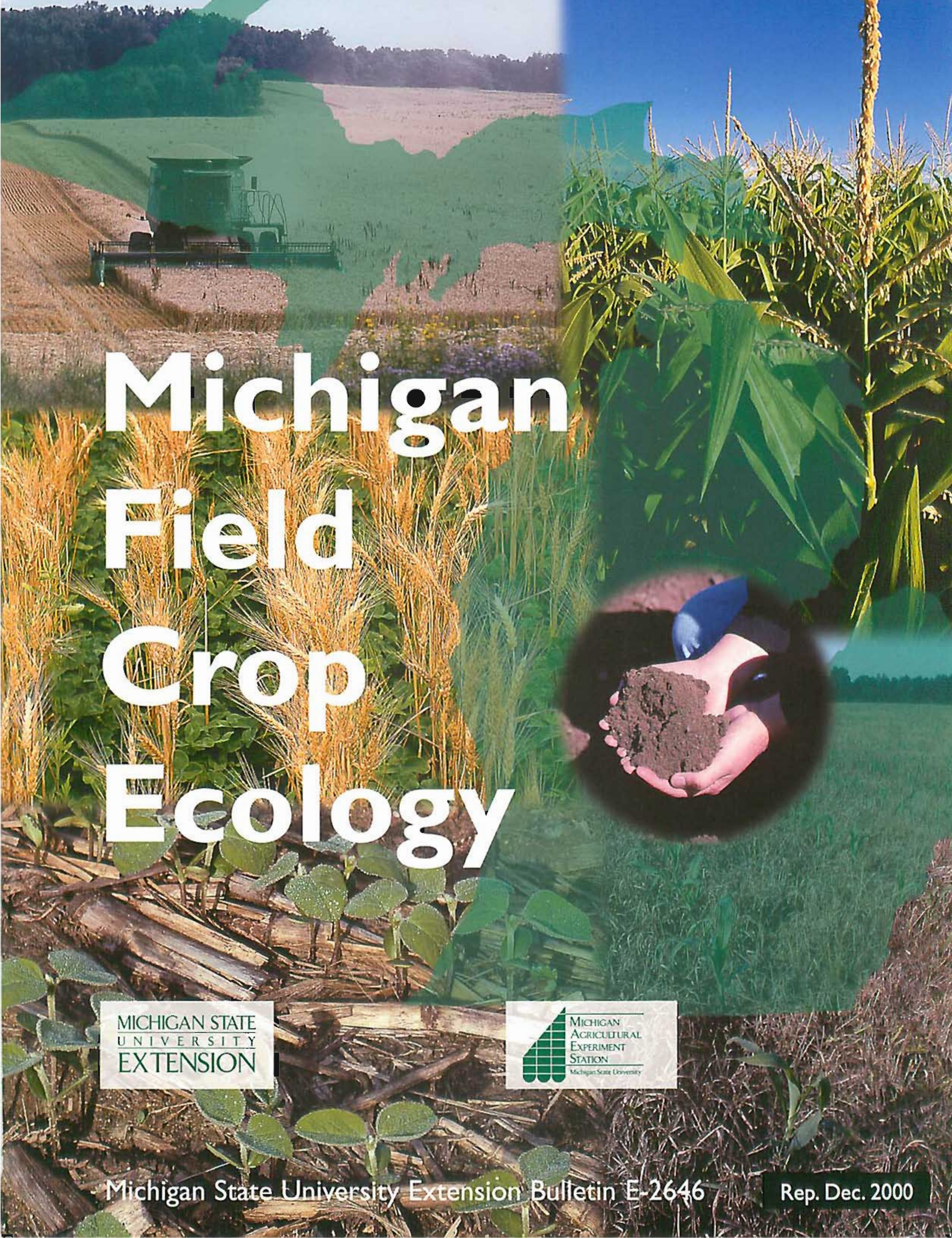

Michigan Field Crop Ecology

MICHIGAN STATE UNIVERSITY EXTENSION

MICHIGAN AGRICULTURAL EXPERIMENT STATION
Michigan State University

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Michigan Field Crop Ecology

Managing biological processes for productivity and environmental quality

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Introduction

Richard R. Harwood

Why this book?

This volume was assembled by a group of Michigan agricultural scientists, MSU Extension workers and farmers to promote greater understanding of Michigan field crop ecology in order to help Michigan farmers achieve greater sustainability in their farming systems. We touch briefly on the social, political and macroeconomic dimensions that are critical aspects of agricultural sustainability, but our primary goal is to build an understanding of the **biological basis of sustainability**. Our general approach is to describe management (especially field crop biodiversity and crop rotation) in terms of its influence on organisms' habitats and food sources found in the agricultural landscape. Both agricultural productivity and environmental quality can be significantly enhanced by more effectively managing the biological processes upon which agriculture is based.

Since considerable field crop ecology research in Michigan is being conducted at the W.K. Kellogg Biological Station (KBS) in Kalamazoo County, this book draws heavily on research conducted there. Research results are gleaned from three KBS projects in particular: the Long-Term Ecological Research project in Row Crop Agriculture (LTER), the Living Field Laboratory (LFL) and the Cover Crop Program. The LTER is funded in cooperation by Michigan State University, the Michigan Agricultural Experiment Station and the National Science Foundation. The research at the KBS LTER centers on the ecological interactions underlying the productivity and environmental impact of field crop ecosystems and on patterns, causes and consequences of microbial, plant and insect diversity in agricultural landscapes. The LFL was designed to integrate basic ecological knowledge gained from the LTER into cropping systems appropriate to Michigan farming situations. The Cover Crop Program, largely farmer-driven, assesses various cover crops for the Michigan environment and evaluates management options such as time of planting, methods of killing and herbicide compatibility.

Living Field Laboratory, W.K. Kellogg Biological Station (KBS), Hickory Corners, Mich. (above). Ag field day at KBS (r).

Goals for Michigan's field crop agriculture

Michigan agriculture is one of the country's most diverse, reflecting the variety of its soils and microclimates. A biologically based agriculture must build on this **diversity**.

To be sustainable, Michigan's agriculture must be globally **competitive** in producing commodities that commonly move great distances at low cost, such as corn, soybeans, wheat, dry beans and sugar. It must also be regionally and nationally competitive in producing potatoes, hay and many animal products.

Agriculture must also provide a range of **ecosystem services** to our people, our economy and our landscape. These services include providing clean surface water, filtered groundwater, clean air, biological diversity and stability, wildlife habitat, waste recycling and an aesthetically pleasing landscape. Since farms dominate the landscape in many parts of Michigan, services provided by agricultural ecosystems benefit all Michigan residents.

What is field crop ecology?

Field crop ecology is a part of agricultural ecology, or agroecology, which is the study of the interactions among the many biological, environmental and management factors that make up and influence agriculture. Another way of defining agricultural ecology is that it is the study of material and energy flows within and across agricultural fields, from the level of the individual soil organism to the global scale. Important interactions within this complex web include those among soil, plants, animals, humans, landscapes and the atmosphere. An ecological perspective recognizes that these interactions occur in an often-changing environment and that it is impossible to change one aspect of a farming system without affecting others. In other words, agricultural ecology considers farming systems from a "holistic" rather than a "reductionistic" perspective.

Field crop ecology is different from the broader field of agricultural ecology only in that it specifically addresses field crop production; thus, the principles we discuss in this publication are applicable to all farming systems, but the details are specific to field crop production. An introduction to field crop ecosystems is given in the next chapter.

Integrating ecology into farming system design

At the production level, most technological developments have been aimed at reducing labor and increasing yields, largely by considering commodity production from the perspective of the engineer, chemist and plant breeder. While great strides have been made using this largely engineering approach, some unexpected consequences have resulted by not adequately considering the complex biological web that is at work in a system of healthy, efficient soils, plants and animals.

Ecological management of farming systems is an approach that considers this complex biological web and recognizes that management decisions affect the habitats and food sources of organisms important in regulating biological processes and, therefore, agricultural productivity. The relationship between soil quality and crop health is at the heart of field crop ecology.

The major objectives of ecological management are:

1) enhancing **soil quality** (and productivity),

2) **managing pests** and diseases with minimal environmental impact, and

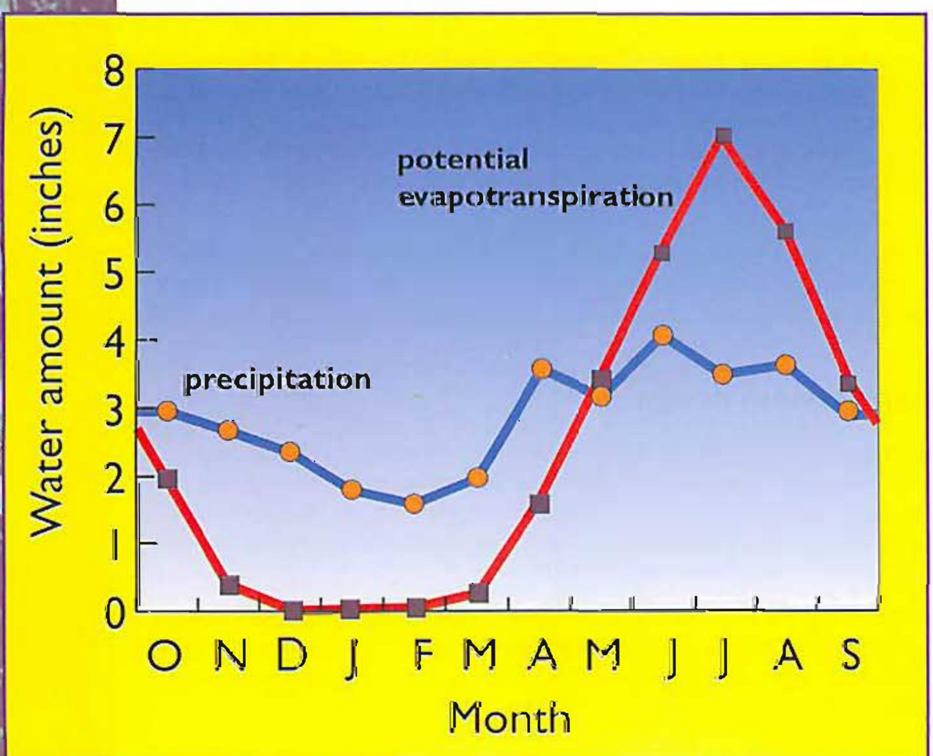
3) **recycling nutrients and residues** effectively and efficiently.

Management practices that help achieve all three of these goals, such as the use of **crop rotation and cover crops**, are highlighted in this book. This book provides guidelines for using these practices. Specific combinations of practices should be designed for individual farms based on microclimate, soils and other factors.

Michigan climate and soils: problem and opportunity

Effective management begins with an assessment of an area's climate and soils, the fundamental base of agricultural productivity. Since Michigan land costs, taxes, soil types and climate are often not ideal, we must compensate by using the resources we have (water, soil and local markets) efficiently and protecting them from degradation.

Most Michigan counties receive 30-34 inches of rainfall annually, ranging from 26 inches in the Saginaw area, to nearly 40 inches in the southwest. About half falls during the main, five-month growing season (May-Sept). During the summer, evaporation and crop demand exceeds rainfall in most regions, so little water moves into groundwater. During the seven-month cold season, however, precipitation exceeds demand, with soil recharge always occurring, regardless of cropping pattern.



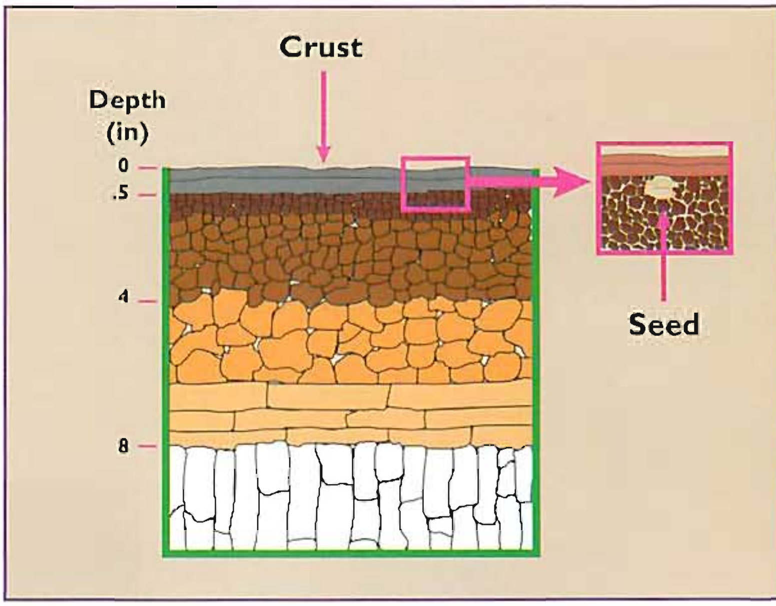
Monthly average precipitation and potential evapotranspiration for the years 1956-1986 at KBS.

The effect of climate and soils on Michigan field crop ecology is discussed on the following pages using three examples: soil quality, control of Hessian fly damage to wheat and the use of cover crops. Each example addresses the importance of climate and soils on management decisions.

