flight. Chopping or shredding stalks can help reduce ECB survival. Crop residue also provides habitat for a variety of beneficial arthropods. The numbers of ground beetles that feed on other insects and weed seeds increase with residue. Many spiders also are more likely to colonize fields where residues are present.

Insect pest management tables

The tables on the next three pages summarize management practices for the most common Michigan field crop, beneficial insects and insect pests.

Management practices

Key

☆ = greatly reduces pest risk

✣ = reduces pest risk

❍ = no or little effect on pest

× = small increase in pest risk

✘ = strong increase in pest risk

Insect pests	Soil type		Soil quality	Cover crops	Crop rotation			Tillage			Planting date		Plant population		Row width		Cultivation		Field size and borders		Pest resistant varieties	Sanitation
	Course	Fine			Continuous	2+ year	3+ year	No-till	Chisel	Moldboard	Early	Late	Low	High	Narrow	Conventional	Early	Late	Small w/borders	Large w/o borders		
CORN																						
European corn borer	❍	❍	✣	✣	×	❍	✣	×	×	✣	❍	×	❍	❍	❍	❍	❍	❍	✣	×	☆	✣
Corn rootworm, larvae	✣	×	✣	✣	✘	☆	☆	❍	❍	✣	❍	×	×	❍	❍	❍	❍	❍	❍	❍	☆	❍
White grubs	✣	×	✣	×	❍	❍	❍	❍	❍	✣	×	✣	×	✣	❍	❍	❍	❍	❍	❍	❍	❍
Cutworms	✣	×	✣	❍	❍	❍	❍	✘	×	✣	×	✣	×	✣	❍	❍	❍	❍	❍	❍	❍	❍
Wireworms	✣	×	✣	×	❍	❍	❍	❍	❍	✣	×	✣	×	✣	❍	❍	❍	❍	❍	❍	❍	❍
True armyworms	❍	❍	❍	✘	❍	❍	❍	✣	✣	❍	×	✣	×	✣	❍	❍	❍	❍	✣	×	❍	❍
SOYBEANS																						
Spider mites	✘	✣	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	×	❍	✣	❍
Cutworm	❍	❍	❍	✣	❍	❍	❍	✘	✣×	❍	×	✣	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Seedcorn maggot	❍	❍	✣	×	❍	❍	❍	✣	❍	×	×	✣	×	✣	❍	❍	❍	❍	❍	❍	❍	❍
Potato leafhopper	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	×	×	❍	✣	❍		❍	❍	❍	☆	❍
WHEAT																						
Cereal leaf beetle	❍	❍	❍	❍	×	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Hessian fly	❍	❍	❍	❍	×	❍	❍	❍	❍	❍	✘	☆	×	✣	❍	❍	❍	❍	❍	❍	☆	❍

Management practices

Key

- ☆ = greatly reduces pest risk
- ✣ = reduces pest risk
- ❍ = no or little effect on pest
- × = small increase in pest risk
- ✘ = strong increase in pest risk

Insect pests	Soil type				Crop rotation			Tillage			Planting date		Plant population		Row width		Cultivation		Field size and borders			
	Course	Fine	Soil quality	Cover crops	Continuous	2+ year	3+ year	No-till	Chisel	Moldboard	Early	Late	Low	High	Narrow	Conventional	Early	Late	Small w/borders	Large w/o borders	Pest resistant varieties	Sanitation
ALFALFA																						
Alfalfa weevil	×	❍	❍	❍	×	❍	❍	❍	❍	❍	❍	❍	×	✣	❍	❍	❍	❍	❍	❍	❍	❍
Potato leafhopper	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	☆	❍
Aphids	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
SUGAR BEETS																						
Sugar beet root aphid	×	✣	❍	❍	✘	×	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Spinach leaf miner	❍	❍	❍	❍	×	×	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	✣×	❍	❍	❍
DRY BEANS																						
Potato leafhopper	❍	❍	❍	✣	❍	❍	❍	❍	❍	❍	✣	✘	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Seedcorn maggot	❍	❍	❍	×	❍			✣	❍	×	✘	✣	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Management practices

Key

☆ = greatly reduces pest risk
✣ = reduces pest risk
❍ = no or little effect on pest
× = small increase in pest risk
✘ = strong increase in pest risk

	Soil type				Crop rotation			Tillage			Planting date		Plant population		Row width		Cultivation		Field size and borders			
Beneficial insects	Course	Fine	Soil quality	Cover crops	Continuous	2+ year	3+ year	No-till	Chisel	Moldboard	Early	Late	Low	High	Narrow	Conventional	Early	Late	Small w/borders	Large w/o borders	Pest resistant varieties	Sanitation
Parasitic wasps	❍	❍	✣	✣	✣×	✣×	✣×	✣	✣	×	❍	❍	❍	❍	❍	❍	×	×	☆	×	❍	❍
Ground beetles	×	❍	✣	✣	✘	✣	✣	☆	✣	✘	❍	❍	❍	❍	❍	❍	×	×	☆	×	❍	❍
Lady beetles	❍	❍	✣	☆	×	✣	☆	❍	❍	×	❍	❍	❍	❍	❍	❍	❍	❍	☆	×	❍	❍
Syrphid flies	❍	❍	✣	✣	×	✣	✣	❍	❍	×	❍	❍	❍	❍	❍	❍	❍	❍	☆	✘	❍	❍
Meteorus communis	❍	❍	✣	✣	×	❍	✣	✣	✣	×	❍	❍	❍	❍	❍	❍	×	×	☆	×	❍	❍
Lacewing	❍	❍	✣	✣	×	✣	✣	❍	❍	×	❍	❍	❍	❍	❍	❍	❍	❍	☆	×	❍	❍
Pirate bugs	❍	❍	✣	✣	×	✣	✣	❍	❍	×	❍	❍	❍	❍	❍	❍	❍	❍	☆	×	❍	❍
Damsel bugs	❍	❍	✣	✣	×	✣	✣	❍	❍	×	❍	❍	❍	❍	❍	❍	❍	❍	☆	×	❍	❍
Tetrastichus julis	❍	❍	✣	✣	×	❍	✣	❍	❍	×	❍	❍	❍	❍	❍	❍	❍	❍	✣	×	❍	❍
Microtonus aethiopoides	❍	❍	✣	❍	✣	×	×	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	✣	×	❍	❍

Weed Ecology and Management

Karen A. Renner

Key Points:

- Weeds are different than other crop pests because most weeds do not need a host.
- There are usually many different weed species in a field, not a single weed 'pest'.
- Weeds compete with crops every year because seeds produced one year remain in the soil to cause future weed problems.
- Annual weeds produce large numbers of seeds that resist decay and remain dormant in the soil. Biennial and perennial weeds may produce many seeds, but also rely on overwintering tubers, bulbs or root systems.
- Weeds compete with crops for moisture, nutrients and light. Weed competitiveness varies by crop, crop row spacing, the weed species and weed density, the time of weed emergence relative to crop emergence and the environmental conditions during the growing season.
- Weed seeds are dispersed by wind, water, insects, birds, mammals and people.
- Weed seeds have many fates. They can germinate and emerge, germinate and die, decay, be eaten as a food source, become non-viable (dead) or remain dormant in the soil.
- Managing field crop weeds requires tipping the competitive balance between weeds and crops to favor the crop. This strategy involves reducing the number of weed seeds in the soil, reducing weed emergence, controlling emerged weeds and maintaining optimum crop growth.

Study Questions:

- Think of two weed species on your farm. Why is one species more of a problem than the other?
- Why is one crop more competitive with weeds than another crop?
- Why do we have more biennial and perennial weeds in no-till systems? Where in a field do these weed infestations start? How can we manage these initial infestations?
- If weeds produce seed in a given year, should the field be tilled immediately? If tillage is delayed or eliminated would weed pressure increase the following year?
- Does spreading manure always increase weed problems? How can manure be handled to reduce the number of weed seeds and provide nutrients primarily to the crop?
- What practices could be implemented on your farm to tip the competitive balance between weeds and crops to favor your crops?

What are weeds?

Weeds are plants that are undesirable because they compete with a crop for water, nutrients and/or light. Some plants are weeds because they are toxic to livestock.

Weeds contribute to field plant diversity and may have some beneficial effects on soil biology. They also protect the soil from erosion. However, if weeds are not controlled they can reduce crop yield, set seed for future weed problems and act as hosts for other pests.

Hemp dogbane in wheat.

Common ragweed in soybeans.

Foxtail in corn.

Characteristics that make weeds different from other pests (insects, plant pathogens and plant parasitic nematodes):

- Weeds germinate and grow wherever space is available.
- Weeds usually do not require a host crop, so they are not crop-specific.
- There are usually many different weed species in a field at the same time. The word 'weeds' often refers to many different species.
- All weeds need the same resources to germinate and grow: water, nutrients, light and adequate temperature. Different species respond to different levels of these resources.
- The competitiveness of different weed species varies. Controlling some weed species may be more economically important than controlling others.
- If left unmanaged, weeds compete with crops every year.
- Agricultural soils contain 50 to 15,000 weed seeds per square foot.
- Some weed seeds can stay in the soil for more than 20 years before germinating, so one year's weed problem can result in future weed problems.
- Weeds can serve as hosts for nematode, insect and many plant pathogen pests.

Weed	Host for
Nightshades	Colorado potato beetle
Redroot pigweed	White mold
Common lambsquarters	Root aphids
Common lambsquarters, winter annuals	Soybean cyst nematode
Various weeds	Aphids that carry barley yellow dwarf virus

Weed competition

Weed competitiveness varies by crop, row spacing, weed species and density, time of weed emergence relative to crop emergence and environmental conditions.

Variation by crop

Weeds are more competitive with low-growing crops such as sugar beets because the weeds capture light more easily.

Crop yield loss due to one velvetleaf plant in 10 feet of crop row

Crop	Row spacing	Yield loss (percent)
Corn	30"	2
Soybean	30"	2
Sugar beet	22"	12

Source: Schmenk, R. M.S. thesis. 1994, MSU; Schweizer, E. 1984. Abstract, Weed Science Society of America, 25:60.

Crop row spacing

Weeds are more competitive in wide crop rows than in narrow or drilled crop rows.

Photo: Steven R. Deming

Drilled soybeans.

Photo: Karen A. Renner

Velvetleaf seedlings growing with sugar beets.

Soybean yield loss from weeds compared to a weed-free control

Year	7-inch rows (drilled)	30-inch rows
	yield loss (percent)	
1995	49	60
1996	35	57
1997	74	81

Weeds in the weedy plots emerged at the same time as soybeans and were not controlled.

Source: MSU Research 1995-1997.

Weed species and density

Some weed species are more competitive than others. Velvetleaf and cocklebur, for example, are more competitive with crops than redroot pigweed or annual grass plants.

Photo: Steven R. Deming

Velvetleaf.

Corn yield reduction varies by weed species in 10 feet of crop row

- 30 giant foxtail reduced corn yield by 13-14 percent
- 27 velvetleaf reduced corn yield by 21-34 percent

Sources: Fausey, J. 1996, Schmenk R. 1994. M.S. theses, MSU.

Dry bean yield losses with 30 weeds per 10 feet of crop row

Weed	Yield loss (percent)
Hairy nightshade	45-55
Common ragweed	5-45
Wild proso millet	12-31

Source: Adapted from: Chikoye et al. 1995. Weed Science 43:375-380; Wilson R. 1993 Weed Science 41:607-610; Blackshaw R. 1991. Weed Science 39:48-53.

Weed emergence relative to crop emergence

Weeds that emerge before the crop or at the same time as the crop are more competitive.

Weed	Weed numbers	Crop	Weed emergence	Yield loss (percent)
Barnyardgrass	10 weeds/square foot	Corn	With corn	30
Barnyardgrass	10 weeds/square foot	Corn	Corn at first collar (4-leaf stage)	4
Redroot pigweed	2 weeds/square foot	Soybean	With soybean	12
Redroot pigweed	2 weeds/square foot	Soybean	Soybean at V2 (1st trifoliate stage)	0
Common ragweed	1 per 1-1/2 feet crop row	Navy bean	With navy bean	10-22
Common ragweed	1 per 1-1/2 feet crop row	Navy bean	Beans at V3 (2nd trifoliate stage)	4-9

Source: Bosnic and Swanton. 1997. Weed Science 45:276-282; Dieleman et al. 1995. Weed Science 43:612-618; Chikoye et al. 1995. Weed Science 43:375-380.

Weeds that emerge with the crop must be controlled to eliminate or reduce yield loss

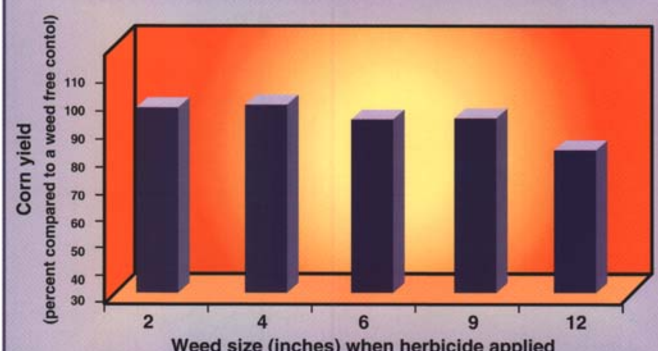
Crop	Crop development stage by which weeds must be controlled
Corn	4th collar
Soybeans	V5 (4th trifoliate)
Dry beans	V2 (1st trifoliate)

Source: Bosnic and Swanton. 1997. Weed Science 45:276-282; Dieleman et al. 1995. Weed Science 43:612-618; Chikoye et al. 1995. Weed Science 43:375-380.

Photo: Kelly A. Nelson

Common ragweed emerging with soybean seedlings.

Corn yield following herbicide weed removal*



*1998 Data from 22 Midwest locations. Herbicide applied was glyphosate.

Source: CAT Alert, Michigan State University, Mar. 18, 1999.

Environmental conditions

During growing seasons with adequate soil moisture, crops may yield more, but high densities of weeds cause higher yield loss.

Why are weeds weeds?

What makes one plant a major pest and another plant a minor pest or not a weed at all? Those plants that become weeds have many of the following characteristics:

- Strong competitor for water, nutrients and light.
- Grow under adverse conditions.
- Roots may grow three-to six-feet deep.
- Produce seeds at a young age.
- Produce seeds quickly.
- Produce huge numbers of seeds per plant.
- Many are self-pollinated, allowing one single plant to produce thousands of seeds.
- Seeds resist decay.
- Seeds remain dormant in the soil.
- Seeds have several dormancy mechanisms.
- Seeds can mimic crop seed size and shape.
- Leaves and stems adapt to repel grazing animals.
- Low growth habit allows weeds to survive in alfalfa fields that are cut three or four times a year.
- Avoid control mechanisms.

Environmental influences on soybean/weed competition

	Weeds per 10 ft.	Yield loss in year of low soybean yield	Yield loss in year of high soybean yield
		percent	
Cocklebur	1	3	5
	13	28	66
Smartweed	6	2	10
	11	26	46
Giant foxtail	6	0	2
	117	6	17

Source: Stoller et al. 1987. Reviews of Weed Science 3:155-181.