Soil quality and climate interactions

In Michigan, most soil deterioration, groundwater contamination and soil loss occur during the winter. Fall plowing exposes soil to weathering and disrupts soil organisms' habitats. The best way to minimize soil deterioration is to leave crop residues on the surface and/or plant a cover crop. Both dead and living cover physically protect the soil from degradation that occurs from direct exposure to rainfall. In addition, the roots of live cover crops can take up excess soluble nitrogen, provide a favorable environment for soil organisms and supply fresh crop residue to "pulse" the biota in the spring.

Soil types differ in their demand for such "tender loving care." Coarse-textured soils, with a water infiltration rate of above two inches per hour, require much more careful nitrate management than do fine-textured soils. Other soils develop a crust or are susceptible to compaction if steps are not taken to protect them.



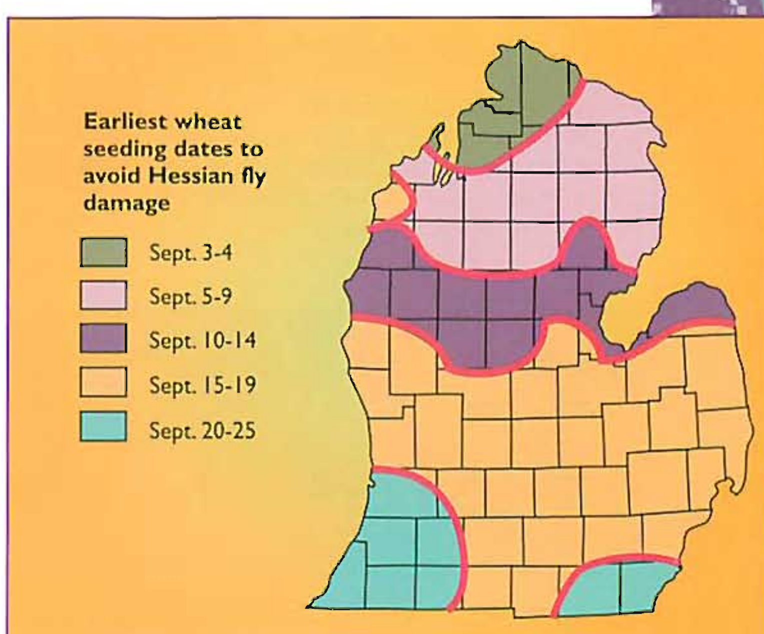
Source: Soil Management, Ontario Ministry of Agriculture, Food and Rural Affairs, 1994.

Soil Crusting

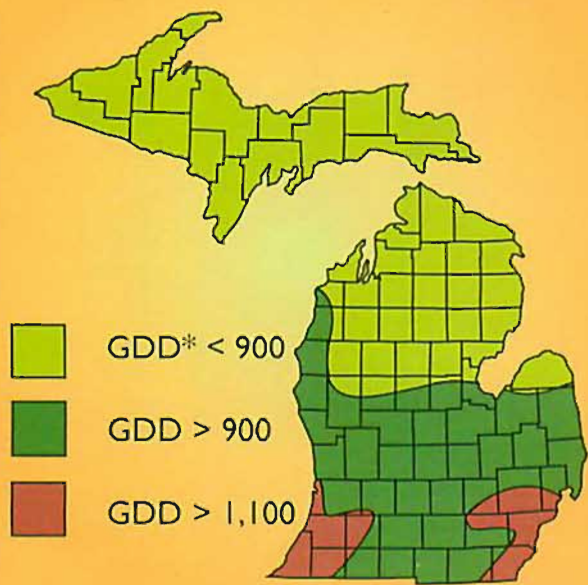
Following the rapid wetting and drying of an overworked seedbed, a solid sheet of soil, 0.01-2 inches thick, forms that is tight enough to prevent crop emergence. This is known as soil crusting.

Hessian fly and Michigan climate

Seasonal temperature and moisture changes also affect insect and disease incidence. An example familiar to many farmers is scheduling wheat planting dates to avoid damage by the Hessian fly, a potentially serious wheat pest. As temperatures drop in the fall, Hessian fly activity decreases and wheat can be safely planted after fly activity has reached a minimum threshold. This Hessian fly-free wheat planting date is adjusted in unusually cold or warms years, in recognition that Hessian fly activity is weather-dependent. This is a good example of using ecological information about pests to aid in field crop management.



Michigan's three cover crop zones



*GDD = growing degree days above 40° F for September and October.

Cover crops and climate

In a crop rotation system with at least one winter crop, and where early harvest permits, a fall cover crop is desirable for many reasons, including those noted above. Fall temperatures determine the capacity for crop management during the cold season. A wide range of species is available for August seeding; fall temperatures, however, determine the potential for September and October seedings. Michigan has three zones for fall growth that correspond to the growing degree days (GDD) above the 40° F base considered appropriate for most cover crops. A total GDD for September and October above 900 is ideal for cereal-legume mixes. Those areas above 1,100 GDD have further options, including legumes like hairy vetch.

Annual ryegrass planted into sweetcorn.

Red clover in corn.

Cover crops can markedly reduce nitrate leaching as shown in the table below. In several studies, cover crops reduced nitrate leaching in continuous corn by as much as 36 percent. Reduction in nitrate loss also occurred when compost and/or a four-crop rotation were used, but yields and profits were sometimes lower.

Nitrate leaching in different cropping systems using various nitrogen sources (pounds of nitrogen per acre)

Nitrogen source	Fertilizer	Fertilizer + cover	Compost + cover
Nitrate leaching	64	23	41

Source: The Living Field Laboratory, KBS, 1993-96.

These are just a few examples of the influence of climate and soils on management decisions that influence soil quality, pest populations and nutrient recycling. This book addresses these and other issues in greater detail.

Field crop ecosystems

G. Philip Robertson

Key concepts and questions

- What is an ecosystem? How do field crop ecosystems differ from unmanaged ecosystems? What can we learn from unmanaged systems to help manage field crop ecosystems sustainably?
- How do field crop ecosystems and surrounding ecosystems affect each other?
- What is primary productivity and what influences it?
- How do energy and nutrients flow through field crop ecosystems?
- What are the different components of field crop ecosystems and how do they interact?
- How do biodiversity and crop rotation influence field crop ecosystems?

Additional reading

E. Jackson (ed.). 1997. Ecology in agriculture. Academic Press, New York.

What is an ecosystem?

An ecosystem is a geographic location on the earth's surface where energy and nutrients are captured and transformed by plants, animals and microbes.

An ecosystem can be as large as the planet or as small as a clump of soil. Within each, complex communities of organisms interact to transform energy from one form to another, and to take up and transform nutrients such as nitrogen and phosphorus.

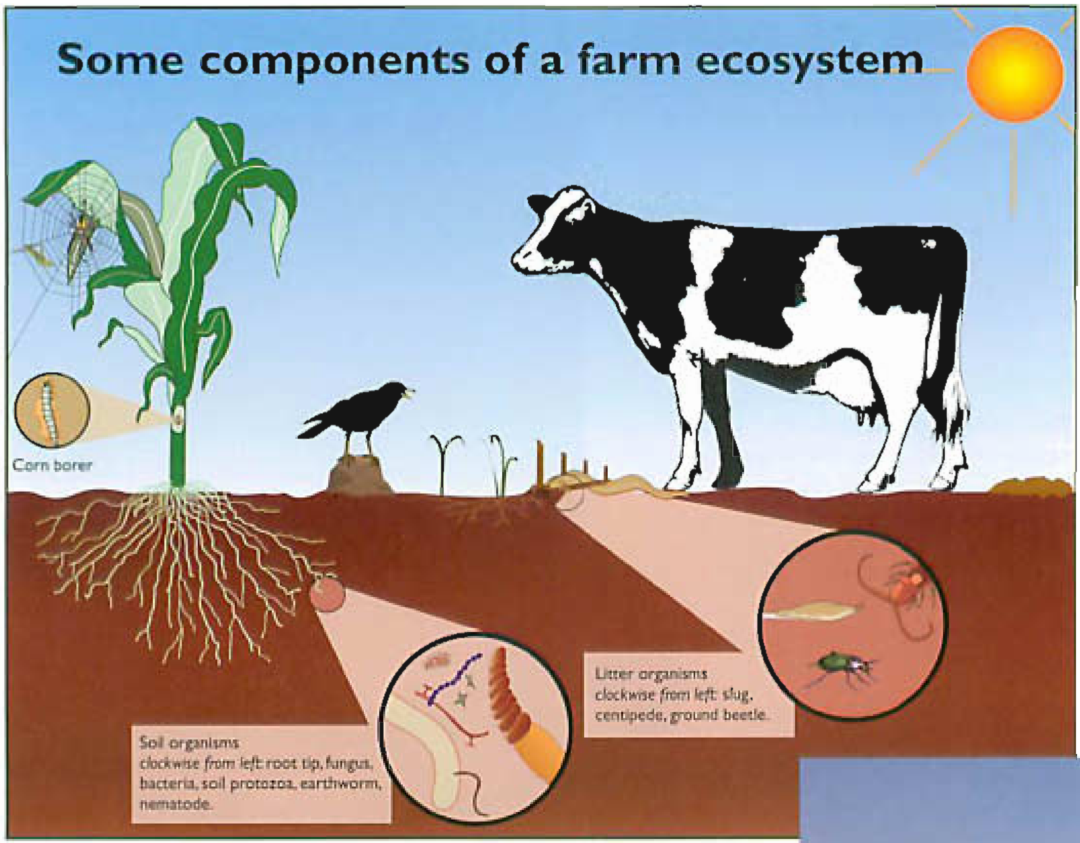
Source: ©1997, reprinted by permission of The Living Earth, Inc./Earth Imaging, Santa Monica, CA 90404.

Effective ecological management of field cropping systems is based on understanding farms and fields as ecosystems.

To most of us, an ecosystem is an area with well-defined boundaries that set it apart from adjacent areas.

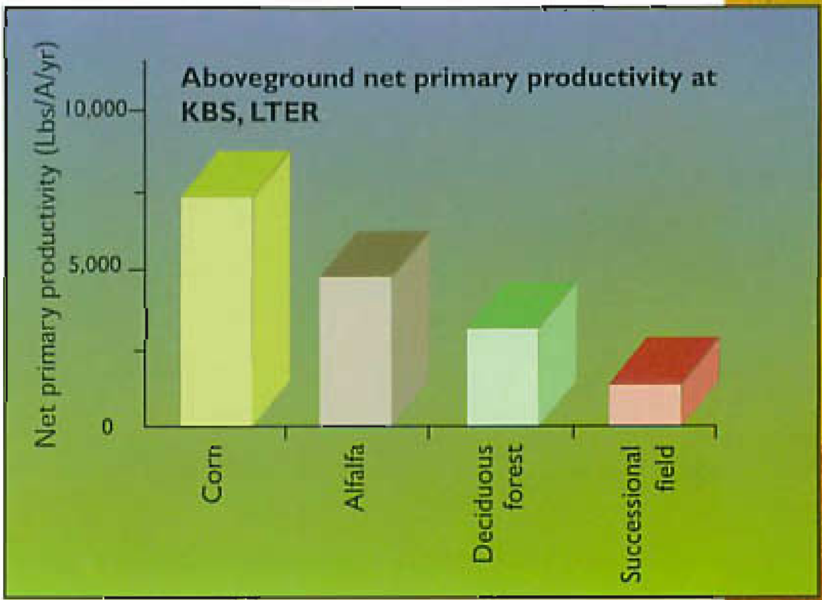
In a forest ecosystem, trees use sunlight to transform carbon, water, nitrogen and other molecules into green or woody material (**biomass**) that is harvested, burned, eaten or decomposed by other organisms. Nutrients enter the ecosystem in rainfall and air and leave the ecosystem dissolved in streamwater or air.

In a lake ecosystem, energy is provided both by sunlight (captured by phytoplankton and plants such as water lilies) and by organic material washed in from the watershed via streams and groundwater. Many nutrients leave by streamwater, eventually making their way to coastal areas where they become inputs to marine ecosystems.



Farms are human-managed ecosystems designed to produce as much **harvestable biomass** (crop yield) as environmental conditions will allow. Natural inputs contribute tremendously to a farm's productivity, as do supplemental inputs such as fertilizers and pesticides. As a result, farms tend to be more productive than the natural ecosystems they replaced.

In a formal comparison of cropped and natural ecosystems at the KBS LTER site, corn appears to produce twice as much aboveground biomass as the deciduous forests it replaced when agriculture moved into the area in the 1850s. Soil resource needs are correspondingly high – during July a corn crop can take up two pounds of nitrogen per acre per day; in contrast, the deciduous forest receives only about 10 pounds of nitrogen per acre per year in precipitation.



The productivity of a field crop ecosystem can place enormous demands on environmental resources. Some of these effects are discussed in this chapter.

Ecosystems as parts of landscapes

Field crop ecosystems are not isolated units – they are parts of landscapes, and affect other ecosystems downwind and downstream. Likewise, they are also influenced by forces and events in other ecosystems upwind and upstream. Field crop ecosystems can be managed to maximize the environmental services they provide and minimize the environmental degradation they cause.

Southwest Michigan landscape.

An average field crop ecosystem in the Great Lakes region may be about 40 acres in size. Any particular field is surrounded by a mosaic of other fields, woodlots and wetlands that provide habitats for insects, birds, mammals and other organisms. Many of these organisms can help regulate agricultural pest populations.