Photo: Kelly A. Nelson

Velvetleaf seed capsules.

Giant foxtail seed head.

Typical Michigan weed seed production

Weed	Number of seeds per plant	Weed density (per 33 feet of crop row)	Crop
Velvetleaf	400 - 1,500	90	Corn
Giant foxtail	2,500	100	Corn
Common lambsquarters	57,000	8	Soybean

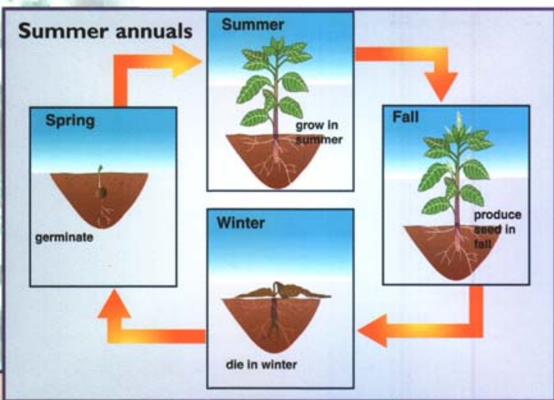
Source: Fausey, J. 1996.; Schmenk, R., 1994.; and Crook, T. 1986, Masters theses Michigan State University.

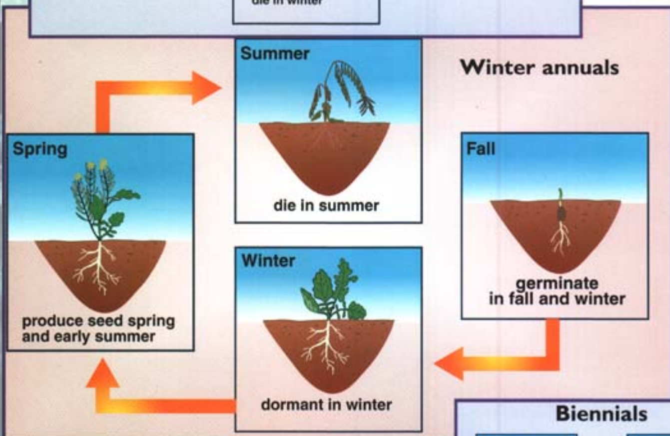

Photo: Kelly A. Nelson

Think about a common agricultural weed such as common lambsquarters. This weed produces thousands of seeds and at a young age. It produces seeds with two distinct degrees of seed dormancy. One seed type germinates readily while the other seed type is more dormant. It is no wonder that common lambsquarters seed is one of the most dominant weed seeds in Midwestern farm field soils.

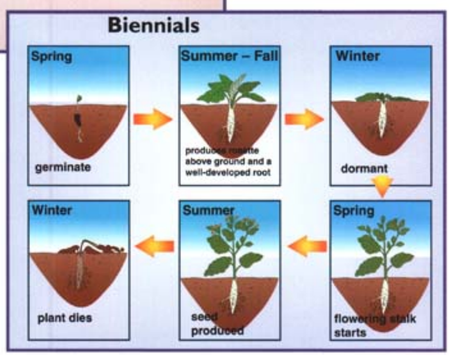
Weed adaptations to field crops

Weeds can be classified by their life cycle. Most weeds are annual plants. This means they complete a life cycle by germinating from a seed and produce seed in one year. **Summer annual** weeds germinate in the spring and produce seed in late summer and fall. Summer annuals are usually weed problems in summer annual crops such as corn and soybeans. **Winter annuals** germinate in the fall, produce seed in the late spring and die by early summer. Winter annuals are usually problems in winter annual crops such as winter wheat.





Source: Adapted from Marian Reiter.



A few Michigan weeds are **biennials**. These weeds live longer than one year, but less than two years. In the first year biennial plants form a rosette (leaves are all from a single center crown) which is the overwintering stage. The next spring biennial weeds produce a stem with flowers and seeds. Wild carrot (Queen Anne's lace) is a common Michigan biennial weed in no-till fields. Everyone recognizes this weed's flower, but few realize that the plant was in the field the previous year as a rosette.

Some Michigan weeds are **perennials**. We often joke that "all weeds are perennials" because the same weed species emerge every year. However, perennial refers to a specific plant life cycle. Simple perennials reproduce from seed, but if the root system is injured or cut, each root piece can regenerate. Dandelion is an example of a simple perennial.

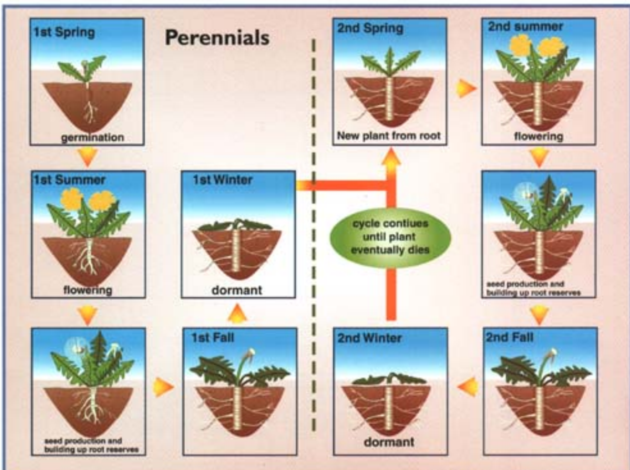
Creeping perennials live longer than one year because the underground vegetative structures (rhizomes, tubers, stolons) continue growing year after year. Quackgrass is an example of a creeping perennial. Perennial weeds, like dandelions, tend to be problems in no-till fields because the vegetative structures remain intact. This characteristic allows the perennial weeds to emerge rapidly in the spring, have a competitive advantage each year and continue to spread further each year.

Photos: Kelly A. Nelson

Biennial - wild carrot flowers and first-year rosette (inset).

Photos: Kelly A. Nelson

A creeping perennial, quackgrass.



Source: Adapted from Marian Reiter.

Dandelions in no-till corn.

Weed seed ecology: A key to weed management

Managing weeds means reducing the vegetative structures of perennial weeds and reducing the potential number of annual weed seeds in the weed seed germination zone. What is the weed seed germination zone? It is that portion of the soil in which weed seeds germinate. The zone's depth depends on soil type and weed seed types. Small-seeded weeds, like pigweed and lambsquarters, germinate at very shallow depths (less than one-half inch) in most soils. In sandy soils they may germinate at depths of up to one inch. Larger-seeded weeds, like velvetleaf, have more seed reserves, and may germinate at depths of one-half to four inches depending on the soil type.

Many of the characteristics that make some plants weeds are related to their seeds. This means we need to understand what happens to a weed seed once it is produced, and then look at crop management factors that will reduce the competitiveness of weeds after they emerge.

Weed seed dispersal

How do weed seeds find their way into crop fields? Weed seeds can be dispersed by wind, water, mammals, birds and people. Dandelion, Canada thistle, perennial sowthistle and milkweed seeds, for example, are **wind** dispersed. They blow through the air until they land in a field. If the field is cropped, seeds often have a difficult time blowing very far because their path is obstructed by the crop. We often see wind-dispersed species on the edges of farm fields.

Water can carry weed seeds. One or two new weed species often emerge the year following field flooding from adjacent drainage ditches or rivers.

Birds ingest berries that contain weed seeds, spreading new weed infestations underneath power lines or poles where they roost.

Photo: Kelly A. Nelson

Photo: Bay County Soil Conservation District

Photo: Kelly A. Nelson

Animals can disperse weed seeds by walking through crop fields or, more importantly, by defecating. **Livestock manure** can be an important weed seed source. Not all manures are created equal when it comes to weed seeds. Weed seed survival in animal guts varies by weed species. Small weed seeds with hard seed coats, like pigweed, survive digestion better than those with soft seed coats, such as annual grasses. The animal producing the manure also makes a difference. For example, poultry manure, contains fewer viable weed seeds than other manures because many seeds are destroyed in the birds' gizzards. Manure storage also impacts weed seed viability. Manure that is stored results in fewer viable weed seeds.

Photo: Kelly A. Nelson

Photo: Steven R. Deming

Weed seed in cow manure

- Manure from 17 of 20 New York dairy farms averaged 45 weed seeds per pound (90,800 seeds per ton of manure).
- If a farmer spread 20 tons of manure per acre each year, he would spread 1,816,000 weed seeds per acre each year, or 42 seeds per square foot.

Source: Mt. Pleasant and Schlather. 1994. Weed Technology 8:304-310.

Weed seed germination before and after cow consumption and following manure storage

	Before feeding	After digestion	3 months after manure storage
	percent germination		
Redroot pigweed	98	36	12
Common lambsquarters	70	58	22
Green foxtail	21	20	0

Source: Atkeson, F.W., H.W. Holbert and T.R. Warren. 1934. Journal of the American Society of Agronomy 26:390-397.

Animal feed can be a weed seed source. Weed seeds are regularly transported in feed for cattle. Corn silage seldom contains viable weed seeds because the low pH, high organic acid content, and lack of oxygen kills most weed seeds.

Photo: Thomas Winebrenner

Weed seed germination following ensiling

	Four weeks before ensiling	Weed seed germination Two weeks after ensiling	Four weeks after ensiling
	percent germination		
Redroot pigweed	85	4	0
Common lambsquarters	82	34	0
Barnyardgrass	38	0	0
Yellow foxtail	13	0	0

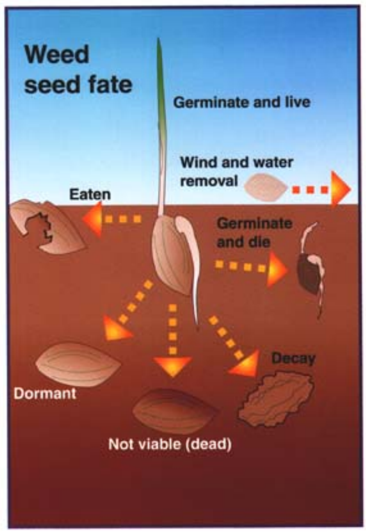
Source: Tildesley, W.T. 1937. Science in Agriculture 17:492-501.

Photo: Kelly A. Nelson

Humans spread a lot of weed seeds. Combines spread weed seeds in the direction of the combine path, while tillage spreads weed seeds and perennial weed roots in the direction of the tillage implement. Moving equipment and vehicles from one field to another moves pieces of perennial weed roots and weed seed with the soil. Soil also moves from one field to another on farm boots. Containing a weed infestation to one area of one field is difficult because of the effect of farm equipment. Cleaning equipment reduces seed spread between fields.

Weed seed fate

Once seed is produced and dispersed, it can either germinate and emerge, germinate and die, lay dormant, become non-viable, decay, be eaten or be removed by wind and water. More seeds fall onto soil than the number found in the soil seed bank, but we do not yet know what percentage of the seeds meet each of these fates. This is an area of active research.



Weed seed germination

If a farmer could make every weed seed germinate early in the spring, all the weed seedlings could be killed with cultivation and there would be no weed seeds left to germinate, emerge and compete with the crop. Unfortunately, weed seeds require specific environmental conditions to germinate.

How many seeds are in the weed seed bank?

Site	Number of seeds per square foot
W.K. Kellogg Biological Station - Long Term Ecological Research site, Hickory Corners, Michigan[1]	465 – 1,394
MSU Agronomy Farm field research site, East Lansing, Michigan[2]	1,394 – 2,787
U.S. Corn Belt[3]	56 – 14,864

Source: [1]Renner, K.A., et al. 1998. Abstract. Weed Science Society of America., 38:37. [2]Renner, K.A. et al. Weed Science 47:338-348. [3]Forcella, F. et al. 1997. Weed Sci. 45:67-76.

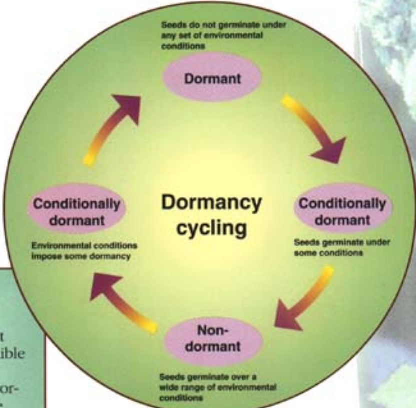
Weed seed dormancy — dispersal through time

When a seed is dormant it won't germinate regardless of environmental conditions. However, dormancy is not permanent. The range of conditions under which seeds can germinate is initially narrow, then broad, and then narrow until the seed is dormant again. Thus, some seeds go from dormancy to nondormancy and back while in the soil. This is called **dormancy cycling**. Not all weed species have a dormancy cycle.

Many annual weed seeds in the seed bank are **physiologically dormant,** meaning that they cannot germinate under any environmental conditions because of internal factors. When weed seeds disperse, they are often physiologically dormant. Over time the range of conditions under which the seed can germinate increases. If seeds do not germinate during this time because of unfavorable environmental conditions – such as drought or being too deep in the soil to receive adequate light or oxygen – they may become dormant again. This form of dormancy is called **environmental dormancy**. Dormancy can also be caused by a water-impermeable seed coat.

In studies across the Midwest, only 31 percent of the giant foxtail, 28 percent of the velvetleaf, 15 percent of the common ragweed and three percent of the common lambsquarters seeds germinated each year. The remaining weed seeds did not germinate either because they did not have the right moisture and/or light conditions for germination, because they were dormant or because they were not viable (dead seed).

Source: Forcella et al. 1997. Weed Sci. 45:67-76.



Source: Adapted from Baskin, C.C. & J.M. Baskin. 1998. Seeds: Ecology, Biogeography and Evolution of Dormancy and Germination. Academic Press pp. 666, San Diego, CA.

Seed dormancy variation in pigweed species

- The degree of dormancy among atrazine-resistant pigweed seeds is greater than in atrazine-susceptible pigweed seeds.
- Redroot pigweed seed has different degrees of dormancy depending on the latitude from which the seed was collected.
- Redroot pigweed seeds that developed while the plant was water stressed produced heavier seeds with less dormancy than those that developed without water stress.
- Redroot pigweed seed produced from plants growing in the shade with a 16-hour day length had lower germination rates in the dark than pigweed seed produced in a sunny environment.

Sources: Weaver, S.E. and A.G. Thomas. 1986. Weed Science 34:865-870; McWilliams, E.L. 1968. Ecology 49:290-296; Chadoeuf-Hannel, R. and G. Barralis. 1983. Weed Research 23:109-117; Kigel, J. 1977. Journal of Experimental Botany 28:1125-1136.

Two seed types are better than one

Some weed species produce more than one type of seed, each with different dormancy characteristics. Common cocklebur has two seed types. Both are encased in a bur and are dispersed together. In the majority of the burs, one seed does not germinate until after the other seed has germinated. Common lambsquarters also produces two seed types: a brown seed with a thinner seed coat that germinates immediately, and a black seed with a thicker seed coat that germinates later. These strategies assure that common cocklebur and common lambsquarters seeds germinate under different environmental conditions, increasing the likelihood that the seeds will eventually produce plants and more seeds.