Small wetlands and riparian areas help protect water quality by filtering nitrates and other contaminants that leach from cropped fields.

Typical southwest Michigan wetland.

In the last century, agriculture contributed to the global atmospheric carbon dioxide build-up as land was cleared and soil organic matter decomposed. In the coming century, soil organic matter gains in well-managed soils may help offset further increases in atmospheric carbon dioxide from fossil fuel combustion and deforestation.

Mammoth clover and annual ryegrass seeded into sweetcorn.

Satellite image of KBS (infra-red).

The effect of agriculture on downstream environments may occur over very long distances. **Nitrate leached from farms in the Mississippi watershed – which includes most of the U.S. corn-belt – is the apparent cause of a seasonal oxygen deficit in the Gulf of Mexico that significantly harms Gulf Coast fisheries.**

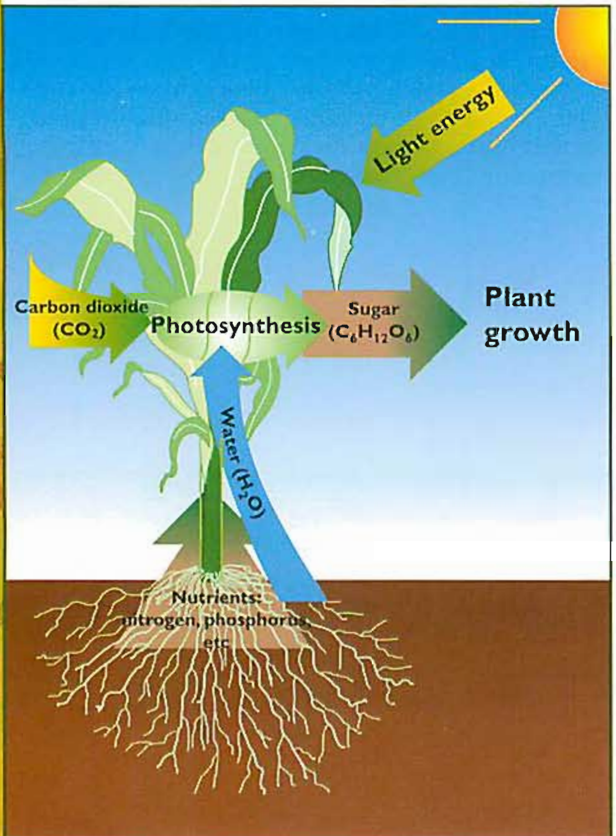
Source: ©1997, reprinted by permission of The Living Earth, Inc./Earth Imaging, Santa Monica, CA 90404.

Likewise, field crop ecosystems may be affected by very distant activities. **Ozone, nitrogen oxides** and other industrial pollutants can be transported great distances by winds and affect crop and forest ecosystems far away.

Insect and pathogen outbreaks in distant parts of the U.S. can also be delivered to Michigan farms on weather fronts and through high-altitude winds. The potato leafhopper, for example, is carried by southwest winds to Michigan farms.

Source: ©1997, reprinted by permission of The Living Earth, Inc./Earth Imaging, Santa Monica, CA 90404.

Primary production basics



Ecologists call the production of plant biomass from sunlight, water, atmospheric CO_2 and nutrients **primary production**. Primary production is based on **photosynthesis** and is the basis for the global food chain. During photosynthesis, energy from sunlight is stored in the chemical bonds holding carbon atoms together.

Plants use the sugar (fixed carbon) produced from photosynthesis for everything from seed production to growing new root hairs to chemical defense compounds. These uses can be broadly categorized into three classes: growth, reproduction and maintenance. **Growth** is what we harvest in a forage crop; **reproduction** is what we harvest in a grain crop. **Maintenance** energy is lost as CO_2 during growth and reproduction.

Perhaps 50 percent of the energy fixed by a field crop ends up below ground as **root biomass** – but we don't really know how much, because it is hard to track small roots that are produced and shed constantly as soil conditions change through the growing season.

Of the **aboveground biomass**, about 50 percent is removed as grain, though this varies by crop species. The remaining aboveground productivity is either removed as **secondary harvest** (such as wheat straw), or returned to the soil as **soil organic matter** to provide energy for the invertebrate and microbial decomposers in the soil food web.

Net primary productivity

Net primary productivity (NPP) is the amount of plant biomass produced during a given time period within a particular ecosystem. Ecosystem NPP depends on the plants' photosynthetic efficiency, leaf area, leaf duration and on water and nutrient availability.

Photosynthetic efficiency

Some plants (notably corn), warm-season grasses and common weeds have a photosynthetic pathway dominated by four-carbon (C_4) molecules. At high temperatures these C_4 plants can photosynthesize at much higher rates than their C_3 counterparts such as wheat, soybeans and cool-season grasses.

Leaf area

Up to a point (about four acres of leaf surface area per acre), an ecosystem with more leaf area (photosynthetic tissue) will fix more carbon over a given unit of time. A typical Michigan deciduous (hardwood) forest has about eight acres of leaf surface per forest acre, while a typical corn field has about four acres. A corn field may be considered more efficient with respect to leaf area.

Leaf duration

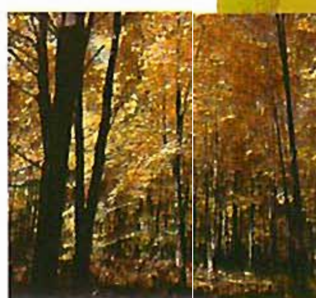
The length of time that leaves are present in an ecosystem during the year affects the amount of energy captured. In a prairie or an early successional ecosystem, at least a few green plants are present year-round, even under snow, and are ready to photosynthesize as soon as temperatures permit. In a conventional annual monoculture, plants may exhibit significant growth for only 10-12 weeks per year.

October in Southwest Michigan

Annual crop.

Abandoned (early successional) field.

Alfalfa.



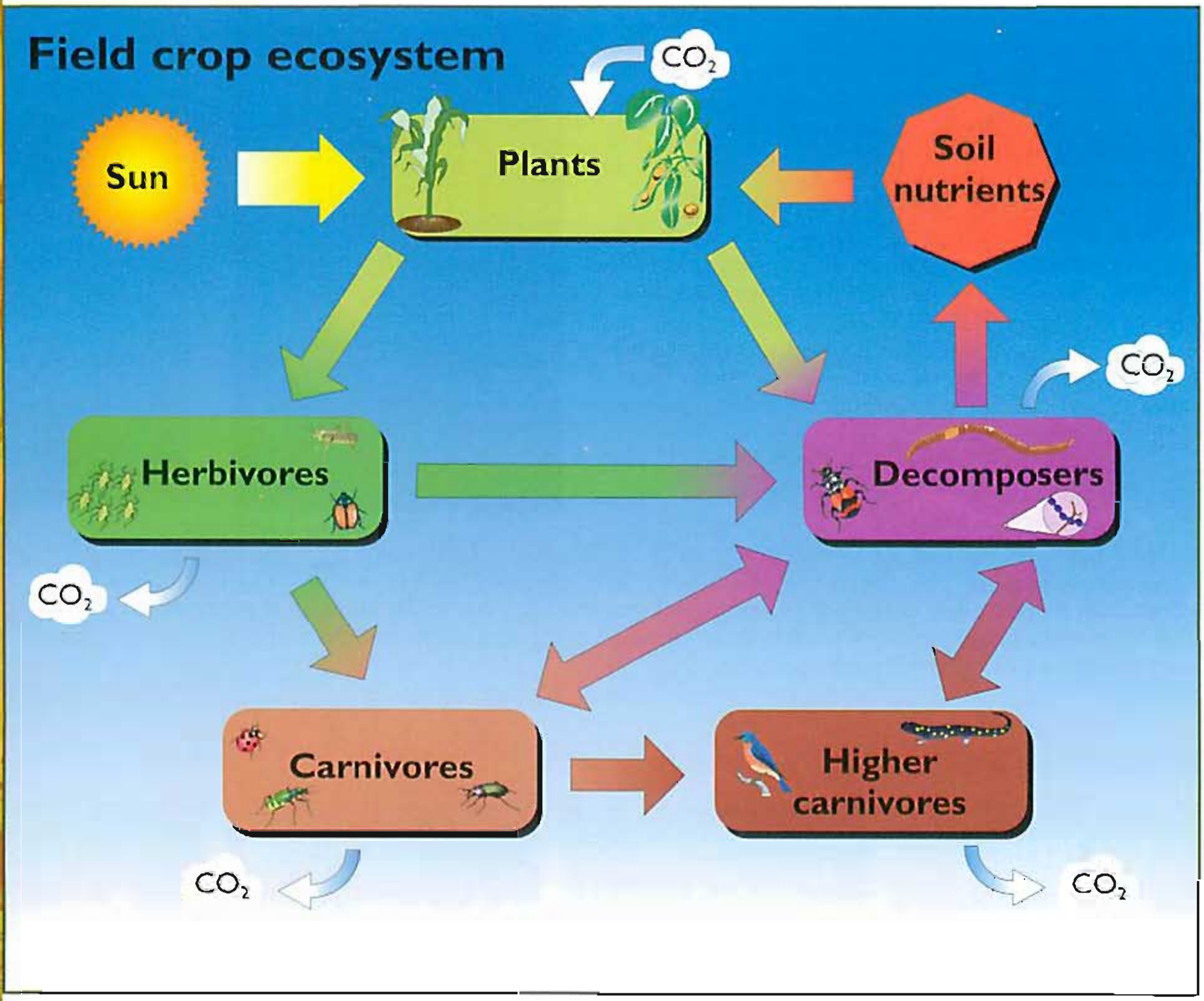
Deciduous forest.

Water and nutrient availability

Ecosystems with a similar plant community, whether a deciduous forest, a successional old-field or an annual field crop community, can produce only as much plant biomass as essential plant resources permit. By far, the most limiting resources in terrestrial ecosystems are nitrogen and water, although in certain situations other resources, such as phosphorus, potassium or micronutrients, can also limit plant growth.

Energy flow in the field crop ecosystem

Only a tiny fraction of the light energy striking the earth is transformed to the chemical energy that holds plant molecules together. This fraction is eventually converted to heat and CO_2 through various pathways, involving every organism in the ecosystem.



Plants use photosynthesis to convert light energy and CO_2 to chemical energy, stored mainly as bonds holding carbon atoms together. **Nutrients**, such as nitrogen and phosphorus, are taken up from soil and used to construct tissue and carry out biochemical processes. Plants and the nutrients they contain may be consumed by **herbivores**, which in turn may be consumed by **carnivores**. When plants, herbivores and carnivores die they are consumed by **decomposers** such as bacteria, fungi, earthworms and some insects. Decomposers may also be consumed by carnivores. Stored carbon is returned to the atmosphere as CO_2 whenever it is consumed for energy. Nutrients are likewise returned to their inorganic forms when decomposed.

The **herbivore** and the **decomposer** pathways are the two major energy flow pathways in terrestrial ecosystems. The **carnivore** pathway is a much smaller pathway, but can be very important in pest control strategies. Herbivores tend to feed only on plants, while carnivores feed at several levels. For many organisms, food sources change seasonally along with availability.

Field crop ecosystems are designed to maximize energy flow from plants to the primary herbivore consumers (humans and livestock).

Herbivores

The herbivore pathway in field crop ecosystems is dominated by **humans** and **livestock**. Perhaps 25 percent of the net primary productivity of a field crop system is removed as grain, and depending on the crop, this grain is either fed to livestock (i.e. corn) or consumed directly by humans (i.e. wheat).

There are other herbivores in the field crop ecosystem. Leaf-eating insects, such as **grasshoppers**, sap-sucking insects such as **aphids**, stalk-boring insects such as **corn borers**, root-chewing insects such as **parasitic nematodes** and seed-eating vertebrates such as **birds** and **mice**, all derive their energy directly from living plants.

Herbivore communities are different in various plant communities. For example, corn borers prefer corn instead of soybean plants. On the other hand, soybean cyst nematode populations will be larger in soybean than corn fields.

Decomposers

In most natural ecosystems more energy flows from plants into the decomposer pathway than the herbivore pathway. This is also the case – though less so – for field crop ecosystems. In field crops, more than 60 percent of net primary productivity usually directly enters the decomposer pathway, which is dominated by **bacteria**, **fungi** and **invertebrates**, such as **earthworms**. These organisms derive their energy from old leaves, stems and roots.

Source: R. Carvajal

Some of the chemical bonds in dead plants are easier to break than others, so some plant biomass disappears quickly. Other bonds can be broken only by specialized decomposers. Soil contains organic matter in widely varying stages of decomposition, providing energy for an equally wide variety of microbes and microinvertebrates.

Although less well understood than hervbivore communities, the decomposer community is also strongly influenced by field crop biodiversity and crop rotation.