Non-viable weed seed

Over time many weed seeds in the soil are not dormant, but become non-viable (dead), meaning they cannot germinate. Weed seed longevity varies considerably by weed species, as shown in this table. In some, but not all studies, weed seeds remain viable longer when buried deeper in soil. Fifty percent of the seeds in seed banks sampled across the Midwest corn belt were non-viable.

Weed seed viability in soil

	Seeds buried for 3.5 years	Seeds buried for 5.5 years
	— percent viable —	
Velvetleaf	65	36
Cocklebur	10	<1
Redroot pigweed	2	<1
Common purslane	2	<1
Large crabgrass	4	<1
Barnyardgrass	<1	0

Source: Egley, G. H. and J. M. Chandler. 1983. Weed Science 31:264-270.

Ragweed and quackgrass in seedling soybeans.

Predicting weed emergence

Weed species start and stop germinating at specific temperatures. Can we use this information to predict weed species emergence? The **Weedcast model** (http://www.infolink.morris.mn.us/~lwink/products/weedcast.htm) predicts emergence times for many common north central U.S. weed species based on soil temperature. The model assumes there is enough soil moisture for germination and can generally predict emergence times for each species.

The model has some limitations. For example, dormancy requirements differ for weed seeds, even within a species. Weed seeds of the same species collected from different states or from different locations within a state or at different times from the same location may have different temperature requirements or different moisture requirements for breaking seed dormancy. Seed collected from one plant may differ in degree of dormancy depending on where the seed was produced on that plant. Because dormancy in some weed species is cyclic, variation in seed dormancy and germination characteristics within a weed species make it difficult to accurately predict total weed emergence. However, we can predict the order of weed species emergence and group weed species by time of emergence.

Germination times for common Michigan weeds

Previous fall (Winter annuals and biennials) | Early spring - April → Late spring - June

Group 0	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
Horseweed/marestail	Prostrate knotweed	Quackgrass	Smooth brome	Canada thistle	Green foxtail	Black nightshade	Fall panicum
Downy brome	Wild mustard	Orchardgrass	C. ragweed	Giant foxtail	C. milkweed	Venice mallow	Crabgrasses
Field pennycress	Dandelion	Giant ragweed	Velvetleaf	C. cocklebur	Hemp dogbane	Waterhemp	Morning glories
Shepherd's purse	White cockle	P. smartweed	Wild buckwheat	Yellow nutsedge	Wirestem muhly	S. groundcherry	Jimsonweed
Biennial thistles		Ladysthumb		Redroot pigweed	Barnyardgrass	J. artichoke	Witchgrass
Wild carrot		C. lambsquarters			Yellow foxtail		
Dandelion (from seed)		Hairy nightshade			Wild proso millet		

Source: Adapted from: Buhler, D.D., R.G. Hartzler, F. Forcella and J.L. Gunsolus. 1997. Iowa State University, University Extension, SA-11, April 1997.

What is the fate of seed that remains in the soil?

Weed seed decay

Many weed seeds decay in soil. Soil bacteria and fungi are suspected of killing many weed seeds, but little proof is available. Insect feeding may introduce pathogenic microorganisms into some weed seeds. Velvetleaf, for example, is more susceptible to fungal attack and death after being attacked by scentless plant bugs. Does decay occur faster on the soil surface or when the seed is buried? Are some weed species' seeds more vulnerable to soil microorganisms? What crop rotations or field conditions promote weed seed death by microorganisms? These important questions need to be answered.

Weed seed predation

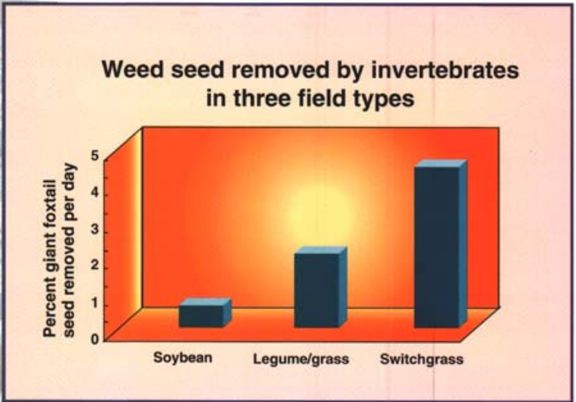
There are many weed seed predators living in and around Michigan farm fields, including rodents, birds, ground beetles (carabids) and northern field crickets. These natural enemies play an important role in reducing the number of weed seeds present in crop fields. Adjusting farming practices may help these natural biological weed control agents become "more productive on the job."

Photo: Kelly A. Nelson

Ground beetle eating giant foxtail seed.

Photo: Kelly A. Nelson

Northern field cricket eating redroot pigweed seed.

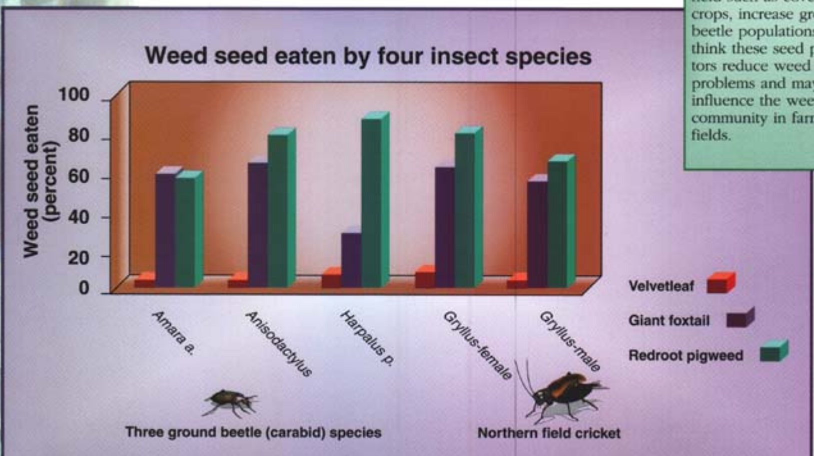


Source: Menalled, F. and D.A. Landis. Unpublished data.

Weed seed-eating ground beetles

There are more than 2,500 carabid (or ground) beetle species. Fifty-one species have been found in Michigan crop fields. Thirty-seven species feed on other insects; 14 species feed on weed seeds. Some carabid beetles prefer certain broadleaf weed seeds, while other species prefer grass seed.

Northern field crickets also eat weed seeds. One female cricket in the laboratory consumed 223 redroot pigweed seeds in one day! Together, these natural enemies reduce potential weed populations by reducing weed seed numbers on the soil surface. Natural vegetation bordering farm fields like hedgerows, and vegetation in the field such as cover crops, increase ground beetle populations. We think these seed predators reduce weed pest problems and may influence the weed community in farm fields.



Source: White, S., K.A. Renner, F. Menalled, D.A. Landis. 1998. North Central Weed Science Society Proceedings 53:150.

Management practices influence weed seed germination and weed competition

Weeds are present every year. To reduce germination, it is important to reduce weed seed numbers in the germination zone and not provide the appropriate germination conditions. For those weeds that emerge, we need to tip the competitive balance so the crop has the advantage.

Reducing weed seeds in the germination zone

How can we reduce the number of weed seeds in the germination zone?

- Don't allow weeds to go to seed.
- Don't apply fresh manure containing weed seeds to farm fields.
- Leave weed seeds on the soil surface – readily available for predation and other sources of mortality.
- In irrigated systems, don't provide moisture for weed seed germination until after crop emergence.
- Don't provide light for weed seed germination during the growing season.
- Bury weed seeds deeper than the weed seed germination zone.

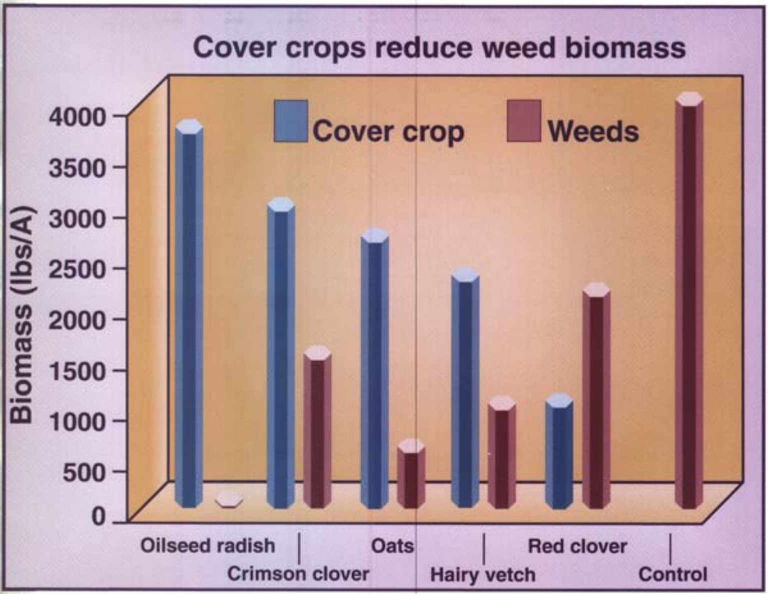
Tip the competitive balance between crops and weeds

Weeds need space to germinate and grow. Unlike other pests, weeds cause problems in places with **low** crop plant density. Winter annual weeds grow quickly and summer annual weeds germinate and grow where winter wheat is winter killed. In an alfalfa stand, weeds fill in the spaces where alfalfa is not present. In row crops, common chickweed germinates and grows in the fall when light reaches the soil between the crop rows.

Cover crops

Plant a cover crop and weeds won't have a space to grow. Cover crops reduce the opportunity for weed germination after the main crop is harvested and/or before it is planted. The figure on the next page shows weed populations when four different cover crops were planted following a snap bean crop. All cover crops reduced weed growth. Unlike other cover crops, red clover is a perennial legume. Its lower growth and biomass resulted in a higher weed biomass compared to annual cover crops. Both hairy vetch and red clover overwintered and produced greater spring biomass than the other cover crops. Oilseed radish was a very competitive cover crop. There were few weeds where oilseed radish was planted. Oilseed radish may produce allelopathic chemicals that prevent weed seed germination. Rye is another vigorous cover crop that overwinters and grows rapidly the following spring. For more information on cover crops see pages 44-53 in ***Michigan Field Crop Ecology*** **(MSUE Bulletin, E-2646)**.

Oilseed radish.



Source: Mutch, D.R., T.E. Martin. 1999. Michigan On Farm Research and Demonstration, p 36.

Crop rotation

The more diverse a crop rotation, the less opportunity for weed populations to build. The weed seed germination niche changes with crop rotation, which discourages weed populations that are well adapted to a specific crop's growing conditions. A winter annual crop, such as winter wheat, often out-competes summer annual weeds while a summer annual crop, like corn, doesn't provide a niche for emerging winter annual weeds. Many perennial weeds have a difficult time growing in perennial crops like alfalfa, because frequent cutting depletes root reserves.

Tillage

No-till leaves weed seeds on or near the soil surface. This means the number of weed seeds in the germination zone *decreases* under no-till if new weeds are *not* allowed to set seed.

Deep tillage buries weed seeds, reducing potential seed numbers the following year. Burying short-lived annual grass seeds in the soil seed bank reduces annual grass weed pressure in following years. For broadleaf weed seeds, however, burying seeds can create a long-lived seed bank.

Tillage also influences soil moisture. If a crop can be planted into moist soil, but the upper one inch of soil remains dry, few weeds will germinate before or with the crop. In Michigan we cannot control moisture following planting, but we can try to time planting when surface soil is dry but soil at two- to three-inches depth is still moist.

Tillage spreads perennial weed root systems and spreads annual weed patches. Chisel plowing moves perennial weed patches in the direction of the tillage operation. Though tillage can break up perennial root systems, it requires repeated tillage to control perennial weeds.

Planting date

Adjusting planting dates can change weed competitiveness. Common lambsquarters and smartweed emerge in cool weather. Shallow tillage following their emergence kills these weed seedlings. On the other hand, planting early allows a crop to get a head start on weeds that emerge in warmer weather, such as redroot pigweed. Pigweed seeds also have low germination with reduced light under a closed crop canopy. The effect of planting date depends on what weed species are dominant in the field.

Crop plant population and row spacing

Using wide row spacing gives weeds a greater opportunity to germinate and grow because of the additional light. Planting crops in narrow rows and/or at higher populations causes quicker and more complete canopy closure between crop rows, but eliminates most cultivation options.

Rotary hoeing and cultivation

Rotary hoeing five to seven days after crop planting and again seven days later, removes very small weed seedlings and gives the crop a head start in competing with weeds. Cultivate to remove weeds, but don't cultivate if there are no weeds and the crop doesn't need aeration. Cultivation disturbs soil, gives weed seeds light and cause a new flush of weeds.

Maintain optimum crop growth

Maintain soil fertility and soil quality for optimum crop growth. Crops are more competitive with weeds if they are not stressed by other production factors. Place fertilizer for maximum availability to the crop and not the weeds. Band fertilizer two inches to the side and two inches below the crop seed at planting. Inject nitrogen below the soil surface for uptake by the crop and not the weeds.

Photo: Steven R. Deming

Rotary hoeing soybeans.

Summary

Important cultural and biological weed control methods include:

- **Plant cover crops** – fill the space between crop rows and after crop harvest.
- **Rotate crops** – reduce weed adaptation to the crop's life cycle.
- **Reduce tillage** – weed seed in the seed germination zone will decrease over time if new weed seed is not added.
- **Delay planting** – control emerging weeds with shallow tillage.
- **Plant narrow rows or higher plant populations** – increase crop competitiveness with weeds. However, if plant diseases such as white mold are important pests, plant wide rows.
- **Maintain soil fertility** and soil quality at optimum levels for good crop growth.
- **Fertilizer placement** – fertilizers should be available to the crop and not to weed seeds in the germination zone.
- **Rotary hoe** – control small weed seedlings and let the crop emerge ahead of the weeds. **Cultivate** only if needed.

Weed management tables

The table on the next page summarizes management effects on the most common Michigan field crop weeds.

Photo: Steven R. Deming

Management practices

Key

- ☆ = greatly reduces pest risk
- ✣ = reduces pest risk
- ❍ = no or little effect on pest
- × = small increase in pest risk
- ✘ = strong increase in pest risk

Weeds	Soil quality	Cover Crops	Crop rotation				Tillage			Planting date		Plant population		Row width		Cultivation	
			Continuous	2 year	3 year	4+ year*	No-till	Chisel	Moldboard	Early	Late	Low	High	Narrow	Conventional	Early	Late
ANNUAL BROADLEAVES (lambsquarters, pigweed, common ragweed, nightshade, velvetleaf)																	
Corn	✣	✣	×	×	✣	☆	✣×	✣×	✣×	✣×	✣×	×	✣	✣	×	✣	✣
Soybean/dry bean	✣	✣	×	×	✣	☆	✣×	✣×	✣×	✣×	✣×	×	✣	✣	×	✣	✣
Sugar beets	✣	✣	×	×	✣	☆	✣×	✣×	✣×	✣×	✣×	×	✣	✣	×	✣	✣
Small grain	✣	✣	NA	×	✣	☆	✣×	✣×	✣×	✣	×	×	✣	NA	NA	NA	NA
Forages	✣	NA	✣	NA	✣	✣	✣×	✣×	✣×	✣	×	×	✣	NA	NA	NA	NA
ANNUAL GRASSES (foxtails, crabgrasses, fall panicum, barnyardgrass)																	
Corn	✣	✣	✘	×	✣	☆	✣×	✣×	✣×	✣×	✣×	×	✣	✣	×	✣	×
Soybean/dry bean	✣	✣	✘	×	✣	☆	✣×	✣×	✣×	✣×	✣×	×	✣	✣	×	✣	×
Sugar beets	✣	✣	✘	×	✣	☆	✣×	✣×	✣×	✣×	✣×	×	✣	✣	×	✣	×
Small grain	✣	✣	NA	×	✣	☆	✣×	✣×	✣×	✣	×	×	✣	NA	NA	NA	NA
Forages	✣	NA	❍	NA	✣	☆	✣×	✣×	✣×	✣	×	×	✣	NA	NA	NA	NA
PERENNIALS (Canada thistle, quackgrass, yellow nutsedge)																	
Corn	✣	❍	✘	×	❍	✣	✘	×	✣	❍	❍	×	✣	❍	❍	×	×
Soybean/dry bean	✣	❍	✘	×	❍	✣	✘	×	✣	❍	❍	×	✣	❍	❍	×	×
Sugar beets	✣	❍	✘	×	❍	✣	✘	×	✣	❍	❍	×	✣	❍	❍	×	×
Small grain	✣	❍	NA	✣	✣	✣	✘	×	✣	❍	❍	×	✣	NA	NA	NA	NA
Forages	✣	NA	✣×	NA	✣	✣	✘	×	✣	❍	❍	×	✣	NA	NA	NA	NA

*4+ year rotation includes a winter annual or forage crop.

I. Continuous mowing of forages will control Canada thistle but not quackgrass. Yellow nutsedge will not be competitive in forages.

II. Small-seeded broadleaves will germinate in no-till systems if present in the seed bank. Large-seeded broadleaves such as velvetleaf, can be reduced under no-till systems.

III. Early planted crops will reach canopy closure sooner than late plantings and gain a competitive advantage. Early planted crops will emerge before late emerging weeds such as jimsonweed and crabgrass, giving the competitive advantage to the crop. Late planting allows an opportunity to control early germinating weed species such as common lambsquarters and smartweed with tillage prior to crop planting. However, delaying planting too long (late May, early June) will result in a lower potential crop yield.

IV. MSU research indicates weeds that exceed four inches are competitive with corn and weeds that exceed eight inches are competitive with soybeans and can reduce yields.

V. Yellow nutsedge has very rapid growth early in the season. Early planting will increase the crop competitiveness with the weed. Conversely, late planting would allow tillage prior to planting and control nutsedge that has germinated.

Plant Pathogen Ecology and Management

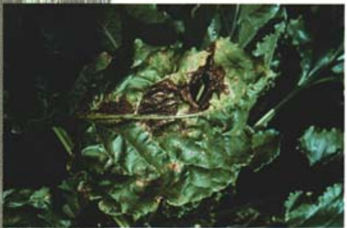
L. Patrick Hart and Andrew M. Jarosz

Key Points:

- **Since pathogen-specific pesticide applications are often not cost effective for field crops, disease management is focused on preventing disease.**
- **Management strategies emphasize reducing pathogen survival during the time period between susceptible crops and limiting dispersal into a susceptible crop.**
- **Crop rotations and resistant varieties will remain the dominant disease management tools for field crops.**
- **Disease levels can be further reduced with appropriate use of tillage practices, planting date, row spacing, seed treatments and cover crops.**

Study Questions:

- **Does no-till farming increase the incidence of pathogens that survive on crop residue? Can incidence be reduced by simply chopping stubble into smaller pieces?**
- **Will the availability of herbicide-resistant crop varieties result in an expanded role for cover crops in disease management?**



Cercospora leaf spot on sugar beet leaf.

What are plant pathogens?

Plant diseases are caused by a very diverse group of organisms called pathogens. We will discuss diseases caused by fungi, bacteria and viruses. While these groups have very different biologies, they often share similar disease development traits.

Plant pathogens included in this chapter

Organism name	Organism type	Disease caused/common name
Barley yellow dwarf virus (BYDV)	virus	barley yellow dwarf
Wheat yellow mosaic virus (WYMV)	virus	wheat yellow mosaic
Pseudomonas syringae pv. phaseolicola	bacterium	dry bean halo blight
Xanthomonas campestris pv. phaseoli	bacterium	dry bean common blight
Cercospora beticola	fungus	Cercospora leaf spot of sugar beets
Cercospora zeae-maydis	fungus	corn gray leaf spot
Erysiphe graminis	fungus	powdery mildew
Fusarium graminearum	fungus	wheat scab, corn root and stalk rot, corn ear mold
Fusarium solani	fungus	dry bean root rot
Phytophthora sojae	fungus	soybean root and stem rot
Puccinia recondita f. sp. tritici	fungus	wheat leaf rust
Rhizoctonia sp.	fungus	damping off
Sclerotinia sclerotiorum	fungus	white mold in soybeans, dry beans and 300 other species
Septoria tritici	fungus	septoria leaf blotch
Ustilago tritici	fungus	wheat loose smut

Pathogen adaptations to field crops

To cause plant disease, plant pathogens must cope with a constantly changing ecosystem: farmers rotate crops, till and cultivate the soil, plant genetically different varieties (some with pathogen resistance) and weather patterns change constantly. In such an environment, a major portion of a plant pathogen's life cycle is often spent without a susceptible host present. In a field with a three- or four-year rotation, a pathogen may contact a susceptible host for only five months. A successful plant pathogen then must survive for the remaining 31 to 45 months or disperse to a susceptible host crop on nearby fields. Many disease management strategies, therefore, focus on a pathogen's ability to survive and/or disperse, with the goal of reducing its potential to cause an epidemic when susceptible plants are present.

Typical Michigan field crop rotations

Rotation	Rotation length (years)	Number of months between corn, soybean, dry bean or beet crops	Number of months between wheat crops
Corn-Soybeans	2	19	—
Corn-Soybeans-Wheat	3	31-32	26
Sugar beets-Wheat-Corn	3	31-32	26
Sugar beets-Dry beans-Wheat/Corn	4	43-45	38

Survival and dispersal: Coping without a susceptible host

The relative importance of survival and dispersal strategies varies among pathogen species. **Soil pathogens**, such as the dry bean root rot fungal pathogen *Fusarium solani* and the soybean root and stem rot fungal pathogen *Phytophthora sojae*, are good examples of pathogens that emphasize a survival strategy. As with many soil pathogens, they have a very limited dispersal ability and epidemics begin when a susceptible plant's roots come in contact with the pathogen. For these pathogens, plant roots disperse toward the pathogen.

Dry bean root rot fungal pathogen, *Fusarium solani*.

Erysiphe graminis, wheat powdery mildew pathogen.

At the other extreme, some **foliar pathogens** such as *Puccinia recondita*, which causes wheat leaf rust, and *Erysiphe graminis*, which causes powdery mildew produce widely dispersing spores. These pathogens must disperse widely across North America to find susceptible hosts. Between these two extremes, many pathogens use some combination of survival and dispersal to cope with an ever-changing environment.

Soybean root and stem rot fungal pathogen, *Phytophthora sojae*.

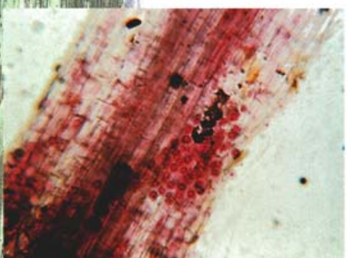
Surviving without a susceptible host

Plant pathogens have evolved many ways of surviving without a susceptible crop

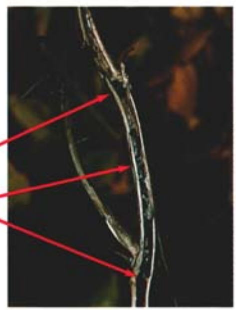
Survival mechanism	Viruses	Bacteria	Fungi
Resistant structures	–	–	+
Survival on crop residues	–	+	+
Survival on seeds	+	+	+
Alternate hosts	+	+	+

Resistant structures

Plant pathogens, like plants, are subject to damage by other microorganisms. Many fungal plant pathogens produce structures that resist microbial degradation, allowing them to survive for many years without a host plant. *Fusarium solani* and *Phytophthora sojae*, for example, produce special spores (**chlamydospores** and **oospores**, respectively) that resist microbial degradation. They may lay dormant in the soil for many years until an appropriate host's roots grow near them. They may also germinate near non-host plant roots, such as weeds, alfalfa, wheat or corn, and produce new spores to replace the aging spores. The white mold fungal pathogen *Sclerotinia sclerotiorum* produces a structure called the **sclerotia** that is very resistant to microbial degradation and may also survive in the soil for several years. Unlike specialized spores, the sclerotia is a hardened mass of fungal tissue. Since the sclerotia is very resistant to degradation by microorganisms, crop rotations are often ineffective in reducing soil populations of this species. Foliar pathogens may also produce structures that help the pathogen survive: *Erysiphe graminis* produces perithecia, and *Septoria tritici* and *S. nodorum* produce pycnidia. Pycnidia and perithecia are small dark structures full of spores protected from adverse environments. They could be thought of as very small, hollow golf balls.



Oospores of *P. sojae* in soybean roots.



White bean mold sclerotia (arrows) in a soybean plant stem.

Photo: MSU Dept. of Botany and Plant Pathology

Survival on crop residues

A pathogen infecting a plant uses it both as a food source and as a refuge from competition and degradation by other microorganisms. The longer the tissue stays intact, the longer the pathogen is protected from the environment and other microorganisms. The current increase in no-till farming practices means that pathogen survival on crop residues is increasing. While no-till provides excellent erosion control, it leaves crop residues on or above the soil surface where they degrade more slowly compared to when they are disced or plowed into the soil. The wheat scab pathogen, *Fusarium graminearum*, which causes disease on small grains and corn is becoming more common. The increase may be due to increased use of no-till where the Fusarium head blight (i.e. scab) pathogen survives on corn residues left on the soil surface.

Survival in seed

Many pathogens, especially viruses and bacteria, survive by infecting seeds and remaining dormant until the seeds are planted. A few pathogens must infect a seed to survive. Some can be removed from the seed by chemical seed treatment, but many can only be eliminated by destroying the seed. The bacterial pathogens that cause halo blight (*Pseudomonas syringae pv. phaseolicola*), and common blight (*Xanthomonas campestris pv. phaseoli*), in dry beans can survive for a little more than one year on crop residues, but many years in the seed.

Alternate hosts

Most pathogens have a limited host range, but a few infect a large number of different plant species. A pathogen with a large host range is difficult to manage because the pathogen can often infect the succeeding crop, or it can infect a crop or weed growing near the field. For example, the white mold fungus *Sclerotinia sclerotiorum*, well known in soybeans and dry beans, can also infect canola, tomatoes, cucumbers, snap beans, potatoes and about 300 other plant species. Fortunately, it does not infect monocots such as corn or wheat, and rotations that alternate white mold susceptible crops with corn or wheat can reduce its survival rate.

Other pathogens such as *Phytophthora sojae* may infect the roots of non-host plants such as dry beans, alfalfa and wheat without causing disease. Although harmless to the alternate host, infecting these plants allows the pathogen to survive and cause root and stem rot when soybeans are planted again.

Alternate hosts are not always plants

Wheat yellow mosaic virus (WYMV, also known as wheat spindle streak mosaic virus) has adapted a unique survival method when wheat is not present. This virus infects a common root-inhabiting fungus called *Polymyxa graminis*, which does not cause disease, but lives inside many crops' roots. *Polymyxa graminis* thus allows WYMV to survive until wheat is planted again. At that time, the fungus enters the next wheat crop's roots and transmits the virus to the wheat plant.

Dispersal: finding a susceptible host

After surviving off the host, a pathogen must successfully disperse to susceptible plants in order to infect and cause disease. The dispersal and infection process can be divided into three phases: 1) a **trigger**, or cue, that induces germination or spore production, 2) **spore movement** to the plant, and 3) **infection**.

Triggers

Many pathogens require an environmental trigger to initiate germination or spore production. These cues are usually tied to conditions that are likely to favor dispersal and infection. For many soil pathogens, germination or spore production is triggered by a nutrient or chemical exuded by plant roots. *Fusarium solani* chlamydospores, for example, germinate when nutrients are produced by seeds and root tips.

Water- or air-dispersed spore production is often triggered by weather conditions. Spore production by *Sclerotinia sclerotiorum's* sclerotia, for example, is triggered in the spring when soil temperatures are between 65 and 85 degrees F, soil moisture levels are high for seven to 14 days, and the sclerotia is within two inches of the soil surface. Spores are then puffed out of a structure called the **apothecia** and carried on air currents.

Fusarium graminearum, which causes wheat scab, survives on corn and wheat debris. This pathogen requires a long wet period, so it is not surprising that spores are only produced after several days of rain.

Other pathogens have less restricted conditions for infection and less specific cues for spore release. *Erysiphe graminis* spores, the cause of powdery mildew on wheat, are released diurnally throughout the growing season and can infect plants under a wide variety of weather conditions.

Wheat seed heads showing varying degrees of wheat scab, *Fusarium graminearum*, infection.

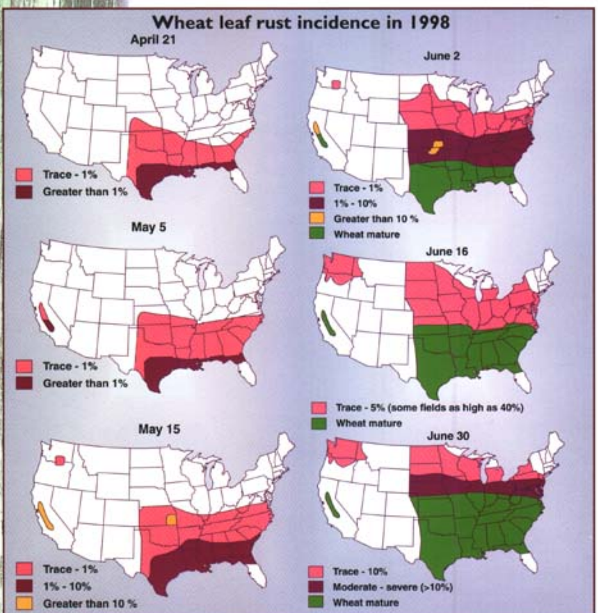
Spore movement

Once produced, spores must disperse to the plant. For soil-borne fungal pathogens, whose resting spores germinate in response to root exudates, the dispersal distance is minimal. The germinating spore can find the plant root by growing in the direction of increasing nutrient concentration, often towards a root surface.

For other pathogens, spores must move larger distances to reach the host plant. There are two types of spore movement, active and passive. **Active movement** refers to spores that are carried by another organism, ensuring directed movement towards a susceptible host. Seed-borne pathogens are probably the best examples of directed movement. They are deposited on or in the plant before harvest and are then carried with the seed. Other examples include viral diseases, which often use insects to move to a plant. Aphids, for instance, move barley yellow dwarf virus from plant to plant. Aphids efficiently disperse pathogens because they move around a lot searching for food.