Carnivores

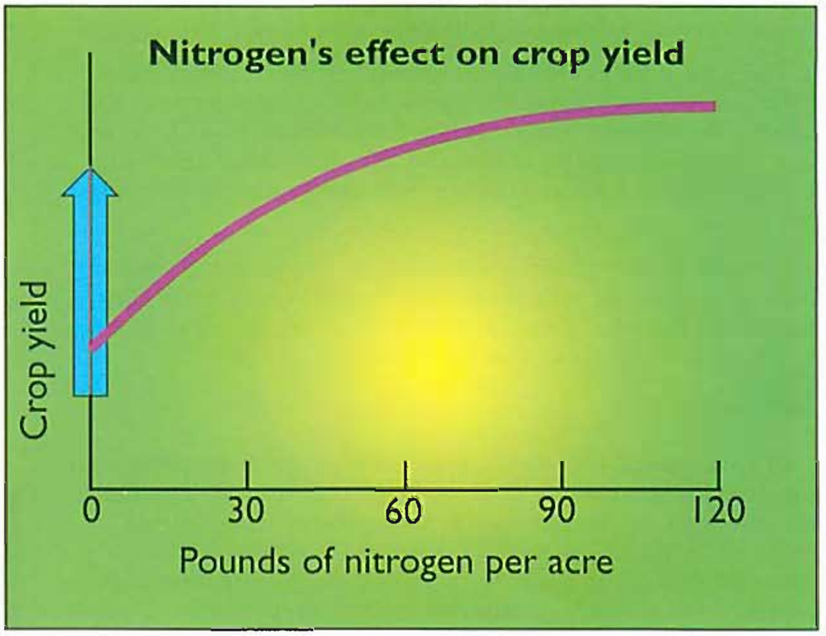
About 90 percent of the energy consumed by herbivores is respired as heat or excreted. The remaining 10 percent is transformed to growth and reproduction. This herbivore biomass may be consumed by carnivores.

In a field crop ecosystem, carnivores come in many forms. **Ladybird beetles** eat aphids, **birds** and **spiders** eat leafhoppers, **ground beetles** eat grubs, **nematodes** eat soil protozoa and fungi and humans eat livestock.

Since the carnivore community depends on the herbivore community, the carnivore community is also affected by field crop biodiversity.

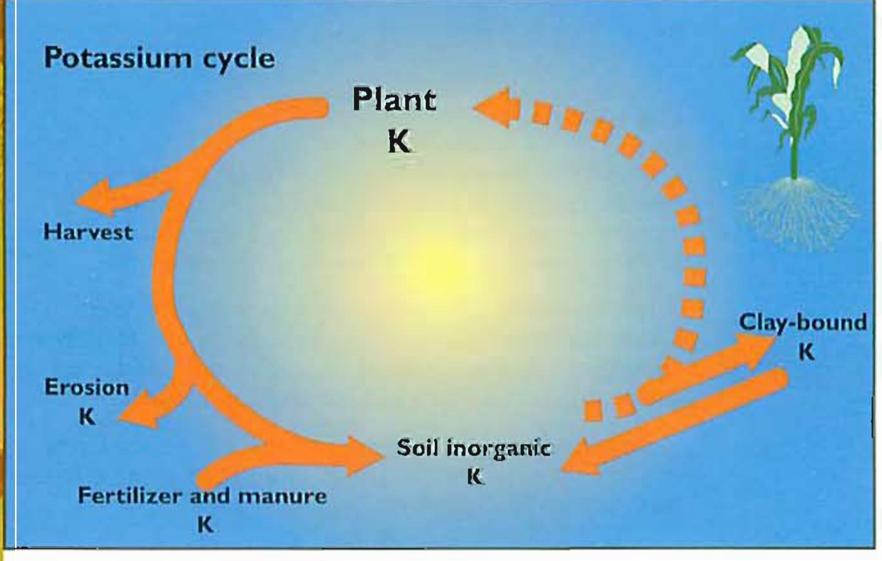
Biogeochemistry: How nutrients cycle

Crop productivity often depends on making nutrients available to the crop at the right time. Plants require many chemical elements for growth, but usually only a few (often just nitrogen) are in limited supply. A nutrient is considered limiting to plant growth when plant growth responds positively to the addition of the nutrient, as in this graph.

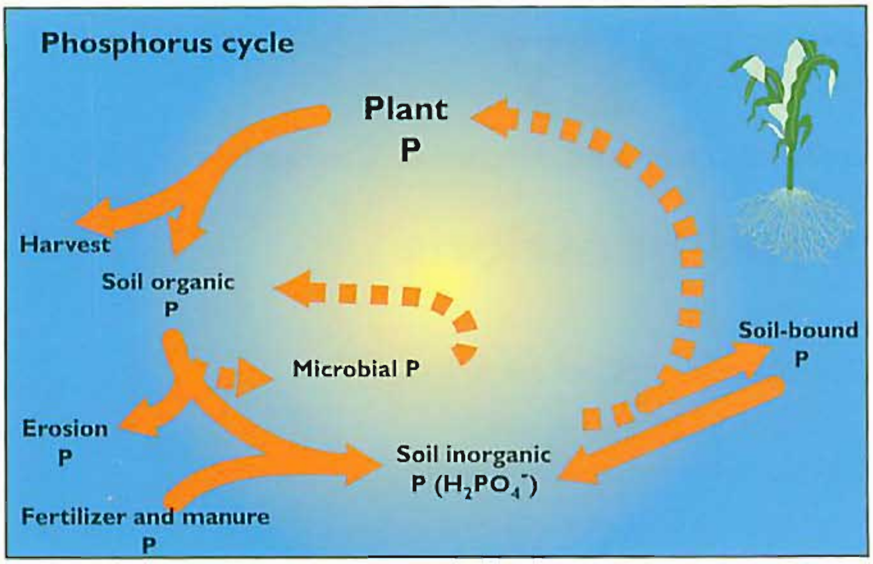


Crop nutrients such as nitrogen, phosphorus and potassium come from many different sources and exist in many different forms in soil, only a few of which are available to plants.

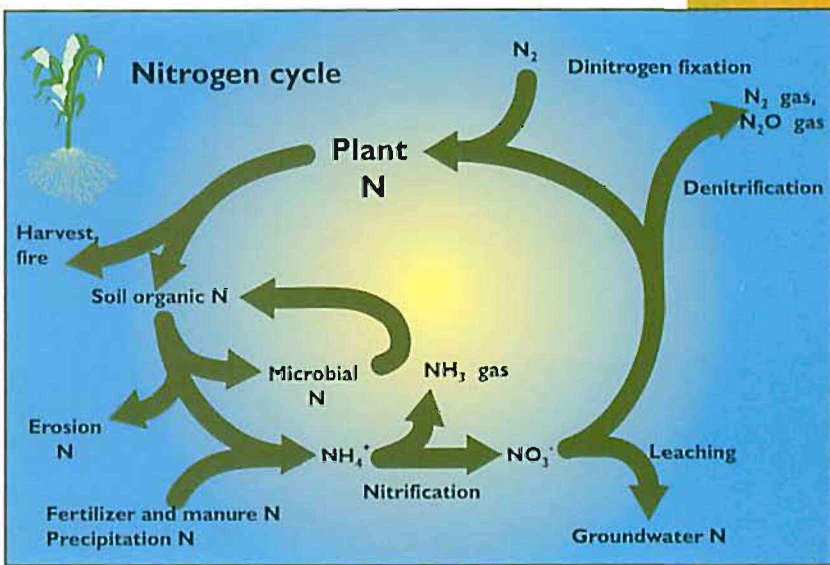
Nutrient availability is dependent on biological, geological and chemical processes. **Biogeochemistry** is the study of how, when and in what forms nutrients become available to plants, microbes and other organisms.



Some elements, such as potassium, are under largely **geological control** – geological weathering provides more potassium than most plants need, although in some high-potassium crops such as alfalfa, soil reserves may be depleted after several decades.



Some elements, such as phosphorus, are under largely chemical control – most Michigan soils strongly bind phosphorus, releasing only a trickle to the soil solution in a form such as $H_2PO_4^-$ that is available for plant uptake.



Nitrogen is under strong biological control. Although chemically abundant in the atmosphere, only a few types of plants– in a symbiotic partnership with microbes – can use atmospheric nitrogen. All other plants depend on nitrogen provided by decomposers or synthetic fertilizer.

A typical corn crop that yields 150 bu/A contains about 240 lb/A of nitrogen, 100 lb/A of phosphorus and 190 lb/A of potassium in aboveground biomass (grain and stover). More than half of this nitrogen and phosphorus and about one-quarter of this potassium are removed in the grain.

To maintain long-term productivity, farmers must periodically replace all of these nutrients plus the amounts lost by other pathways such as leaching. These nutrients may be replaced with the use of manure, specific cover crops or synthetic fertilizers. The various nutrient sources behave differently in soil and it is important to understand these cycles to manage nutrients effectively. Nitrogen management and cycling are discussed in detail in a subsequent chapter.

Yield and nutrient content of common crops

Crop	Yield bu or ton per A	Nutrients removed in harvest N	P_2O_5	K_2O
Alfalfa hay	6 ton	270	60	270
Corn, grain	150 bu	135	64	42
Corn, stover	4.5 ton	101	36	144
Soybean, seed	50 bu	188	44	66
Soybean, straw	2.5 ton	127	30	76
Wheat, grain	60 bu	75	38	23
Wheat, straw	2.5 ton	30	8	53

Source: *North Central Region Research Publication No. 341.*

Soil Ecology

George W. Bird, Michael F. Berney and Michel A. Cavigelli

Key concepts and questions

- What is soil?
- What are the abiotic (non-living) components of soils?
- What are the biotic (living) components of soils?
- How do abiotic and biotic soil components interact?
- What is soil quality?
- How can biological diversity and crop rotation benefit soil quality?

Additional reading

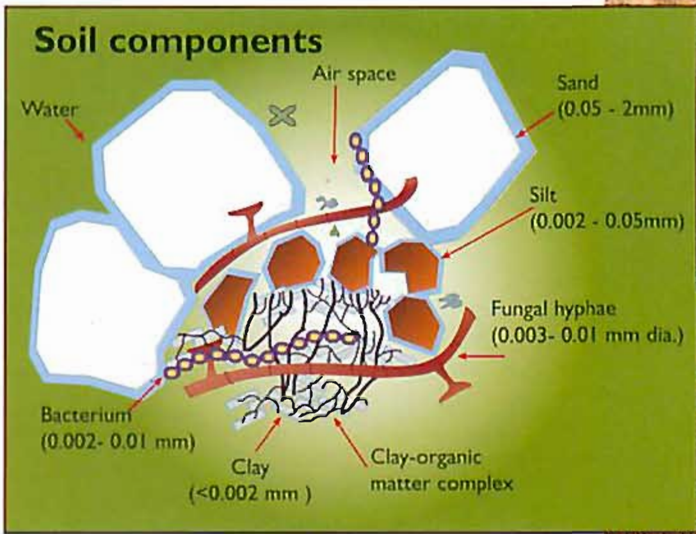
Doran, J. W., D. C. Coleman, D. F. Bezdicek and B. A. Stewart. 1994. Defining soil quality for a sustainable environment. Soil Science Society of America Special Publication Number 35, ASA, Madison, Wis.

Ontario Ministry of Agriculture, Food and Rural Affairs. 1994. Best management practices: Soil management. Ontario Federation of Agriculture, Toronto, Ont., Canada.

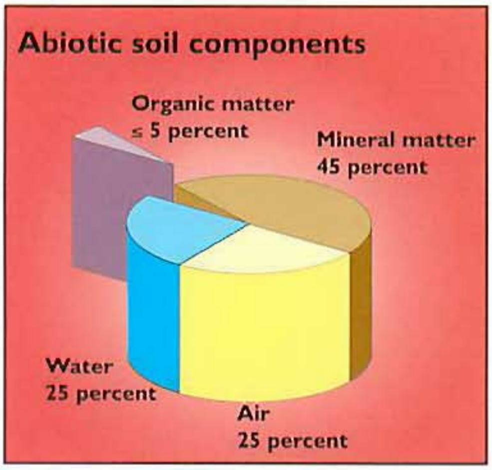
What is soil?

Soil is a living ecosystem. Management of field crop ecosystems recognizes that soil is a place where energy and matter are captured and transformed by plants, animals and microbes.

Soils are composed of both **abiotic** (non-living) and **biotic** (living) components.



Source: Exploring the role of diversity in sustainable agriculture. Olson, Francis and Kaffka (eds.) ©1995, reprinted by permission of American Society of Agronomy, Madison, Wis.



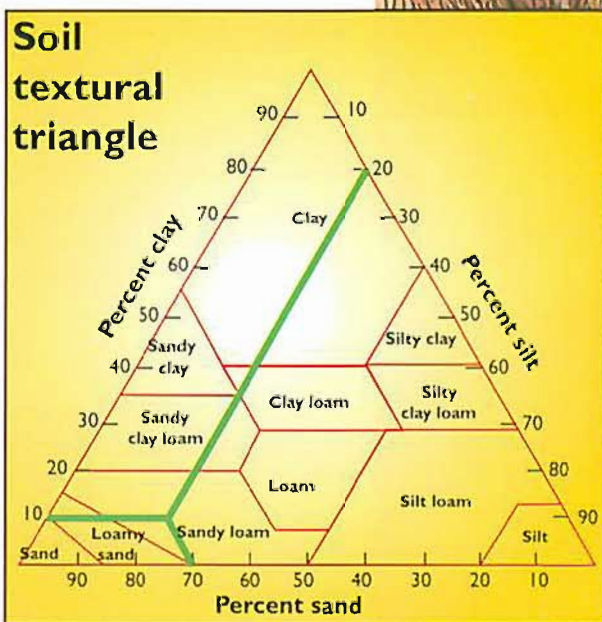
Source: Soil management. Ontario Ministry of Agriculture, Food and Rural Affairs 1994

Abiotic soil components

Abiotic soil components include mineral matter (clay, silt, sand), water, air and organic matter. Air and water percentages vary significantly with soil texture, weather and plant water uptake.