Passive movement involves wind or water as the dispersal agent. Most fungal and bacterial foliar pathogens disperse their spores passively. Since neither wind nor rain movement is necessarily directed towards a plant, these pathogens produce many spores to increase the chance that some will be deposited on susceptible plants.

Passive movement can result in very long-distance spore movement. For example, *Puccinia recondita f. sp. tritici* spores, which cause wheat leaf rust, are carried on air currents from Mexico each year, spreading the disease throughout the United States.



Source: Mark Hughes, Cereal Disease Laboratory, USDA-ARS.

Wheat leaf rust only survives by actively infecting a wheat plant. Because Michigan farmers do not grow wheat during August and much of September, rust spores do not survive here. They do survive in Mexico, where the weather is mild and wheat is grown continuously.

Farm activities can also be an important mode of passive dispersal, especially for soil pathogens. For example, plowing and discing may spread spores throughout a field. Contaminated farm equipment can also move soil pathogens between fields.

Despite the impressive ability of *P. recondita* to travel great distances, increasing the distance a pathogen must move to reach a field usually lowers the probability of a serious epidemic. This is especially true for soilborne pathogens. If a field is free of a particular soilborne pathogen at the beginning of a season, the chance of having a major epidemic of this pathogen that year is near zero. This means that reducing established pathogen survival and vigilantly preventing accidental introductions are critical for controlling soilborne diseases.

Unfortunately, increasing dispersal distances is difficult in Michigan. Small fields found in a patchwork pattern are common. This landscape structure presents three problems for disease management. The first problem is that small fields have relatively large borders, which expose the crop to inoculum from adjacent fields. The second problem is that pathogens can disperse across small fields relatively quickly once established at the field margin. A third problem occurs because adjacent fields are at different rotation stages, creating a landscape pattern that supports many different pathogens each year. Thus, wheat pathogen survival is not favored in a field when soybeans precede wheat in a crop rotation. Adjacent fields, however, may harbor wheat pathogen inoculum on corn and wheat residues that can migrate into the wheat fields. Indeed, scientists suspect that most wheat scab infections are caused by spores blowing in from nearby fields. Unfortunately, we do not think this problem can be remedied under current Michigan farming practices. Farmers should, however, understand the risk posed by adjacent fields at different rotation stages.

Bay County farmland.

Infection, reproduction and disease development

After dispersing into a susceptible crop, a pathogen must successfully infect its host to establish itself within a field. Disease severity usually increases with time as the pathogen spreads to new plants within a crop field. The amount of disease present at the end of a growing season is determined by the interaction of five factors: 1) the amount of spores initially entering a field, 2) pathogen virulence, 3) host resistance, 4) favorable environment for pathogen infection and 5) time available for disease increase.

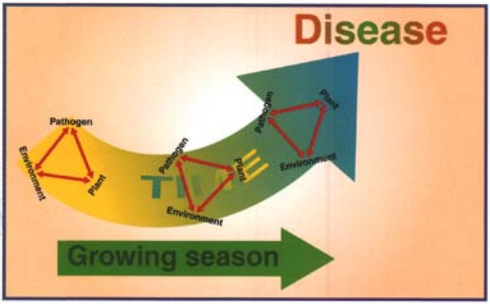
For field crops, methods that reduce inoculum entry into a field are perhaps the most important means of disease control, since there are few economically viable alternatives for controlling disease during the growing season. At planting time, however, farmers have two other disease management options: adjusting planting date to avoid disease and planting disease-resistant crop varieties.

Farmers may also have some limited ability to alter the environment and reduce pathogen infection. For example, irrigation times can sometimes be altered to reduce periods when plants are wet, making infection less likely. A strategy like planting soybeans in wide rows decreases white mold problems because the soil dries out faster during the critical infection period.

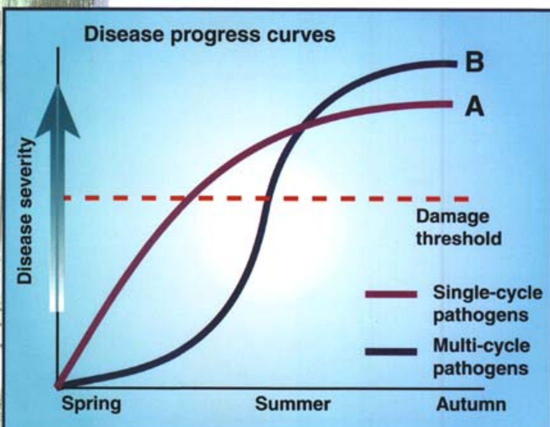
Grey leaf spot, *Cercospora zeae-maydis*.

Disease development

A pathogen's ability to cause disease is determined by the interaction between it and the plant and environment. This interaction has traditionally been depicted as a **disease triangle.** Since the final amount of disease is also influenced by length of time favorable for an epidemic, the disease triangle moves through time. Diseases tend to be more severe when the pathogen is highly virulent, the plant is susceptible and the environment is favorable for pathogen infection over an extended period.



Changing any side of the pyramid, such as adding an unfavorable environment, or using a disease resistant variety, can significantly reduce disease development. Although farmers can influence disease development, disease epidemics often occur because the environment favors it. Farming practices are directed toward delaying the start of epidemics, reducing their severity and keeping disease yield losses low when environments are only marginally favorable for epidemic development.



Michigan disease progress curves

Soilborne pathogens that have only a single reproduction cycle (one generation) during the year have disease progress curves similar to A, while foliar pathogens, which have multiple generations during a single growing season, often have disease progress curves similar to B.

Because of their ability to increase explosively once in a field, multiple cycle pathogens are less likely to be controlled by reducing the initial spore load entering a population. Managing these diseases calls for using pathogen-resistant crop cultivars.

Single-cycle diseases are more easily controlled by reducing the number of spores entering a field. Unfortunately, several single-cycle diseases that are important to Michigan field crops produce resistance structures that are difficult to eradicate once they become established in a field. For example, the sclerotia produced by *Sclerotinia sclerotiorum* can survive in the soil for several years and can produce an abundance of spores any time a susceptible crop is planted in a field.

The following management practices help reduce plant pathogen population densities.

Management practice	Effect on pathogen (noted as ✓)		
	Survival	Dispersal	Reproduction
Rotation	✓		
Tillage	✓	✓	
Planting date		✓	
Variety selection			✓
Seed treatment	✓	✓	
Seed quality	✓		✓
Irrigation		✓	✓
Chemicals	✓	✓	✓

Crop rotation

The longer and more diverse a rotation, the more time soil microorganisms have to degrade a pathogen. Rotations that favor large active soil microbial communities can accelerate pathogen degradation. For plant pathogens that have a wide host range, the crop rotational sequence can also affect disease development. Since *Sclerotinia sclerotiorum* can infect soybeans, dry beans, potatoes, tomatoes, canola and brassica cover crops, rotations that include two of these crops should be avoided because the pathogen populations can increase faster than with only one host present in the rotation. The rotation sequence can also influence disease levels. For example, the wheat scab pathogen, *Fusarium graminearum* (also called *Gibberella zeae*), is also a corn pathogen, causing root rot, stalk rot and ear mold. Winter wheat planted in or near first-year corn residues has a greater potential to develop scab than it does when an intervening crop is planted. Fortunately, planting corn into wheat stubble doesn't seem to influence the incidence or severity of corn diseases caused by *G. zeae*.

Tillage

Just as crop residues degrade faster when they are buried, so do plant pathogens. Burying the crop residue promotes contact between the pathogen and soil microbes. These microbes can prey directly on the pathogen or competitively exclude it from the soil environment, reducing pathogen population size. Corn gray leaf spot, caused by the fungal pathogen *Cercospora zeae-maydis*, occurs most commonly from corn residues left on the soil surface and during periods of high daytime temperature and relative humidity. Eliminating surface residue reduces this disease's incidence and severity, but the trade-off can be reduced soil erosion control. In some areas it may be more important to control soil erosion than gray leaf spot.

Chopping corn stalks.

Clear hilum soybeans in 30-inch rows.

Row spacing

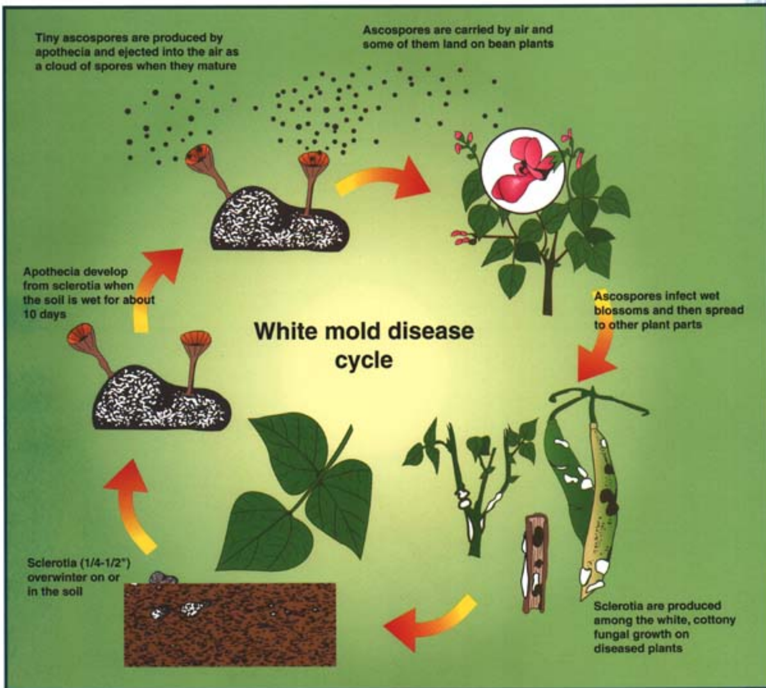
White mold in soybeans or dry beans occurs only when the soil surface remains wet for 10-14 days in early July. It usually occurs when more than three inches of rain falls within two weeks and after the plant canopy has closed, preventing the soil from drying out. Timing is critical because the pathogen enters the plant only through the flowers (see life cycle, p 79). One way to influence soil moisture (the environment side of the pyramid) is to plant wider rows so that the soil surface dries out faster. Michigan State University research has shown that white mold incidence always increases as row width decreases.

Photo: MSU Dept. of Botany and Plant Pathology

White mold in soybeans.

Row width effects on white mold incidence and yield and weight of sclerotia produced in three soybean varieties in 1996 and 1997 Michigan field trials

Variety	Row width (inches)	Yield (bu/A)	Diseased (plants %)	Sclerotia (grams/plot)
1996				
Elgin 87	7	34	73	4.4
	14	43	43	7.4
	28	39	24	2.4
Conrad	7	35	25	1.8
	14	35	1	1.5
	28	24	0	0.1
NK1990	7	40	1	0.2
	14	38	0	0.1
	28	24	0	0.1
1997				
Elgin 87	7	31.5	73	30.8
	14	31.3	50	22.8
	28	31.7	13	12.5
Conrad	7	36.4	60	35.6
	14	35.0	55	25.7
	28	40.9	20	16.2
NK1990	7	41.2	14	2.4
	14	40.1	8	5.0
	28	40.7	6	4.5



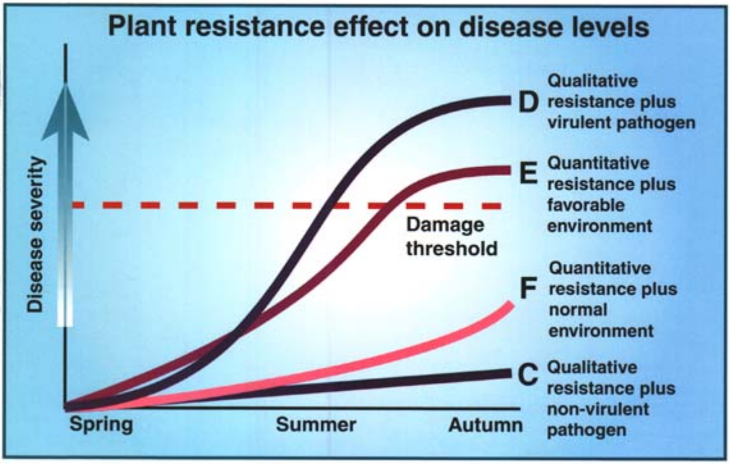
Planting and flowering date

Adjusting planting date helps avoid some diseases. Delaying winter wheat planting until ten days past the Hessian fly-free date reduces the chances that the aphids that transmit BYDV will feed on wheat. In addition, this strategy reduces the chance that powdery mildew, septoria leaf blotch and leaf rust will develop during the fall and early spring, when the environment for these diseases is favorable. In most of Michigan, dry bean planting is delayed until early June to avoid a soil environment favorable to early season root rot pathogens such as *Pythium* and *Fusarium*. For oats, planting before May 15 allows the oat plant to mature and develop resistance before the aphids that transmit BYDV are attracted to these fields. In the case of wheat scab, planting varieties with different flowering dates helps minimize the risk of total crop failure. This strategy works because some flowering occurs during periods that are not conducive to pathogen infection.

Variety selection

Cultivars that are resistant to a number of different pathogens are available, and farmers must consider the probability of disease when making variety selections. Resistance can be divided into two types: qualitative resistance, which is aimed at specific strains of a pathogen, and quantitative resistance, which reduces the rate of growth of all strains of a pathogen. Qualitative resistance is usually governed by a single resistance gene, and often gives excellent disease control (Line C). Unfortunately, this type of resistance can be overcome by new variants of the pathogen (Line D). When resistance is overcome, the results are disastrous because the cultivar is then essentially fully susceptible to the pathogen. Quantitative resistance retards the growth of all pathogen strains (Line F), but can be overcome in years when initial inoculum is extremely high, or when the environment is particularly favorable for disease development (Line E).

Specific crop varieties can influence pathogen ecology and disease development and spread. A variety that is resistant or immune to a specific pathogen may act like a non-host crop, effectively expanding a three- or four-year rotation to a six- or eight-year rotation, and doubling the amount of time a pathogen must survive without a susceptible host.



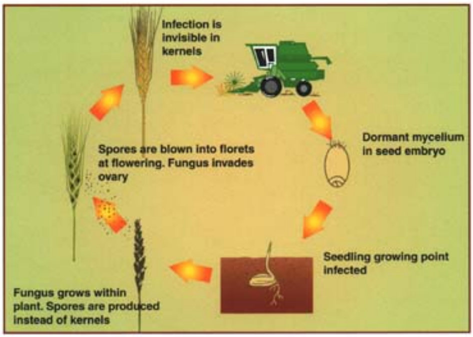
Plant varieties express different degrees of resistance to many disease. A partially resistant variety may not prevent the spores of a pathogen from germinating and growing, but may reduce the number of new spores produced. This trait reduces the rate at which a pathogen moves across a field and may keep the pathogen from reaching yield-reducing thresholds, or cause minimal yield losses to a minimum. This type of partial resistance may also prevent or reduce new survival structures from developing. The pathogen life cycle can be broken because inoculum levels are reduced in succeeding years.