Mineral matter is composed of various proportions of sand, silt and clay particles. **Sand** particles are 0.05 to 2 mm in diameter, **silt** particles are 0.002 to 0.05 mm in diameter and **clay** particles are less than 0.002 mm in diameter. Because clay particles have a very large surface area to volume ratio, they can hold much more water and nutrients than larger particles.

Soil texture is the proportion of sand, silt and clay in a soil. The **soil textural triangle**, shown here, is used to classify a soil into one of 11 different categories, each of which has different physical and chemical properties. The example shown here (10 percent clay, 70 percent sand and 20 percent silt) is a sandy loam. Soil texture affects nearly every aspect of soil use and management, but is not affected by management unless significant soil erosion occurs.



Water and air. Since each size particle confers different physical and chemical properties on a soil, soil texture is an important determinant of water retention, bulk density, aeration and fertility. The aeration and water status of a soil, in turn, have important influences on soil biota activity.

Organic matter. Soil organic matter (SOM), though usually comprising less than five percent of a soil's weight, is one of the most important components of a field crop ecosystem. SOM strongly modifies soil organism habitat and provides a food source for much of the soil biota. When soil microorganisms feed, they change the form of SOM and in the process release inorganic nutrients, especially nitrogen, phosphorus and sulfur. This process is called **decomposition** and is an important process in all healthy ecosystems. Because soil microorganisms are continually consuming the SOM portion of their home, SOM must be continuously replenished to maintain soil quality.

Biotic soil components

	Typical numbers or length (in one handful of soil)	Typical biomass (pounds/acre)
Plant roots	60 - 150 inches (annual crops) 1,500-3,000 inches (perennial grasses)	3,000 (annual crops) 15,000 (perennial grasses)
Bacteria	300 million - 50 billion	400 - 4,000
Fungi	500,000 - 100 million	500 - 5,000
Actinomycetes	100 million - 2 billion	400 - 4,000
Nematodes	1,000 - 10,000	5 - 50
Protozoa	100,000 - 50 million	5 - 100
Arthropods	100 - 1,000	1 - 10
Earthworms	0 - 2	10 - 40

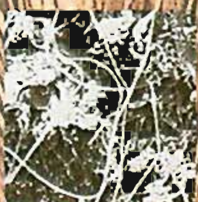
Plant roots

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

Bacteria

- along with fungi, are the most important group in organic matter decomposition
- extracellular compounds help bind soil particles into aggregates
- specialized groups are involved in each portion of the nitrogen cycle

Source: M J Klug



Fungi

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

Source: M.J Klug

Actinomycetes

- type of bacteria with growth form similar to fungi; functions similar to both
- produce compounds that give soil its distinctive aroma

Source: G. Garrity, MSU Center for Microbial Ecology.

Nematodes

- are the most numerous animals in the soil
- help accelerate decomposition when they graze on bacteria, fungi and plant residues

Source: W L Goodfriend

Protozoa

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

Source: V.V. S R. Gupta

Arthropods

- help accelerate decomposition when they (mites, collembola and other insects) graze on bacteria, fungi and plant residues
- Collembola, shown in this photograph, are an important arthropod in plant residue decomposition

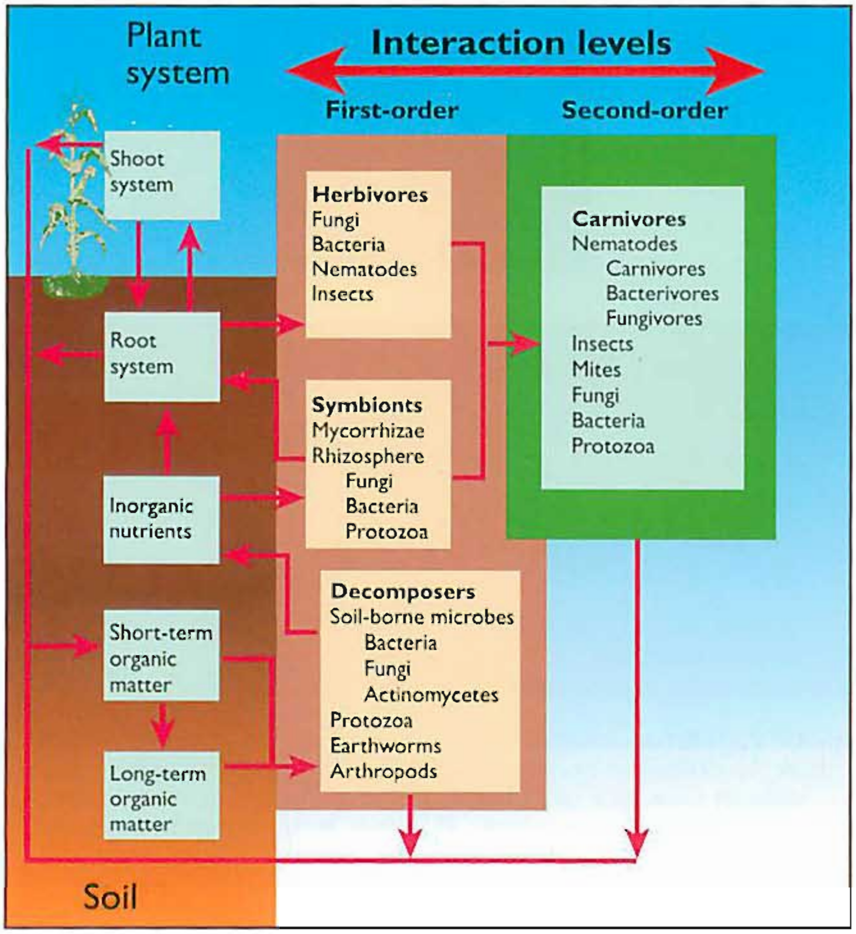
Earthworms

- burrowing activity mixes soils and creates macropores that increase water infiltration and flow and help aerate soil
- soil passage through guts increases aggregation and nutrient cycling

Source: R. Carvajal

Soil organisms interact with each other and their environment

Soil organisms interact in many ways. For example, protozoa eat bacteria and some fungi feed on protozoa or nematodes. Other fungi are consumed by protozoa or parasitized by nematodes. Interactions among soil organisms may be very complex and are crucial to the functioning of soils.



This conceptual model of the soil ecosystem associated with a crop plant illustrates the interactions among the biotic and abiotic factors associated with the growth and development of this plant. It shows the flow of both matter and energy as they move through the system.

In addition to obtaining inorganic nutrients and water from soil, the root system serves as a host for various herbivores, including fungi, bacteria, nematodes, arthropods and insects. Decomposers, including fungi, bacteria, actinomycetes and earthworms, mineralize labile and resistant substrates (soil organic matter). These are referred to as **first-order interactions**. In **second-order interactions**, organisms feed on organisms involved in first-order interactions. Further levels of interaction are called third- and fourth-order interactions. Numerous species of soil-borne organisms including nematodes, insects, mites, fungi, bacteria and protozoa feed as carnivores, bacterivores or fungivores on the organisms involved in the previous activity level. Soil ecosystems seem to function very much the same as the aboveground pastures with which we are all more familiar.

Soil ecosystems function in accordance with the Second Law of Thermodynamics, which states that "in any energy conversion, the final product will consist of less useable energy than the original product, because of the inevitable loss of energy in the form of heat." The amount of biomass, therefore, is less in each subsequent interaction order or **trophic** level.

Soil quality

Soil, air and water, are basic natural resources that provide important **ecosystem services**. For example, soil is a carbon and nutrient cycling site and also helps clean both water and air. Much of our drinking water in Michigan is filtered through soil as it moves into ground and surface waters. Poorly managed, soils can serve as a pipeline for pollutants, such as nitrate into groundwater, silt into surface waters and nitrous oxide into the atmosphere.

Soil quality is a measure of a soil's function, specifically, a soil's ability to:

1. Accept, hold and release nutrients and other chemical constituents.
2. Accept, hold and release water to plants, streams and groundwater.
3. Promote and sustain root growth.
4. Maintain suitable soil biotic habitat.
5. Respond to management.
6. Resist degradation.

While soil cultivation can result in soil degradation, including loss to erosion and decreased soil organic matter content, a sustainable agriculture, by definition, does not decrease soil quality. While there is currently no consensus on which set of measures to include in an assessment of soil quality, scientists generally agree that measures of both abiotic and biotic soil components will have to be integrated in a holistic manner to assess soil quality. Balanced biodiversity is increasingly seen as an essential component of soil quality.

Soil characteristics important to soil quality:

- Soil organic matter
- Water holding capacity
- Water infiltration rate
- Microbial biomass carbon and nitrogen
- Structure
- Texture
- Bulk density
- Electrical conductivity
- Nutrient availability and release
- pH
- Balanced biotic diversity

Management goals for maintaining or improving soil quality include:

1. Using renewable soil components (such as organic matter and nutrients) no faster than they can be renewed.
2. Using nonrenewable soil components (such as soil particles) no faster than substitute resources can be developed.
3. Generating or applying potential pollutants associated with soil management (such as manure or pesticides) only as fast as the soil system can assimilate or transform them.

Management options that increase soil quality include crop rotations and cover crops. These options can increase soil organic matter, organic nitrogen and protect against soil erosion. Ecological pest management strategies decrease the need for agricultural pesticides and also reduces soils' exposure to toxic compounds. These management options are discussed in subsequent chapters.

Carbon

Michel A. Cavigelli

Key concepts and questions

- Why is carbon the farmer's primary management tool?
- Why is soil carbon (soil organic matter) important?
- What is the carbon cycle and what are its major components?
- How can soil organic matter (SOM) levels be changed through management of crop biodiversity and crop rotation?
- How do crop residue quantity and quality influence SOM levels?
- How do animal manures influence SOM levels?
- How are SOM levels affected by tillage?

Additional readings

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What is carbon?

Carbon is the farmer's primary resource. Farmers manage carbon when they:

Grow a crop

Plants are 40-45 percent carbon on a dry weight basis. Essentially all carbon that enters an agricultural system is brought in by green plants during photosynthesis.

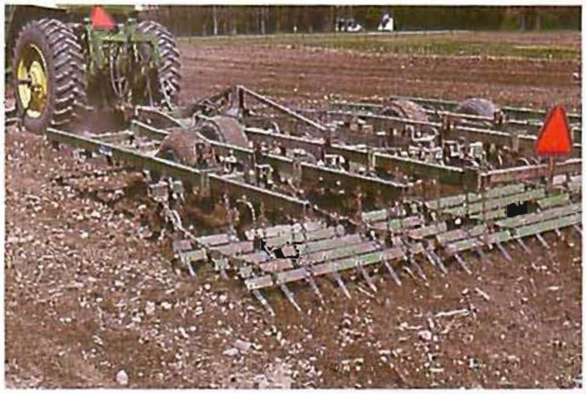
Plant a cover crop/green manure

Using a cover crop extends the length of the "carbon growing season" and helps protect the soil from erosion during critical times.

Manage manure

Manure is plant carbon that has been processed by animals. Proper manure management can convert a potential waste product into a valuable resource.

Till the soil



Soil carbon is strongly influenced by tillage intensity.

Source: Howell, NRCS.

Use soil conservation practices

Protecting soil from erosion is the most important step one can take to conserve soil carbon.

Carbon contributes more than any other resource to a farm's **long-term sustainability** and managing carbon appropriately increases **crop yield potentials**. This chapter focuses on soil carbon's benefits to long-term agricultural productivity and how its inputs and outputs are influenced by farm management decisions. Although managing soil carbon is usually not a priority in farm decision making, practices that improve soil carbon levels and dynamics can be incorporated into economically efficient production systems. This chapter is intended to show how such practices may be integrated into current high-production farming systems.

Why is soil carbon important?

Carbon, in the form of **soil organic matter** (SOM), is a crucial contributor to **soil quality**. SOM is also a major source of plant nutrients (especially nitrogen, phosphorus and sulfur) and is the major food source for most soil organisms. SOM and the soil biota it supports influence many soil physical properties, creating a favorable environment for crop root growth and increasing crop yield potentials.

Soil structure

SOM contributes significantly to **soil structure**, which refers to the size, number and stability of **soil aggregates**. Aggregates are very small clods of soil particles held together by SOM "glue." They help stabilize soil against erosion and create a beneficial environment for crop roots. Since aggregate formation and stability are partially clay dependent, clay soils have greater aggregation than sandy soils.

The importance of SOM to soil physical properties is shown dramatically in a soil of similar texture that has been managed to maximize SOM inputs (A) and one in which SOM has been depleted (B). Notice also the influence of SOM on soil color.

A. Soil with relatively high SOM retains its structure when water is added.

B. Soil with low SOM does not retain as much structure when water is added.

Soil fertility

During decomposition, the **nutrients** that are part of SOM are released and can be taken up by plants.

Soil moisture and aeration

As a result of its effect on soil aggregation, SOM provides more favorable **bulk density** and **pore size distribution**. Lower bulk density allows more extensive root growth; more favorable pore size distribution increases water infiltration rates, water retention and aeration.

Soil erosion

By holding soil particles together as aggregates, SOM reduces soil loss to **erosion**.

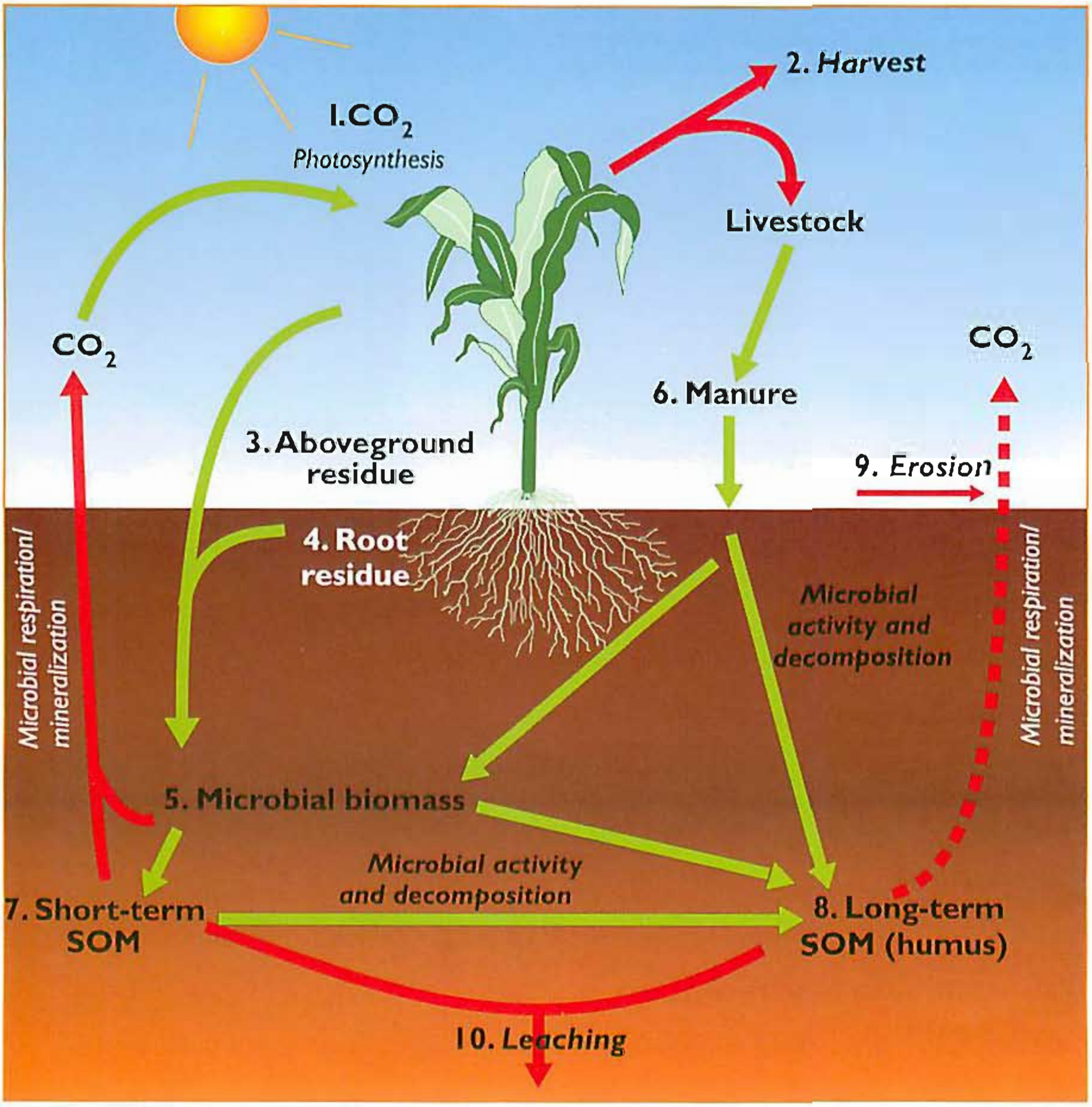
Water and nutrient retention

SOM increases **water and nutrient retention** in the soil, making them more available to plants. SOM has a net negative charge that attracts positively charged plant nutrients (e.g. Ca^{2+}, Mg^{2+}, K^{+}), keeping them from leaching. This cation-retention ability is referred to as **cation exchange capacity** or CEC. Clay particles are also negatively charged and so contribute to a soil's CEC.

SOM's benefits to soil physical and chemical properties tend to increase with a soil's clay content, since clay provides sites for SOM binding.

Carbon cycle

The effects of management decisions on SOM levels can best be understood by first taking a closer look at the carbon cycle. The carbon cycle is a schematic representation of the different forms of carbon within the environment, and the processes that control the transformation of carbon from one form to another. These transformations are mostly biological processes and understanding what influences them is crucial to understanding management effects on SOM dynamics. Each form and process is discussed below. Forms of carbon are numbered and identified in bold and transformation processes are in *italics*. Green arrows indicate inputs and red arrows, outputs. The effects of various management alternatives on these pools and processes are discussed on pages 22-27.



1 **Carbon dioxide** (CO_2) from the atmosphere is incorporated into plant biomass during ***photosynthesis***. The carbon, once incorporated, is referred to as organic carbon. Plants are about 40-45 percent carbon on a dry weight basis, regardless of age or type.

2 A significant portion of the carbon in row crops is harvested. Up to 60 percent of the carbon incorporated into corn is harvested as grain. Selling grain off-farm represents a carbon export from the farm. When crops are fed to livestock on-farm, and the manure is applied to the soil, much more of the original plant carbon is maintained in the farm system.

3,4 After a crop is harvested, both **aboveground** (shoot) and **below ground** (root) **residues** enter the soil. Root residues also enter the soil system while the plant is alive; when old roots die, portions are sloughed off, or carbon compounds leak out of them. Most microbial activity in soils occurs in the rhizosphere, that portion of the soil affected directly by the root. The importance of plant roots in stimulating the biology of the soil is just beginning to be fully appreciated and its implications for management are currently gaining greater research attention.

5 Carbon is a food source for soil microorganisms such as bacteria, fungi and actinomycetes. Thus, some carbon that enters the soil as residue or manure becomes part of the microorganisms (5-15 percent of original plant residues) and is called **microbial biomass**. The largest proportion of residue carbon is released to the atmosphere as CO_2 when soil organisms ***respire*** (60-75 percent of original plant residues). The conversion of organic carbon to CO_2 is called carbon ***mineralization***.

Although the microbial biomass carbon pool generally represents less than five percent of the total soil organic carbon pool, it is fundamental to the functioning of any ecosystem and is crucial in developing SOM. As a result of ***microbial activity***, carbon undergoes many complex chemical transformations that are collectively known as ***decomposition***. Decomposition rates are influenced by factors that influence microbial activity: temperature, moisture, aeration, pH, amount and quality of residue, residue particle size and degree of burial in the soil.

6 **Manure**, compost or industrial by-products (such as sewage sludge or food processing plant waste) can be important SOM sources. The carbon in manure and compost, because it has already undergone some transformations, contributes more to long-term SOM pools, on a dry weight basis, than plant residues.

7 A certain portion of the carbon in residues and manure is readily decomposed and is thus called **short-term SOM**. Short-term SOM provides some benefits to soil physical condition, but it is mostly important as a short duration (one to three years) source of plant nutrients (primarily nitrogen, phosphorus, and sulphur). Manipulating this portion in seasonal patterns is absolutely essential to nutrient use efficiency and preventing nutrient loss to the environment.

8 Other carbon components in residues and manures are converted during decomposition processes to carbon forms that are more resistant to further microbial activity. These compounds make up **long-term SOM** or **humus** and they provide many of the beneficial physical properties described on page 19. Only 10-25 percent of residue carbon is retained as long-term SOM. About one to two percent of long-term SOM is converted to CO_2 each year. A soil that has one percent SOM has about 20,000 pounds SOM, or 10,000 pounds carbon per acre furrow slice.

9 **Erosion**. It has been estimated that more than half of the topsoil has been lost from many sites since production agriculture began in the United States. Because SOM is concentrated in the topsoil, topsoil loss represents a significant SOM loss.

10 **Leaching**. Small amounts of SOM move through the soil profile with water movement, especially in sandy soils and along old root or worm channels.

Managing carbon to maximize SOM benefits

The amount of organic matter in a soil is determined by the balance between soil carbon **inputs** and **outputs**. Inputs include plant residues and manures that are returned to the soil; outputs include harvest, carbon mineralization during decomposition, erosion and leaching. Under native conditions, each soil has a particular SOM equilibrium level that is determined by climate, vegetation, slope and soil type. For mineral soils, this value is usually between one percent (sandy soils) and five percent (clay soils) of total soil, by weight. Following cultivation, there is usually a dramatic decrease in soil carbon levels before a new SOM equilibrium level is reached. This new equilibrium point is largely determined by management decisions.

Guidelines for SOM management can be developed around two important principles: 1) **input management** (the amount, kinds and timing of residues returned to the soil) and 2) **output management** (tillage intensity and erosion control). SOM level changes occur slowly. Therefore, this chapter is based largely on results from long-term studies, many conducted in states other than Michigan.

Carbon inputs: crop residues

The type and sequence of crops grown influences SOM levels and dynamics. Two crop characteristics determine these effects: **residue quantity** and **quality**.

Residue quantity

The effect of residue quantity on SOM levels is fairly straightforward: SOM benefits increase with the amount of residue left on or incorporated into the soil. Crops vary considerably in the amount of residue that is returned to the soil as seen in this table.

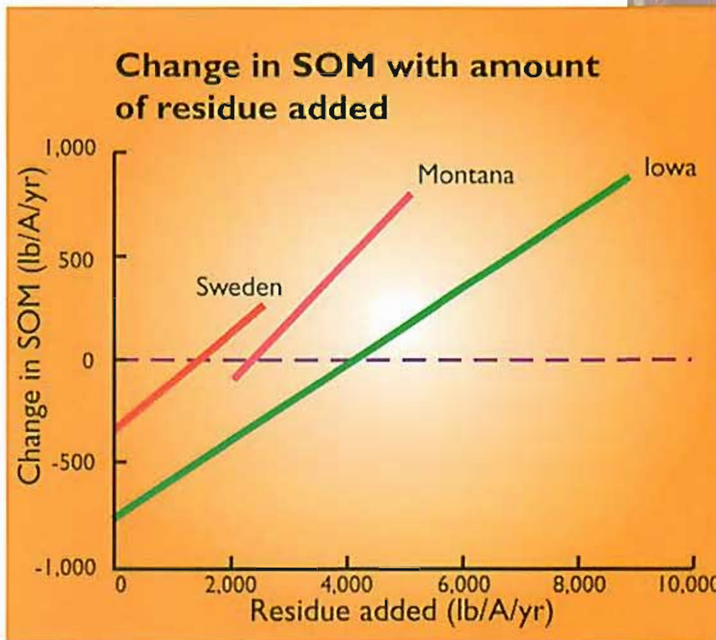
Crop residue production

Crop	Crop residue (lb/A)
Corn	6,100 - 9,100
Soybean	2,500 - 5,000
Wheat	2,400 - 4,500
Oats	1,600 - 2,400
Cover crops (clover)	900 - 4,900
Cover crops (oats, rye)	1,000 - 5,500

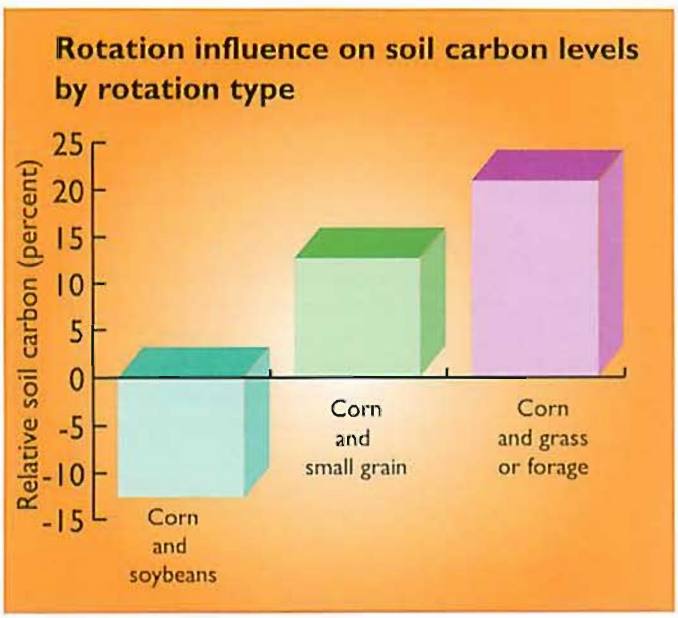
Source: Management controls on soil carbon. Paul, Paustian, Elliot and Cole (eds.). In: Organic matter in temperate agroecosystems. CRC Press and North Central Region Research Publication No. 341.

Soybeans (right) produce less than half the aboveground residue of corn (left).

Because a large proportion of added residues and a portion of already existing SOM is converted to CO_2 during microbial decomposition, large amounts of **residue** are required to maintain or increase SOM levels. This figure shows that to maintain SOM levels (green line) in Iowa under continuous corn, more than 4,000 lb/A of residues must be returned to the soil every year. Because this value is affected by all the factors that influence decomposition (including temperature and moisture), the amount of residue required to maintain SOM levels is different at different sites. About half the residue required to maintain SOM levels in Iowa was required at sites in Montana and Sweden. Carbon return to soils can be increased further by incorporating animal or green manures (cover crops) into a farming system.