Seed treatment

Chemical seed treatment can be an effective management tool when the pathogen depends on plant seed for survival and/or dispersal. Wheat loose smut *(Ustilago tritici)* a fungal pathogen that depends on wheat seed can be prevented from surviving and dispersing by treating wheat seed with a systemic fungicide. The dry bean bacterial blights described earlier also depend on seed for dispersal and long term survival, though in this case chemical seed treatment is only effective when the bacteria are outside the seed, since antibiotics won't eliminate internal seed contamination. When a dry bean bacterial blight test indicates dry bean seed has internal contamination by bacterial blight pathogens, seed treatment is not effective and the seed should be discarded.

Bacterial blight on navy beans (l) and unaffected beans.

Chemical seed treatments are also effective against fungi living in the soil (*Pythium, Rhizoctonia, Fusarium* and others) that cause seed and seedling death shortly after planting. Michigan State University recommends that dry bean, wheat, alfalfa and corn seeds should always be chemically treated prior to planting (MSU Bulletin E-1199). Soybeans are rarely treated, though in some years they may benefit from seed treatment because of pre-emergent damping off problems associated with *Pythium*.



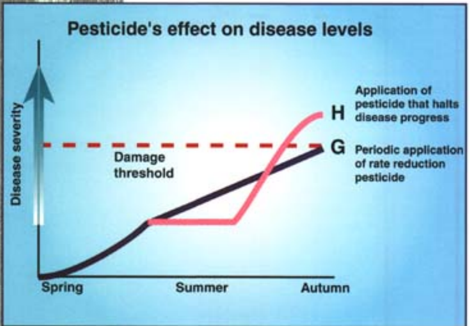
Seed quality

Poor seed quality may be associated with fungal and bacterial pathogens that use seed for survival and dispersal. As described above, seed treatment may be a viable option for such seed, though in many cases the seed should be discarded. Visually inspecting crops grown for seed can be an effective method of identifying seeds that may be infected by bacterial or viral pathogen. Plants infected by a virus or bacterium known to be seed-transmitted should not be used for seed.

Fusarium-infected wheat seed.

Cover crops

Cover crops may contribute to disease management in several ways. They may increase soil microbial diversity, improve soil health, alter soil physical parameters (light, moisture) and act as a shield to prevent pathogen spores from dispersing into the plant canopy. Consider diseases where a cover crop could trap spores before they reach the plant. As an example, *Sclerotinia sclerotiorum* spores are produced from an apothecium that is on the soil surface (see life cycle p 79). A cover crop could trap the spores as they are released from the apothecium. A cover crop option may become more viable as herbicide resistant crop plants become available, allowing the cover crop to be killed before it becomes competitive with the crop, but after it reaches a beneficial size.



Pesticide applications

Once a crop is planted the only major option for controlling disease is pesticide application. Although not economically feasible for many Michigan field crop situations, pesticides are applied to control powdery mildew and rust on wheat, anthracnose and white mold in dry beans, cercospora leaf spot of sugar beets and a variety of diseases on seed corn. Applications can reduce the rate of pathogen increase (Line G) and/or halt pathogen increase for some period after application (Line H). To be effective, pesticides must be applied on a schedule that holds disease levels below the damage threshold for the crop. Chemicals should always be used in conjunction with a scouting program or a weather-based disease prediction program. This is especially true for foliar diseases of wheat and seed corn, cercospora leaf spot on sugar beets, and anthracnose in dry beans. If the weather changes, these diseases may not continue to develop, making chemicals unnecessary. White mold in dry beans and soybeans may receive chemical treatment, but applications are based on crop growth stage and rainfall preceding flowering.

Summary

Disease management options for Michigan field crops are limited. Disease forecasting models and pathogen-specific pesticide applications are usually not cost effective for field crops. There is also currently little opportunity for using biological control measures once a disease is established within a field crop. Consequently, the best available field crop disease management strategies concentrate on preventing disease. Disease prevention is based on understanding plant pathogen ecology, especially how plant pathogens respond to environmental conditions.

Plant pathogen management tables

The table on the following page summarizes management practices' effects on the most common Michigan field crop diseases.

Management practices

Key

- ☆ = greatly reduces pest risk
- ✣ = reduces pest risk
- ❍ = no or little effect on pest
- × = small increase in pest risk
- ✘ = strong increase in pest risk

Diseases	Crop rotation			Tillage			Planting date		Plant population		Row width		Cultivation		Pesticides		Cover crops	Pest resistant varieties
	Continuous	2 year	3+ year	No-till	Chisel	Moldboard	Early	Late	Low	High	Narrow	Conventional	Early	Late	Seed treatment	Foliar		
CORN																		
Corn grey leaf spot	✘	✣	☆	✘	✘	☆	❍	❍	✣	×	×	❍	❍	❍	✣	✣	?	☆
Stewart's leaf blight	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	✣	✣	❍	✣
Corn ear mold	✘	×	✣	✘	×	✣	❍	❍	❍	×	×	❍	❍	❍	❍	❍	?	✣
SOYBEAN																		
Soybean root and stem rot	✘	×	❍	❍	❍	❍	✘	✣	❍	×	×	❍	❍	❍	✣	❍	×	☆
White mold	✘	×	❍	?	❍	❍	❍	❍	✣	×	✘	✣	❍	❍	❍	✣	?	☆
WHEAT																		
Barley yellow dwarf	×	❍	❍	❍	❍	❍	✘	❍	❍	❍	NA	NA	❍	❍	❍	NA	❍	NA
Wheat yellow mosaic	✘	×	❍	❍	❍	❍	✘	❍	❍	❍	NA	NA	❍	❍	❍	NA	?	☆
Powdery mildew	✘	×	❍	✘	✘	✣	×	❍	×	✣	NA	NA	❍	❍	❍	☆	?	☆
Wheat scab	✘	×	❍	✘	×	☆	❍	❍	❍	❍	NA	NA	❍	❍	❍	✣	?	✣
Wheat leaf rust	❍	❍	❍	❍	❍	❍	×	❍	❍	❍	NA	NA	❍	❍	❍	☆	?	☆
Wheat loose smut	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	NA	NA	❍	❍	☆	❍	?	NA
SUGAR BEETS																		
Cercospora leaf spot	✘	×	✣	✘	✘	❍	❍	❍	×	✘	✘	❍	?	?	❍	☆	?	☆
DRY BEANS																		
Dry bean halo blight	✘	×	☆	✘	×	✣	❍	❍	✣	✘	✘	❍	?	?	☆	❍	?	✣
Dry bean common blight	✘	×	☆	✘	×	✣	❍	❍	✣	✘	✘	❍	?	?	☆	❍	?	NA
Dry bean root rot	✘	×	☆	×	?	?	✘	✣	?	×	×	❍	?	?	❍	❍	?	✣
Damping off	✘	×	☆	✘	?	?	✘	✣	?	×	❍	❍	✣	?	✣	✣	?	NA
White mold	✘	×	❍	?	❍	❍	❍	❍	✣	×	✘	✣	❍	❍	❍	✣	?	✣

Nematodes and Soil Quality

George W. Bird

Key Points:

- Nematodes have diverse feeding behaviors and many are not harmful to plants.
- Soilborne nematodes are important components of the soil food web.
- Soil quality management favors beneficial nematodes at the expense of plant-parasitic nematodes.
- Crop rotation remains one of the most effective ways to reduce pest nematode populations in field crop systems.

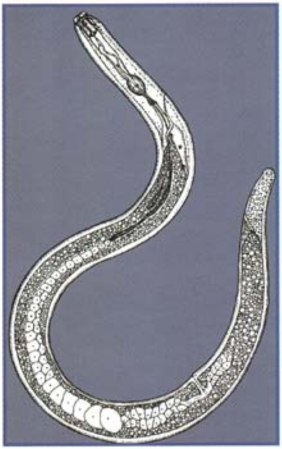
Study Questions:

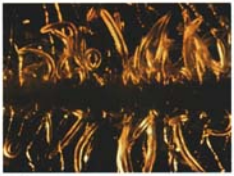
- Why are nematodes good soil quality indicators?
- Identify the strategies used for managing cyst and corn needle nematodes.
- How often should a nematode-resistant soybean variety be planted in a cyst nematode-infested field?
- Why can sugar beets, dry beans, snap beans and peas make soybean cyst nematode problems more severe?

What are nematodes?

Nematodes are roundworms that colonize most ecosystems including Michigan field crop soils. Some species feed on plant roots and reduce crop yields, while other species benefit agriculture. Nematode biology and suggested strategies for managing plant-parasitic nematodes are discussed in detail in ***Michigan Field Crop Ecology*** (MSU Extension Bulletin E-2646).

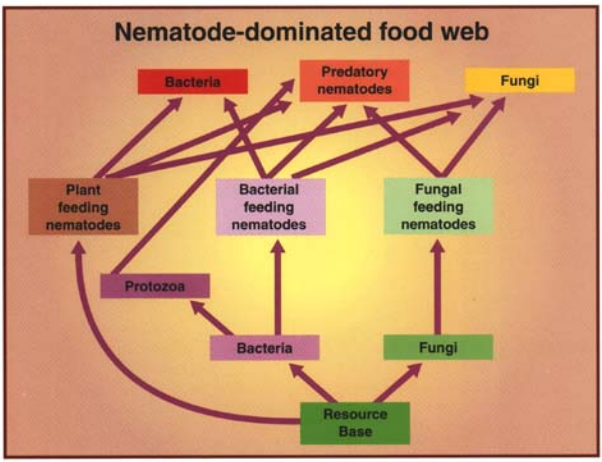
Nematodes have diverse feeding behaviors. They have many roles in food webs, since they feed on most life forms, including bacteria, fungi, protozoa, algae, plants and animals. This is why nematodes are found in most ecosystems. Site-specific information about all nematodes, not just the plant parasites, is useful. The data, however, are most useful when combined with other soil quality information and farming system goals.





Ectoparasitic nematodes feeding on plant tissue.

Photo: Streau, Rutgers University, 1961.



*Note that bacteria and fungi can serve as both food sources for and consumers of nematodes.

Nematodes in the news

On December 11, 1998, a consortium of scientists published the genomic sequence of the bacterial-feeding nematode *Caenorhabditis elegans*. This landmark event in biology is the first complete sequence of an animal genome. The sequence consists of over 19,000 genes and about 97 million base pairs of DNA.

Source: Blaxter, M.1998. Science 282:2012-2018.

Nematodes are classified in the animal kingdom Nematoda which consists of 18 major groups.

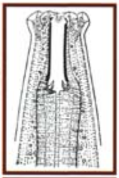
Source: Blaxter, M.1998. Science 2041-2046.

Survival

Nematodes have evolved many different survival strategies. These vary with species. They may involve the egg, juvenile or adult life cycle stages. For example, when the female cyst nematode dies, its body forms a protective structure (cyst) that houses several hundred eggs. This cyst protects the eggs until a suitable host is available.

Dispersal

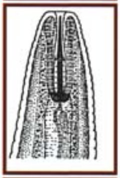
Nematodes are active and move freely over very short distances. They may also be moved passively in soil, water or host materials, such as flood waters, dust storms, infested equipment, soil and wildlife, such as migratory birds.



Drawing: Gerald Thorne. 1961.

Bacterivores

Bacterial-feeding nematodes are common in Michigan field crop systems. Species types, numbers and population densities vary among farming systems and seasons in response to shifts in their food source – bacteria. Some bacterial-feeding nematodes survive disturbance, such as soil tillage, and rapidly recolonize the soil.



Drawing: Gerald Thorne. 1961.

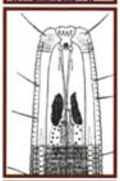
Fungivores

Fungal-feeding nematodes use a stylet (hypodermic needle-like structure) to feed and remove cell contents from fungi. As with bacterivores, this feeding process converts and releases organic matter as mineralized soil nutrients.

Drawing: Gerald Thorne. 1961.

Carnivores

Many nematodes are carnivores, feeding as parasites on livestock (trichnosis), pets (dog heartworm), humans (hookworm) and insects. These are often opportunistic species that cause infectious diseases. Others are predators and feed on small invertebrates, including other nematodes. Some of these species have bacterial-feeding life cycle stages.



Drawing: Micoletzky. 1925.

Algivores

Several algae-feeding nematodes have been found in Michigan field crop soils. We believe these nematodes feed on algal spores. Very little is known about their role in agricultural systems. It may be possible to use this group of organisms as indicators of soil that may not be favorable for field crop production.

Drawing: Gerald Thorne. 1961.

Omnivores

Nematodes that feed on two or more of the major groups of organisms (e.g. plants and animals) are called omnivores. These are usually relatively large nematodes, and are often found in mature ecosystems (e.g. orchards, forests).

Drawing: Gerald Thorne. 1961.

Source: Gerald Thorne. 1961. Principles of Nematology. McGraw Hill.

Herbivores

Most plant-parasitic nematodes feed on plant roots, but some species consume aboveground plant parts. When a large number of these nematodes attack a crop's root system, the result is often an infectious disease. The symptoms vary from major yield losses to subtle changes a farmer might not notice. Plant-parasitic nematodes feed by inserting a stylet into plant cells, injecting digestive chemicals into these cells and withdrawing partially digested cytoplasm (cell material). Some species, known as ectoparasites, live outside the root. Others, called endoparasites, invade and live inside roots.

Ecosystem structure

Soil nematodes live in the thin moisture film surrounding mineral particles and organic matter, or in host tissue. Both biotic (living) and abiotic (nonliving) soil components impact how nematodes grow, reproduce and influence the ecosystem. The abiotic factors include soil texture, moisture, pH, oxygen and nutrients. Biotic factors include hosts, prey and natural enemies, such as bacteria, protozoa, fungi and other nematodes. These organisms may be parasites, predators or pathogens of nematodes. When biological diversity is low, there are generally a few dominant nematode species. As biological diversity increases, nematode community structure tends to become more balanced.

Why are some nematodes pests?

In many field crop ecosystems, the most common nematodes are those that feed on plant roots. In some situations, the population density of one or more plant-parasitic species exceeds the damage threshold. Modifying an ecosystem's structure can alter the type or number of nematodes present. This can change the risk of nematode damage to crops. Although it is not always clear why plant-parasitic nematodes reach damage thresholds, there appears to be an important link between soil quality and nematode damage.

Soil quality management impacts on nematodes

Soil quality measures a soil's function, including its ability to:

- hold and release nutrients and water
- sustain plant and microbial development
- resist degradation
- respond to management

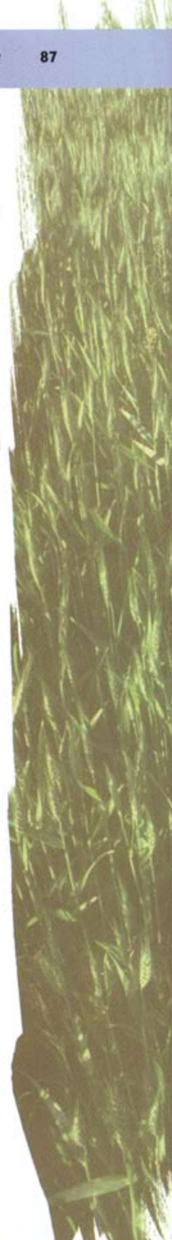
Soil characteristics used to measure soil quality include:

- organic matter content
- water-holding capacity
- water infiltration rate
- microbial biomass
- structure
- texture
- bulk density
- electrical conductivity
- nutrient availability and release
- pH
- biotic diversity balance

Nematodes are everywhere

. . . . if all the matter in the universe except the nematodes was swept away, our world still would be dimly recognizable – we would find its mountaintops, valleys, rivers, lakes and oceans recognizable – by a thin film of nematodes.