Source: Organic matter in temperate agroecosystems. Paul, Paustian, Elliott and Cole (eds). ©1996 adapted by permission of CRC Press, Boca Raton, Fla.

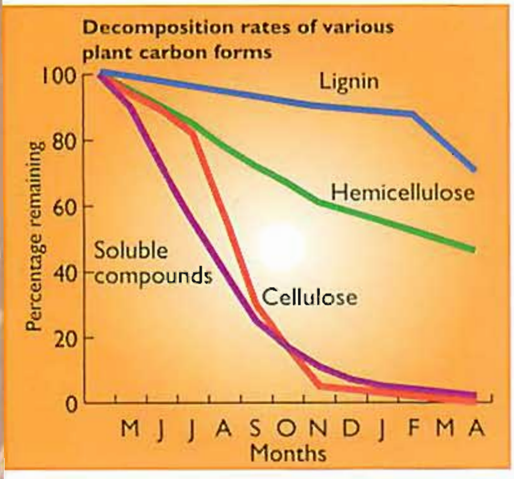


Source: Organic matter in temperate agroecosystems. Paul, Paustian, Elliott and Cole (eds). ©1996 adapted by permission of CRC Press, Boca Raton, Fla.

Crop rotations incorporating perennial crops increase SOM levels more than continuous corn or any other rotation. Compared to continuous corn (a value of zero on this graph), rotations that include perennial crops result in increased SOM levels. Most other rotations, including corn-soybean rotations, result in lower SOM levels (negative values in this graph). The positive influence of perennial crop rotations is due to both the year round presence of roots in the soil and reduced tillage activities in these rotations.

One promising means of incorporating perennial crops into a rotation is **intensive rotational grazing**. Grazed pastures show an even greater SOM increase than those harvested by machine.

The amount of residue produced is also related to a site's fertility. Synthetic fertilizers may slightly increase SOM levels indirectly by increasing plant productivity and residue return. Organic sources of plant nutrients have both this indirect, as well as a direct, effect on SOM levels.



Residue quality

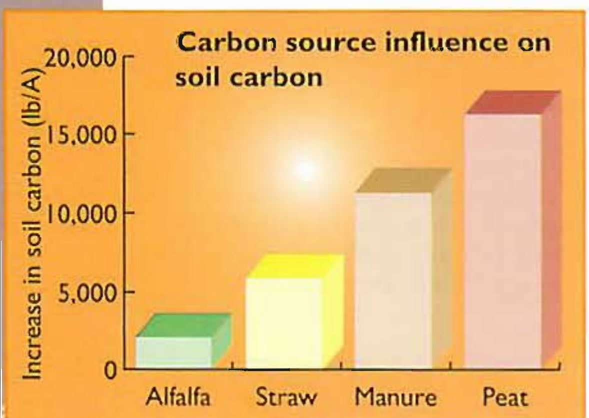
Plant carbon occurs in several forms, including **soluble compounds** (sugars and amino acids), **hemicellulose**, **cellulose** and **lignin**. Each carbon compound decomposes at a different rate, as shown in this diagram.

Carbon compounds are found in differing proportions, depending on the type of plant and its age. Additionally, plants vary in how much nitrogen they contain relative to carbon. This ratio is called the C:N ratio. The C:N ratio is especially important in determining the nitrogen fertilizer value of crop residues. This topic is covered in more detail in the nitrogen chapter.

Crop residue quality

Crop residue	C:N ratio	Soluble compounds	Hemicellulose (percent)	Cellulose	Lignin
Corn	60:1	29	27	28	6
Soybeans	30:1	58	9	22	12
Wheat	80:1	29	18	36	14
Cover crops	20:1	60	10	20	10

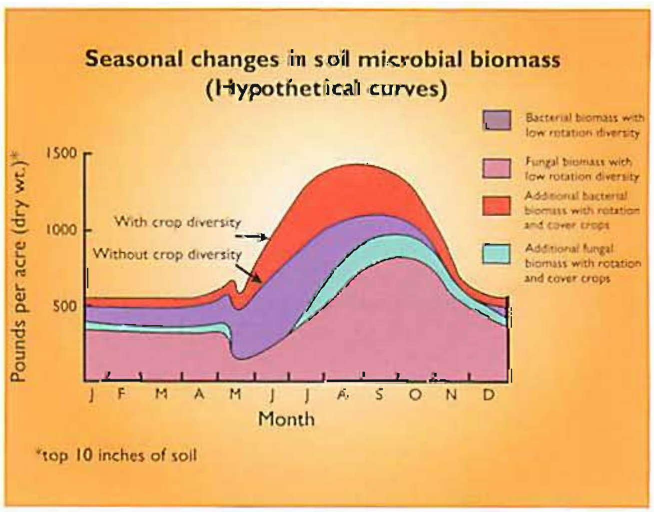
Source: Kononova, Nowakowski and Newman. 1966. Soil organic matter. Pergamon Press and Foth, Withee, Jacobs and Thien. 1982. Laboratory manual for introductory soil sciences. 6th edition, Wm. D Brown and Co Publishers.



Source: Organic matter in temperate agroecosystems. Paul, Paustian, Elliott and Cole (eds). ©1996 reprinted by permission of CRC Press, Boca Raton, Fla.

The various forms of plant carbon have different fates in soil: the more readily decomposable compounds are likely to end up in the microbial biomass or quickly mineralized. On the other hand, up to 50 percent of lignin can end up as long-term SOM. Young plants, such as green manures, tend to benefit soil fertility the most, while corn or wheat stalks tend to improve soil physical properties by increasing long-term SOM levels.

Active plant roots seem to have an important effect on soil microorganisms. Recent findings suggest that cover crop roots stimulate soil microorganisms and increase carbon and nitrogen mineralization rates. This "priming effect" is shown schematically in this diagram. The number of both bacteria and fungi is higher when cover crops or perennials are included in a rotation, and this increase occurs earlier in the growing season than when no cover crops are used. This pattern benefits nitrogen fertility and soil quality as discussed in the cover crops chapter.



Source: Harwood and Willson, KBS 1996

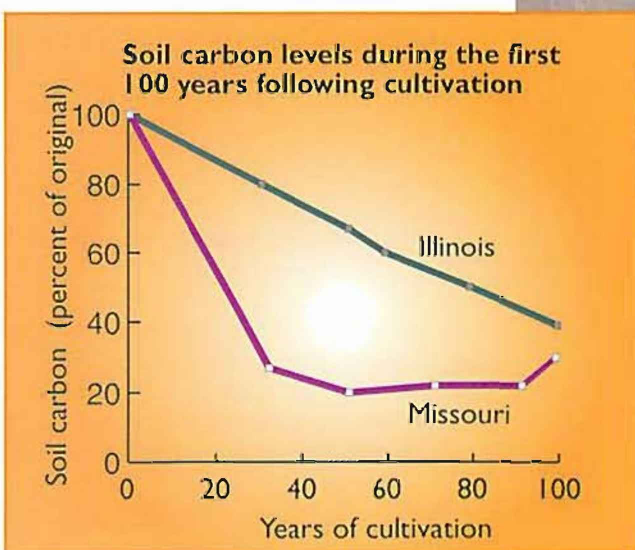
Carbon inputs: animal manures and other sources

Animal manures have long been used to maintain or increase SOM levels and fertility. The biology of animal manure decomposition is similar to that for plant residues: SOM levels increase with the amount of manure added. Manure contains carbon compounds that are more resistant to decomposition by soil microorganisms than plant residues. Therefore, a given amount of manure carbon may contribute more to long-term SOM than would crop residues.

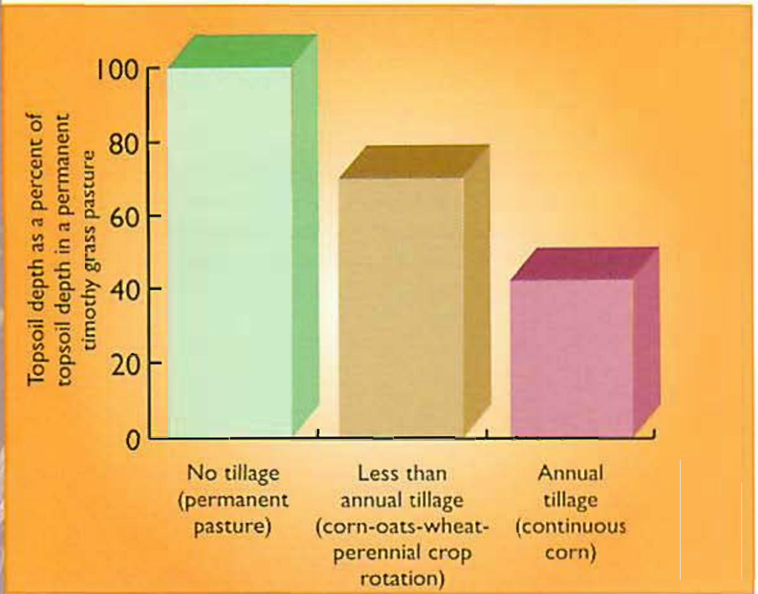
Animal manures, compost, sewage sludge and industrial by-products contain varying amounts and quality of carbon and nutrients. Manure from the same animals varies in composition over time due to feed rations, feed quality, etc. Even greater differences are found between different groups of animals. Manure handling and storage methods affect composition due to differences in drying and decomposition. Application rate recommendations are based on nutrient loading rates, especially nitrogen and phosphorus. Manure should be sampled for these nutrients before being applied in large quantities or on a regular basis. Michigan Right to Farm Guidelines should be consulted for further manure management information. Similar concerns need to be addressed when applying yard compost and industrial sources of organic matter.

Carbon outputs: tillage

After native lands are converted to agricultural production, there is usually a dramatic SOM level decrease. This decrease is usually due to lower residue being returned to the soil and more importantly, increased decomposition and erosion due to tillage activities.



Source: Organic matter in temperate agroecosystems. Paul, Paustian, Elliott and Cole (eds). ©1996 reprinted by permission of CRC Press, Boca Raton, Fla.



Tillage influences erosion by exposing the soil to the effects of wind and water. This figure shows that topsoil loss, after 100 years of cultivation, increases with the tillage frequency.

Source: Buyanovsky, Kucera and Wagner. 1985. Bulletin Ecological Society of America.

Tillage also increases decomposition by:

- burying residues so they are exposed to greater microbial activity
- increasing soil temperature and aeration, both factors that increase decomposition rates
- physically breaking up soil aggregates and exposing the internal SOM to microbial activity.

Tillage, therefore, results in a reduction of long-term SOM and its benefits to soil physical properties. These losses tend to be greater in sandy soils because they have very little clay that performs some of the same functions as SOM, and to which SOM can more readily bind.

Although we have long understood that tillage influences soil depth and SOM, soil quality continues to decline in many areas. This trend can be reduced by using crop rotations with perennials, conservation tillage, and erosion-reducing soil conservation practices.

Conservation tillage helps reduce soil erosion by leaving crop residues on the soil surface and by decreasing or eliminating tillage. There are many forms of conservation tillage, but no-till is most effective at reducing erosion and increasing SOM levels. SOM may increase five to 20 percent under no-till. SOM under no-till tends to concentrate in the top one to two inches of soil.

No-till drill and soybeans planted in corn residue.

No-till, however, is not applicable in all situations. In some areas of Michigan, no-till may not be practical since lack of tillage keeps soils cool, retarding seed germination and potentially reducing crop yields. Also, poorly drained soils are subject to compaction without tillage. Less extreme forms of conservation tillage are more common in Michigan, though they generally show similar SOM levels to conventional tillage. In places where no-till is not feasible, SOM management may depend more heavily on input management. As you'll read in other chapters, carbon input management strategies benefit the entire agricultural ecosystem, including nutrient use efficiencies and biological control of insects and nematodes.

Carbon outputs: soil erosion control

Management practices intended to increase SOM levels and fine-tune carbon dynamics are often wasted if soil erosion rates are greater than the soil formation rate. Excessive soil erosion results in:

- diminished soil quality
- decreased crop yields and
- increased production costs.

When perennial crop rotations, cover crops or reduced tillage intensity do not adequately prevent soil erosion, erosion control practices and structures need to be implemented and installed.

Soil erosion in soybean field.

Terraces and strip (contour) cropping are essential for preventing soil erosion on hilly ground.

Source: Howell, NRCS.

Grassed waterways decrease soil movement with runoff waters.

Source: Howell, NRCS.

Windbreaks can help increase yields 10-20 percent where wind erosion is a problem.

Source: Howell, NRCS.

Correctly establishing and maintaining these measures is crucial. Many of these technologies require trained technical assistance. To learn more about these techniques, contact the Natural Resources Conservation Service.

Nitrogen

Michel A. Cavigelli

Key concepts and questions

- What are the four major sources of crop nitrogen?
- What is the nitrogen cycle and what are its major components?
- Why do organic and inorganic sources of nitrogen behave differently in soils?
- How do soil moisture and temperature affect the major transformations in the nitrogen cycle?
- How does nitrogen lost from farm fields influence environmental quality?
- How can different sources of crop nitrogen be managed to minimize losses and synchronize soil nitrogen availability and crop uptake?
- How can crop biodiversity and crop rotation benefit nitrogen management?