N.A. Cobb, 1915.



Soil quality and nematode ecology

Continuous potatoes with conventional soil nutrients (l) compared to buckwheat-potato rotation with organic nutrient sources (r).

Organic matter

Keeping a field in crop production for many years can decrease soil organic matter levels and quality, resulting in fewer bacterial- and fungal-feeding nematodes and more plant-feeding nematodes in the soil. These changes in nematode community structure are due, in part, to decreased predation by natural enemies and the occurrence of fewer natural chemicals that are toxic to plant-parasitic nematodes.

In contrast, farming systems designed to maintain or increase soil organic matter and improve soil organic matter quality can decrease the risk of root damage caused by nematodes and increase crop health, growth and development. Higher soil organic matter levels can result in higher water-holding capacity, water infiltration rate and microbial biomass, better soil structure, lower bulk density, near optimal pH and biotic diversity. Each of these factors affects nematode communities.

Nematode population changes associated with two potato management systems

Production system	Change in nematode population size*	
	Herbivores	Bacterivores
Continuous potato with conventional soil nutrients	+964	-64
Buckwheat-potato rotation with organic nutrient sources	+368	+221

*At planting versus at harvest.

Source: Bird, G.W. 1997. Unpublished data.

Water-holding capacity

Crops grown during drought are usually at greater risk to damage from plant-feeding nematodes than those grown with adequate soil moisture. Since soil organic matter increases soil water-holding capacity, increased soil organic matter can help increase crop tolerance to plant-parasitic nematodes.

Water infiltration rate

Increasing soil organic matter can increase water infiltration. Good water infiltration decreases water run-off and provides plants with additional water and increased tolerance to plant-parasitic nematodes. Decreasing water run-off helps prevent spreading plant-feeding nematodes to non-infested fields or parts of fields. Soils with poor water infiltration may harbor both algae and algae-feeding nematodes.

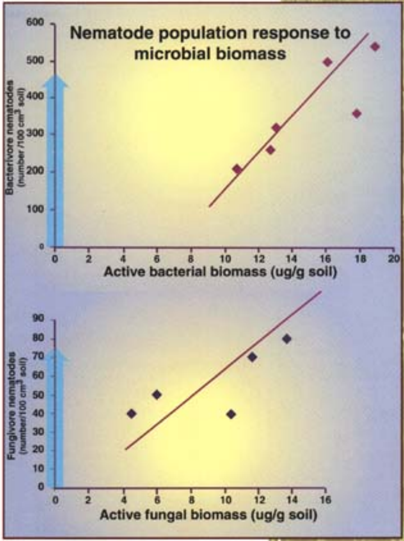
Texture

In Michigan, nematode problems are often more severe in coarse than in fine-textured soils. Soil erosion removes fine-textured mineral particles, leaving the coarser-textured particles behind. In such cases, nematode problems are likely to increase. Under some situations, however, nematode problems can be severe in fine-textured soils, too.

Microbial biomass

Increasing soil organic matter usually increases soil bacteria, actinomycetes and fungi. In response, populations of bacterial and fungal-feeding nematodes increase. This more balanced microbial diversity may reduce plant-parasitic nematode damage due to increased:

- Plant-parasitic nematode diseases caused by bacteria or fungi
- Predation by other nematodes
- Occurrence of natural chemicals that are toxic to root-feeding nematodes
- Tolerance to plant-feeding nematodes as plant nutrition improves with increased nutrient mineralization
- Population density of bacterial and fungal-feeding nematodes that compete with plant-parasitic nematodes for resources



Source: Bird, G.W. 1999. Unpublished data.

Nutrient mineralization

Research highlights

Plants growing in soil with bacteria and bacterial-feeding nematodes grew faster and initially took up more nitrogen than plants in soil with only bacteria, because of increased nitrogen mineralization by bacteria, ammonium nitrogen excretion by nematodes and greater initial exploitation of soil by plant roots.

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

Fungivores increase nitrogen mineralization

Nitrogen mineralization was lower after 21 days in the presence of a fungus (*Rhizoctonia*) than in the presence of this fungus and a fungivore nematode (*Aphelenchus avenae*).

Treatment	Ammonium nitrate (ug NH_4^+-N) recovered* 7 days	14 days	21 days
Fungus	25.9	39.5	1.9
Fungus and nematode	26.1	50.5	19.9

*Greater ammonium nitrate recovery suggests greater nitrogen mineralization.

Source: Chen, J. and H. Ferris. 1997. Journal of Nematology 29:571.

Structure and bulk density

Soil structure refers to the way in which the primary particles – sand, silt and clay – are held together to form aggregates. Soil organic matter generally improves soil structure and decreases bulk density, which improves gas and water diffusion, promotes root growth and possibly increases tolerance to nematode damage. Crops grown in soil with poor structure are at greater risk to moisture stress, nutrient stress and nematode damage than those grown under optimal conditions.

Nutrient availability and release

Nutrient availability and release are largely determined by soil texture, pH and organic matter. Management practices that improve cation exchange capacity and nutrient release, such as increasing soil organic matter, can increase plant tolerance to nematodes. Biologically active nutrient cycles support many soil quality characteristics.

Soil nutrient influence on cyst nematode development in a susceptible soybean variety

Nutrient	Cysts/g root tissue	Eggs/cyst
Water	481	140
Nutrient solution without nitrogen	611	99
Nutrient solution with nitrogen	274	76

Soil nutrient and soybean cyst nematode influence on photosynthesis of a susceptible soybean variety

	Photosynthetic rate[1]	
Nutrient	SCN absent	SCN present
Water	8.20	4.64
Nutrient solution without nitrogen	9.53	6.20
Nutrient solution with nitrogen	10.90	8.82

[1](umol CO_2 m^{-2} s^{-1})

Source: Melakeberhan, H. 1999. Nematology 1:113-120.

pH

Soil pH above or below the optimal range for a specific crop interferes with nutrient availability and release, resulting in unhealthy plants. Plants grown above or below optimal pH are at greater risk to damage by plant-parasitic nematodes and other soilborne pathogens than plants maintained under an optimal soil pH.

Balanced biotic diversity

Agricultural systems that have balanced biotic diversity appear to be at less risk to plant-parasitic nematode damage than systems that do not emphasize soil biology. Although some researchers think that balanced biotic diversity may be the most important soil quality characteristic contributing to healthy and profitable crops, this topic has received little attention during the last 50 years. A field crop ecosystem not managed to favor bacterial-feeding, fungal-feeding and predacious nematodes will often be dominated by plant-feeding species. Diversity is only beneficial when soil food web interactions take place within a vibrant community.

Nematodes as soil quality indicator

MSU researchers are evaluating a soil quality assessment system based on nematode community structure. It consists of three parameters: a) types of nematodes, b) nematode population density and c) extent of ecosystem disturbances. Each parameter is rated on a scale of 1 to 3.

The Soil Quality Index gives a total nematode-based soil quality index of 0 to 6 [(a + b + c) - 3 = 6]. A low number indicates poor soil quality and a high number indicates optimum soil quality. The MSU Center for Integrated Plant Systems/Diagnostic Services currently offers total nematode community assessment. This service was initiated in 1999.

The worms know

- **Nematode community structure reflects differences in types of farming systems**
- **Nematode community structure can be used to detect changes in agricultural ecosystem habitats**

Nematode community structure

W.K. Kellogg Biological Station - Living Field Laboratory

(B + C + F)/H = Nematode index

Farming system	Nematode index
Conventional system	1.70
Integrated fertilizer system	2.42
Integrated compost system	5.66
Transition organic system	7.38

B = Bacterivore nematodes
C = Carnivore nematodes
F = Fungivore nematodes
H = Herbivore nematodes

Source: Berney, M.F. and G.W. Bird. 1998.

Common plant-feeding nematodes in Michigan field crop systems

Although several dozen plant-parasitic nematode species can cause infectious diseases in Michigan field crops, only four will be discussed here. These species exist on one or more of the farms featured in the case studies.

Cyst nematodes

Five cyst nematode species are potential Michigan field crop pests. Two of these species, sugar beet cyst nematode (SBCN) and soybean cyst nematode (SCN), are major pests that cause significant crop losses. Two other species, clover cyst nematode and oat cyst nematode, are present in Michigan, but rarely cause major yield losses. The fifth species, potato cyst nematode, is a devastating pathogen, but has never been detected in Michigan potato production.

Sugar beet cyst nematode

Sugar beet cyst nematode was first identified in Michigan more than 50 years ago. Since sugar beet is this pest's only major Michigan field crop host, SBCN was successfully managed for many years using strict crop rotations in which beets were never grown in any field more than one of every three years.

1998 sugar beet cyst nematode (SBCN) survey[1]

Rotation length	Sites sampled	Fields with SBCN (percent)	SBCN population density[2]
3 years or less	47	60	2,972
4-5 years	128	55	3,177
6-8 years	40	38	1,605
More than 8 years	7	14	4

[1]Survey of 214 Michigan sugar beet fields with SBCN recovered from 115 of the locations.

[2]Eggs and second-stage juveniles per 100 cm^3 soil.

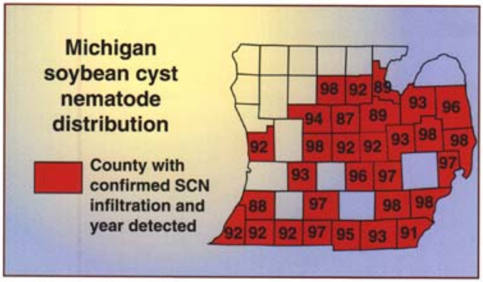
Source: Miller, A. and G.W. Bird. 1999.

Sugar beets affected by sugar beet cyst nematode.

If a field had a known SBCN problem, it was planted to beets only one of every five years, with some farmers expanding the rotation interval to eight years. Nematicides were used only on a very limited basis. During recent years, Michigan sugar beet acreage has increased, rotation length has shortened and crop yields have declined. A 1998 industry survey showed that the SBCN is widely distributed in Michigan sugar beet production areas and may be responsible for a significant portion of this yield loss. The survey found SBCN in 52 percent of low-yielding problem fields and 26 percent of sampled sites not expressing visual symptoms. The Bay County case study farmer is in the process of lengthening his crop rotation to manage this nematode.

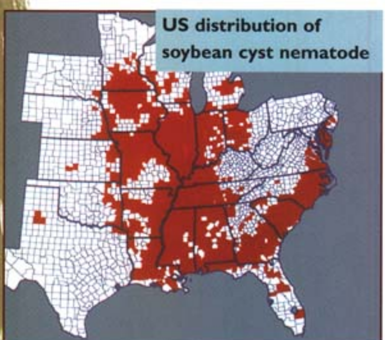
Soybean cyst nematode

Soybean cyst nematode is a major pest in soybean production across the U.S. It was first detected in Michigan in 1987. Losses caused by this nematode range from barely detectable to total crop loss. SCN has been detected in 25 Michigan counties and is reported both nationally and internationally as the most serious limiting factor in soybean production. SCN attacks seedling roots immediately after germination, resulting in significantly reduced plant stands. Surviving plants remain stunted and discolored throughout the growing season. Symptoms may exist uniformly or in circles across a field. Female SCNs can be seen attached to roots early in July. They are less visible when they mature and become brown cysts. Eggs within cysts can remain viable for up to a decade, though their number declines each year.



Source: Warner, F. and G.W. Bird. 1998.

It is best to avoid SCN problems through crop rotation and nematode-free seed and equipment. Farmers with known SCN problems must take extra sanitation precautions to prevent spread. Crop rotation can also help lower nematode population densities and reduce yield losses after a SCN problem is established. Both nematode-resistant and tolerant soybean varieties are available. When the same genetic source of resistance is used repeatedly in a field, SCN may overcome the resistance. A system of three-year rotations should be used if a low to moderate SCN population is discovered. For larger populations, a long-term rotation scheme should be used, including multiple sources of resistance. Although soil fumigants reduce SCN populations and increase soybean yields, they are very expensive. Applying aldicarb, a non-fumigant nematicide, at planting provides short-term nematode population suppression and improves soybean yield; however, it may be too costly for many situations.



Source: Riggs, R. 1997. University of Arkansas.

Soil tests on the Lenawee County case study farm have shown that SCN is present in these fields. The farmer, however, has not seen signs of SCN damage. This pattern is consistent with the fact that there are currently no known SCN problem sites on Michigan certified organic farms. If the current emphasis on organic soybean production leads to shorter crop rotations, it is possible that SCN could become a problem for organic growers.

Other nematodes

Corn needle nematode

Corn needle nematode (CNN) is an ectoparasite. CNN feeds close to the root tips, preventing normal growth and development. It causes root tip swelling, stunted plants, small and barren ears and low grain yields. This nematode is a problem only in very coarse-textured soils. Yield losses may range from 10 to 75 percent. Crop rotation and soil quality management are keys to controlling this localized, but very important pest. A crop rotation with either soybeans or alfalfa can double corn grain yields when CNN is present.

CNN are very sensitive to moisture and temperature, migrating deep into the soil during hot, dry periods. This behavior can make nematode detection and problem diagnosis difficult.

The St. Joseph County case study farmer has observed CNN symptoms on his farm on two occasions. The farmer has resolved this issue by diversifying his crop rotation to include snap beans and potatoes.

Potato early-die

Potato early-die (PED) is a disease complex caused by the joint action of an endoparasitic root-lesion nematode and a Verticillium-wilt fungus. The problem exists on about half of Michigan's potato acreage, and can cause 25 to 200 cwt/A yield losses. Historically, this problem has been managed by reducing pre-plant population densities of the root-lesion nematode using soil fumigants, chemigants or non-fumigant nematicides. Various rotation crops, cover crops and tolerant cultivars also provide positive responses. Recent research has demonstrated that growing alfalfa for two years before a potato crop can help minimize PED risk. Combinations of cover crops like buckwheat composted with cow manure have also improved yield and decreased pre-plant root-lesion nematode population densities.

PED risk on the St. Joseph County case study farm is reduced by this farmer's diverse crop rotation and extensive cover crop use.

Corn needle nematode management

System	Corn yield bu/A
Continuous corn	68
Corn following soybeans	120

Source: Bird, G.W. 1990. Unpublished data.

Corn growth (l) stunted by corn needle nematode.

The St. Joseph County case study farmer includes potato production for managing corn needle nematode.

For further reading

Barker, K.R., G.A. Pederson and G.L. Windham. 1998. Plant and Nematode Interactions. ASA, CSSA, SSSA Agronomy Series No. 36. Madison, Wisconsin. 771 pp.

Berney, M.F. and G.W. Bird. 1998. Nematodes, pp 71-79 (in) Michigan Field Crop Ecology, Cavigelli, M.A., S.R. Deming, L.K. Probyn and R.R. Harwood (eds). Michigan State University Extension Bulletin E-2646, East Lansing. 92 pp.

Bird, G.W. and M.F. Berney. 1998. Pest Ecology and Management pp. 54-58. (In) Michigan Field Crop Ecology, Cavigelli, M.A., S.R. Deming, L.K. Probyn and R.R. Harwood (eds). Michigan State University Extension Bulletin E-2646, East Lansing. 92 pp.

Blaxter, M. 1998. *Caenorhabditis elegans* is a nematode. Science 282: 2041-2046.

Goodey, T. (Rewritten by J.B. Goodey). 1963. Soil and Freshwater Nematodes. Methuen & Co. Ltd. N.Y. 544 pp.

Ingham, R.E., J.A. Trofymow, E.R. Ingham and D.C. Coleman. 1985. Interactions of bacteria, fungi and their nematode grazers: Effects on nutrient cycling and plant growth. Ecological Monographs 55: 119-140.

Mai, W.F., P.G. Mullin, H.H. Lyon and K. Loeffler. 1996. Plant-Parasitic Nematodes: A Pictorial Key to Genera. 5th ed. Comstock Publishing Associates, Cornell University Press, Ithaca, N.Y. 227 pp. 1998. Science 282:2041-2046

Melakeherhan, H. 1999. Effects of nutrient source on the physiological mechanisms of Heterodera glycines and soybean genotype interactions. Nematology 1:113-120.

Niblack, T.L. 1999. Soybean Cyst Nematode Management Guide. North Central Soybean Research Program Publication. University of Missouri, Columbia. 20 pp.

Norton, D.C. 1978. Ecology of Plant-Parasitic Nematodes. John Wiley & Sons. N.Y. 268 pp.

The *C. elegans* Sequencing Consortium. 1998. Genome sequence of the nematode *C. Elegans*: A platform for investigating biology. Science 282: 2012-2018.

Management practices

Key

- ☆ = greatly reduces pest risk
- ✣ = reduces pest risk
- ❍ = no or little effect on pest
- × = weak increase in pest risk
- ✘ = strong increase in pest risk

Nematode pests	Soil texture		Crop rotation			Tillage			Planting date		Plant population		Cultivation		Field size and borders		Row width		Cover crops	Pest resistant varieties	Soil quality	Sanitation
	Course	Fine	Continuous	2 Year	3+ Year	No-till	Chisel	Moldboard	Early	Late	Low	High	Early	Late	Small	Conventional	Early	Late				
CORN																						
Corn needle nematode	✘	☆	✘	☆	❍	❍	❍	×	×✣	❍	❍	❍	❍	❍	❍	❍	❍	❍	☆	NA	☆	×✣
SOYBEANS																						
Soybean cyst nematode	✘	×	✘	×	×✣	☆	×✣	☆	×✣	×✣	❍	❍	❍	❍	❍	❍	×✣	×	×✣	☆	☆	☆
POTATO																						
Root-lesion nematode	×	☆	✘	×	×✣	×	×✣	×✣	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	☆	NA	☆	☆
SUGAR BEETS																						
Sugar beet cyst nematode	×	×✣	✘	×	×✣	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	☆	NA	☆	☆

Putting it all Together: The Big Picture

Kurt D. Thelen

Key Points:

Every pest management practice has potential negative and positive impacts for a cropping system.

Many past agricultural efficiency improvements have been attributed to controlling specific insect, weed, pathogen or nematode pest species.

Though generally successful, pest-specific approaches have resulted in unintended negative effects.

A systems approach to pest management is needed to minimize negative interactions and address emerging pest management issues regarding environmental quality and food safety.

Study Questions:

How do such factors as soil quality, planting date, cover crops, and crop rotations affect crop insect, weed, pathogen and nematode pest levels?

What are the potential positive and negative impacts of spring tillage, planting legume or cereal cover crops, delaying planting or applying pesticides?

Northern Kalamazoo County farmland.

Introduction

How will we define field crop pest ecology in the future? Agricultural technology changes so quickly it is difficult to predict. Many agricultural productivity increases have been attributed to controlling specific insect, weed, pathogen or nematode pest species, and though this approach has often proven effective, a more integrated, interdisciplinary approach is needed to address emerging pest management issues.

Building a systems approach to field crop pest ecology

Three areas that farmers, scientists and consumers have identified as major challenges facing agriculture are food safety, environmental protection and pesticide resistance. These issues differ from historical pest management priorities because they require us to consider broader issues than the targeted eradication of an individual pest. Instead we must look at each pest's ecology: how its population dynamics are influenced by interactions with other pests, other species and their environment.

We also know that growers require several key elements for an effective pest management system: cost effective practices, crop rotation and enterprise flexibility, marketable commodities and a safe environment for their families and farm workers.

Integrated pest management system components

Understanding how specific management practices affect pest populations will help farmers develop crop production systems that integrate cultural and biological controls with reduced reliance on synthetic pesticides. Here are some concepts to keep in mind:

Crop rotation

Crop rotation is the most effective way of reducing many pest populations. Since many pests are host-specific, removing the host by planting another crop may reduce their population densities. Including winter annuals (e.g. wheat), summer annuals (e.g. corn) and perennials (e.g. alfalfa) in a rotation will limit weeds with similar life cycles by decreasing their ability to compete over time. Rotations can also control insect pests such as corn rootworm. Those pests that have wide host ranges, that are not host-specific, or that have long-term resting stages are less affected by crop rotation. Corn wireworm infestation potential, for example, may increase in rotations that include sod crops. Long-term crop rotation systems are very effective in reducing nematode problems in soybeans and sugar beets.

Tillage

Tillage is perhaps the most important means of reducing plant pathogen population densities, such as *Cercospora* (gray leaf spot). No-till practices have come with increased incidence of some field crop diseases, including *Fusarium* head blight in wheat, which survives on corn residues left on the soil surface. Tillage can reduce some pests' overwintering stages. European corn borer (ECB) survival, for example, is lower in moldboard plowed fields. Tillage can also reduce short-term weed populations, but in the long-term, tillage leads to shifts in weed community structure.

The number of weed seeds in the germination zone decreases over time in no-till systems if weeds are not allowed to produce new seed. Tillage, on the other hand, moves buried weed seeds into the germination zone. No-till fields also have higher populations of beneficial insects like ground beetles that control black cutworm damage. Tillage harms these and other ground-dwelling beneficial insects because it buries the residue cover that protects them. In tilled systems it is better to till in the spring to maximize beneficial insect feeding on crop pests in the fall and following spring. Tillage can also spread weed seeds, perennial weed roots, and nematodes within and between fields.

Finally, tillage can decrease soil organic matter levels. Soil organic matter plays a key role in pest ecology. Higher soil organic matter levels and quality can result in higher water-holding capacity, water infiltration rate and microbial biomass, better soil structure, lower bulk density, near optimal pH and a balanced biotic diversity. Farming systems designed to maintain or increase soil organic matter quality can decrease risk of root damage caused by nematodes and may increase crop tolerance to other pests due to better overall plant health.

Cover crops

Introducing cover crops increases a crop rotation's diversity. Cover crops reduce the chance for weed germination after the main crop is harvested and/or before it is planted. Research on one southwest Michigan farm with four different cover crops planted following a snap bean crop showed greatly reduced weed populations. Oilseed radish was especially effective, suggesting that it may produce allelopathic chemicals that prevent weed seed germination. Cover crops can also provide winter habitat for beneficial insects, particularly predators like ground beetles and rove beetles, and may provide early spring cover and food, giving them a head start on pests. Cover crops can also trap soil borne disease spores before they reach the crop.

Some pests, however, can be stimulated by certain cover crops. Armyworms may lay eggs in dense stands of small grain covers in the spring, then attack crops as they mature. Odors given off by covers that have been plowed down too close to crop planting can stimulate seedcorn maggots egg laying. Wait at least two weeks after soil-incorporating cover crops to plant maggot-sensitive crops like corn and soybeans.

The summer annual, common ragweed, quickly germinates in harvested wheat stubble. A cover crop, such as oilseed radish (inset), planted into the stubble suppresses ragweed seed germination.

Variety selection

Variety selection is crucial for effectively managing pests and it may impact disease, nematode, insect and weed populations. As with pesticides, it's important to minimize the potential for pest resistance. With the advent of transgenic crops, additional variety-based pest management options are becoming available. It is critical to use this technology wisely and in conjunction with other management practices to avoid pest resistance problems.

Photo: Steven R. Dewing

Planting date

Planting early into cold, wet soils can delay germination or slow early season growth, making crops more susceptible to certain soil insect pests including wireworms, cutworms and seedcorn maggot. Planting corn very early can lower soil insecticide effectiveness before corn rootworm eggs hatch. While early planted corn tends to be more attractive to European corn borer, it is less attractive to second-generation borers. Some producers use this knowledge to select varieties or make scouting decisions. Planting wheat after the Hessian fly-free date avoids damage by this pest. Delaying dry bean planting until early June helps avoid a soil environment that favors early season root rot pathogens such as *Pythium* and *Fusarium*. Planting oats before May 15 allows the plant to mature and develop resistance before the aphids that transmit Barley Yellow Dwarf Virus can do their damage. Early planted crops reach canopy closure sooner and gain a competitive advantage over seeds. Late planting, on the other hand, provides opportunities to use tillage for controlling early germinating weeds like common lambsquarters and smartweed before planting.

Plant population and row spacing

Planting crops in narrow rows results in quicker canopy closure, reducing light penetration for weeds below the canopy. Narrow rows also reduce options for mechanical cultivation and may increase incidence of white mold, which can thrive in the moist environment created below a closed canopy. Wider rows provide faster soil drying and lower chances for white mold.

Pesticides

Pesticides have been used effectively in many cropping systems. Michigan State University recommends treating dry bean, wheat, alfalfa and corn seeds with a fungicide prior to planting. Foliar and soil-applied pesticides should always be used in conjunction with a field scouting program or a weather-based disease prediction program.

Pesticides have two harmful long-term effects on pest management. Perhaps the most important is the development of pesticide resistance. Not only does resistance decrease pesticide effectiveness, it may also alter pest characteristics. For example, atrazine-resistant pigweed seeds have greater dormancy than non-atrazine-resistant varieties.

Pesticides also impact non-target organisms. Field-applied insecticides almost always kill some beneficial insects. Controlling one insect with a pesticide application can unintentionally result in a second pest outbreak by killing the natural enemies that were previously suppressing it. This is called a secondary pest outbreak. Fungicides can cause secondary pest outbreaks by suppressing beneficial fungi that attack insect pests. Potato leafhopper (PLH) populations are often naturally suppressed in alfalfa and dry beans in August when fungi populations increase. In certain vegetable crops, ill-timed fungicide applications can result in PLH or aphid population outbreaks.

Pesticides also affect natural enemies indirectly. When insecticides reduce a pest population, the surviving natural enemies, left without a food source, may leave or die. Herbicides may also irritate certain beneficial insects, such as ground beetles, increasing their movement and reducing their effectiveness. Finally, pesticides can alter the crop environment, making it less favorable to natural enemies. Herbicides often do this by removing pollen and nectar sources within fields and along field edges and leaving a more open canopy that is less favorable to some natural enemies.

Sanitation

Sanitation means removing and destroying overwintering or breeding sites for a pest, such as removing cull potato piles to help control blight. Sanitation is one of the most important strategies to avoid disease problems by keeping pathogen population densities low. Some sanitation practices, though can harm beneficial insect populations by reducing their habitat.

Fertilizer placement and location

Fertilize the crop, not the weed. Soil fertility levels should be held at optimum levels for healthy crop growth. Deep-band fertilizers so they are available for crop but not weed growth. Time fertilizer applications to correspond with crop uptake and direct fertilizer applications near the row to reduce availability to weeds between rows. Finally, reduce nitrate leaching potential to groundwater by avoiding applying nitrogen fertilizer in the fall for following summer crops.

Harvest

Timely alfalfa harvest can effectively manage both the alfalfa weevil and PLH. Timing first harvest to remove alfalfa before weevil larvae enter the most damaging stage (typically in late May) can maximize forage yield and quality. If PLH numbers increase, cutting forage effectively suppresses their numbers. Timely forage crop harvest also controls some perennial weeds such as Canada thistle. Periodic mowing controls Canada thistle by depleting the weed's energy rootstock. Other perennial weeds such as quackgrass, however, are not controlled with mowing. Mowing field borders can, however, harm beneficial insect habitat.

Residue management

Crop residues provide more ground cover for insect predators and weed seed consumers like rodents, insects and spiders, and may increase seed decay (though this is not known). Residues provide shade that can inhibit weed growth, but it may also delay crop emergence by keeping soils cool. Increased crop residue from no-till may allow greater winter ECB survival, contributing to the following year's first-generation ECB moth flight. Chopping or shredding stalks reduces ECB survival.

The field crop pest ecology tool box

Rotations, tillage, residue management, cover crops, variety selection, planting dates, plant populations, row spacing, pesticides, fertilizer placement, harvest, field sanitation and other management practices are all tools in every farmer's pest ecology tool chest. The tools available to growers will continue to multiply, change and become more complex. Further biotechnology advances – although still somewhat uncertain on the market end – have tremendous potential to provide additional pest management alternatives through variety selection. Growers will be challenged to use the appropriate tools in the best sequence to maximize long-term farm efficiency while meeting societal expectations. We hope this bulletin helped you understand the many complex interactions in field crop pest ecology. After all, "if the farmer knows why, he will teach himself how."

Here's what people are saying about Michigan Field Crop Pest Ecology and Management

I found the material to be very comprehensive in covering the complicated interactions involved with crop rotation, tillage and cultivation options, planting and harvest dates, residue management, cover crops, nutrient management, etc., along with their influence on wind and water erosion control and pest management. The cost-benefit orientation is helpful to farm decision makers. The document treats the large number of "trade-offs" that farm decisions entail. The United States Environmental Protection Agency is proud to have contributed to the development of this document.

David P. Macarus, Ph.D.
Program Manager, Pesticide Environmental Stewardship
U.S. Environmental Protection Agency

Producers are ready for a reference that brings basic biological interactions to the forefront of modern agriculture. Realizing how our actions create a chain effect in the system will change how farming is done in the future.

Natalie Rector
MSU Extension Agriculture & Natural Resources Agent
Calhoun County

Michigan Field Crop Pest Ecology and Management, together with its companion volume, **Michigan Field Crop Ecology**, helps us better manage the biology of our farming systems. This book is an excellent primer for farmers and agricultural specialists who will need a better understanding of production methods coming from the new "biological" revolution that is sweeping agriculture. These methods will support and help stabilize our new crop genetic technologies and lead to more sustainable farming systems.

Richard R. Harwood
C.S. Mott Foundation Chair of Sustainable Agriculture
Department of Crop and Soil Sciences
Michigan State University

Michigan Field Crop Pest Ecology and Management blends solid scientific information with the best agricultural practices to provide biological and cultural alternatives for effective pest control and management. It will fill a void for practical, science-based information that can be of immediate use to those who choose to manage agricultural pests in a manner that conserves our natural resource base.

Dr. Rick Foster
Vice President for Food Systems and Rural Development
W.K. Kellogg Foundation