Additional readings

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Vitousek, P. M. et al. 1997. Human alteration of the global nitrogen cycle: Causes and consequences. Issues in ecology No. 1, Ecological Society of America.

What are major nitrogen sources?

Achieving high yields with current crop varieties requires making large amounts of nitrogen available to meet crop demands. Less than half of applied nitrogen, however, may be taken up by crops the year it is applied. Some of the rest is incorporated into soil organic matter by the soil biota, but some may be lost from the farming system. Nitrogen loss may be economically costly to the farmer and contribute to ground and surface water contamination. These concerns have led to increased interest among farmers, MSU Extension agents, researchers and others in improving nitrogen management strategies to minimize nitrogen losses without sacrificing production.

Efficient nitrogen management strategies take full advantage of all available sources. The four major crop nitrogen sources are:

Soil nitrogen

Most soil nitrogen exists as organic nitrogen, i.e. associated with soil organic carbon.

Legumes

A legume crop can convert up to 200 pounds of atmospheric nitrogen to plant-available nitrogen per acre per year.

Red clover root nodules containing nitrogen-fixing bacteria.

Source: F Dazzo, MSU Center for Microbial Ecology

Manure

Manure can supply much of a crop's nitrogen needs.

Synthetic fertilizers

There are many forms of synthetic nitrogen fertilizer.

All of these except synthetic fertilizers contain most of their nitrogen in an organic form, i.e. bound to carbon. **Organic nitrogen** behaves differently in soil than the **inorganic nitrogen** commonly found in synthetic fertilizers. This is because the bond between nitrogen and carbon in organic nitrogen forms must be broken by soil microorganisms before the nitrogen can be available to plants. Efficient nitrogen management strategies must be based on understanding soil nitrogen dynamics and the carbon cycle. This chapter explains the nitrogen cycle and how it is affected by management. Corn, the most common Michigan field crop, is used as an example here, because it requires the most nitrogen.

The nitrogen cycle

Nitrogen (N) exists in many different forms. The nitrogen cycle is a schematic representation of these forms and the processes that control how nitrogen is transformed and moved from one form to another. Each nitrogen form and process is discussed below. Forms are identified in **bold** and processes are in ***bold italics.*** In the diagram, green arrows represent inputs and red arrows, outputs. The effects of various nitrogen management strategies on these forms and processes are discussed in this chapter. You may wish to refer back to this diagram when reading the rest of this chapter.

1 ***Plant uptake.*** Plants can only take up nitrogen in the inorganic forms ammonium (NH_4^+) and nitrate (NO_3^-).

2 Large amounts of crop nitrogen are found in **harvested grain and hay**. When these are sold off-farm rather than returned to the soil as manure, the amount of nitrogen added to the system must be increased.

3 More than 99 percent of soil nitrogen is present as **organic nitrogen**, i.e. bound to carbon in soil organic matter (SOM). Although substantial amounts of inorganic nitrogen (ammonium and nitrate) may be released from SOM during the growing season, supplemental nitrogen must usually be added in modern agricultural systems that do not emphasize organic sources of nitrogen.

4 **Dinitrogen (N_2)** makes up 78 percent of the earth's atmosphere. This is equal to 35,000 tons of nitrogen per acre. Plants, however, are not able to use this form of nitrogen.

5 As a result of industrial and agricultural activities, **precipitation** adds the equivalent of 5-10 pounds of nitrogen per acre per year (lb N/A/yr) to Michigan soils.

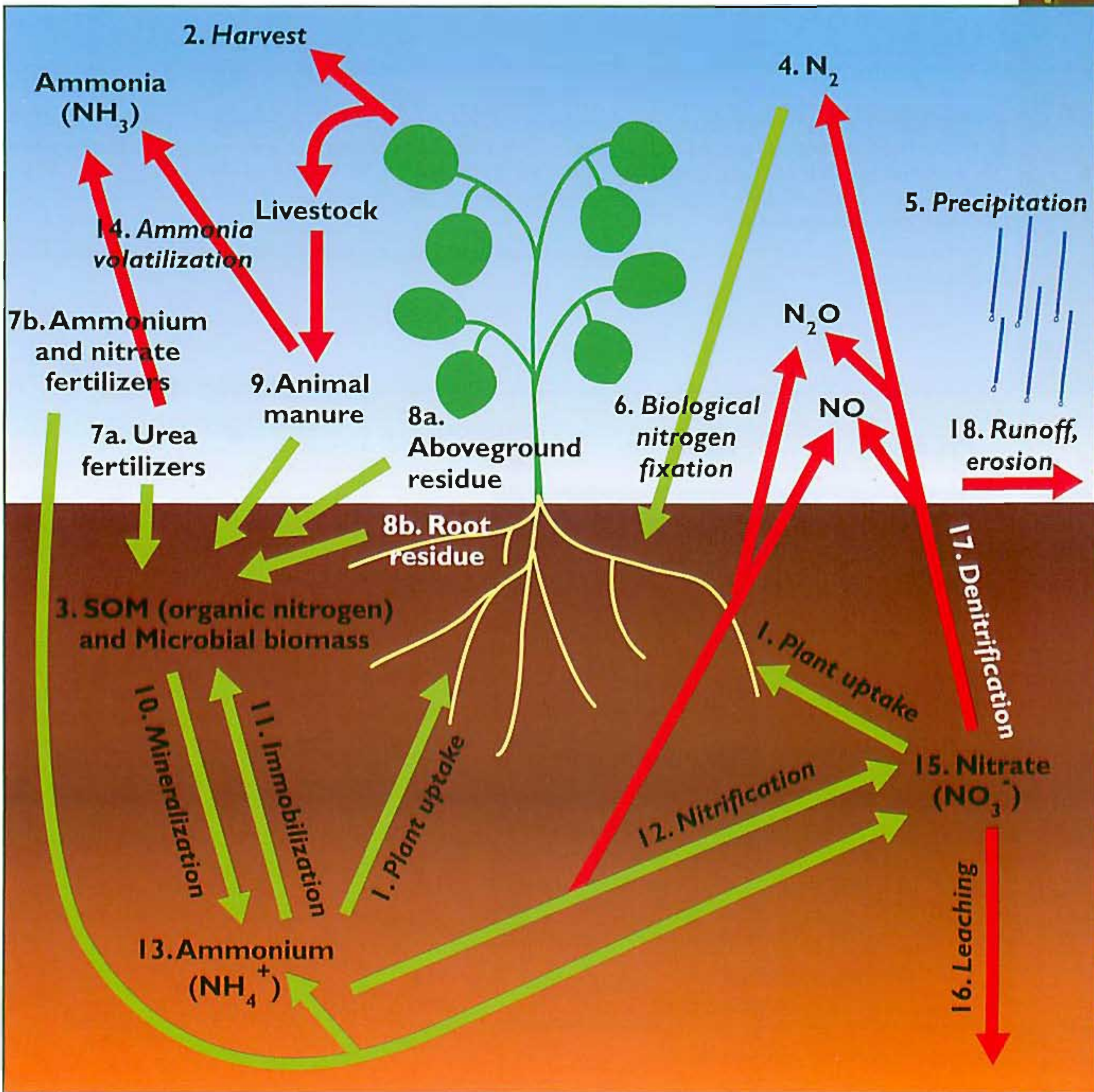
6 ***Nitrogen fixation*** converts N_2 to ammonium by either bacteria (***biological nitrogen fixation***) or chemical processes (***chemical nitrogen fixation***). Some free-living bacteria fix N_2, but this amounts to only 5-10 lb N/A/yr for Michigan agricultural systems. Most biological nitrogen fixation comes from ***symbiotic nitrogen-fixing bacteria*** in legume root nodules. Important legumes include soybeans, alfalfa and a number of green manure crops. Chemical nitrogen fixation is carried out by lightning (about 10 lb N/A/yr) and industry. Industrial nitrogen fixation synthesizes NH_3 using atmospheric N_2 and hydrogen (H_2) from natural gas. This process is energy intensive; it requires about 40,000 cubic feet of natural gas for each ton of anhydrous ammonia produced. Further processing produces the range of fertilizers used in agriculture today.

7 **Synthetic fertilizers** contain one of three nitrogen forms: urea [$CO(NH_2)_2$], ammonia/ammonium or nitrate. All non-nitrate forms commonly used in row crop agriculture are readily converted to soil nitrate by mineralization and/or nitrification (see below).

8, 9 Almost all the nitrogen in **crop residues** and **green manures**, and about half of that in animal manures is in organic forms not immediately available for crop uptake. These forms of nitrogen are naturally slow-released at a rate that depends on the factors that influence mineralization, immobilization and nitrification.

10 Organic nitrogen is converted to ammonium through ***nitrogen mineralization.*** Nitrogen and carbon mineralization occur at the same time, but unlike carbon, the primary product of nitrogen mineralization (ammonium), is not lost to the system, but is readily available for plant uptake. Nitrogen mineralization is conducted by a wide array of soil organisms and is controlled by the same factors that control carbon mineralization: soil temperature, moisture, aeration, pH, amount and quality of residues, residue particle size and degree of burial in the soil. Managing nitrogen mineralization is at the heart of an efficient nitrogen fertility program.

11 ***Nitrogen immobilization*** refers to ammonium and/or nitrate uptake by the **microbial biomass**. When organic carbon is consumed by the microbial biomass, some inorganic nitrogen may also be consumed and then become part of short-term or long-term organic matter pools. Immobilization is the opposite of mineralization since plant-available nitrogen is converted back to organic form. Both nitrogen mineralization and immobilization occur simultaneously, but their rates vary according to soil conditions and carbon and nitrogen demands of soil microorganisms and plants.



12 *Nitrification.* Ammonium is converted to nitrate by specialized bacteria called nitrifiers. Nitrification is a crucial step in the nitrogen cycle because ammonium and nitrate possess very different properties.

13 **Ammonium** is not very mobile in soils. Because of its positive charge, ammonium is attracted to negatively charged soil colloids (clay and organic matter).

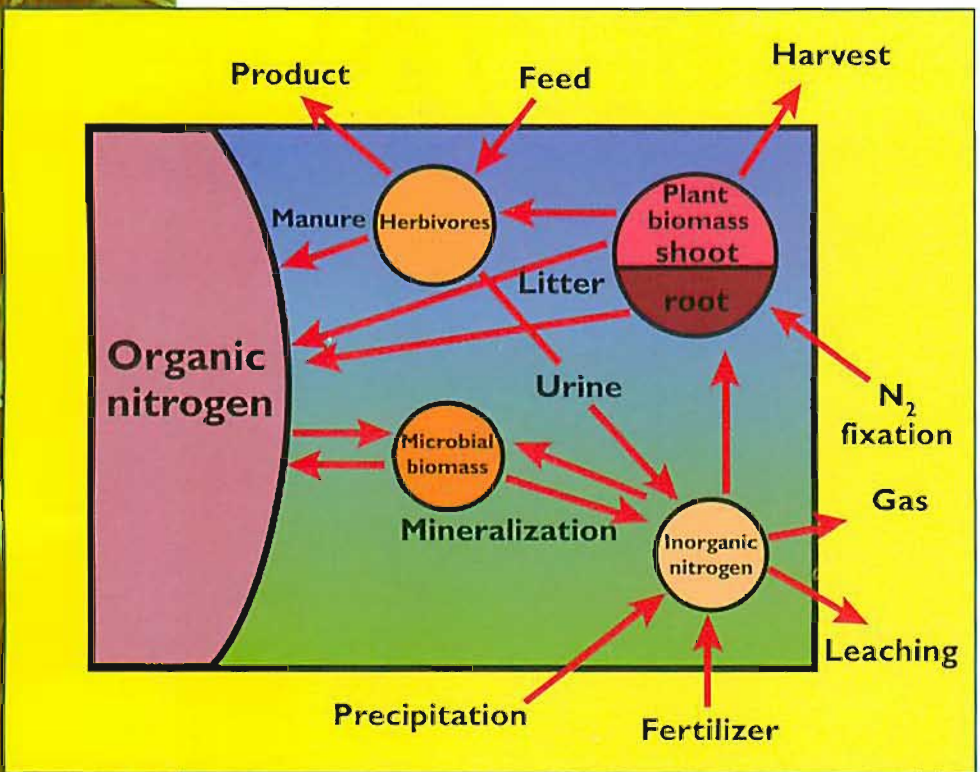
14 Ammonium can be lost from the system via ***ammonia (NH_3) volatilization***, when ammonium is transformed to ammonia, a gas that can readily diffuse into the atmosphere. This chemical process occurs when urea or manure (which contains a large proportion of nitrogen as urea and uric acid) are surface applied. Volatilization rates are highest at high pH (>7.9) and under dry and warm conditions.

15 Nitrate, because of its negative charge, is very mobile in soils. If not taken up by the crop, nitrate is very susceptible to loss by both leaching and denitrification.

16 **Nitrate leaching** occurs whenever soil nitrate is present and water moves down through the soil profile. Leaching potential is highest during those times when crop uptake is low or non-existent, and following rainfall or snowmelt (fall, winter, early spring and following heavy rain storms). Sandy soils are more susceptible to nitrate leaching than clay soils.

17 **Denitrification** is the conversion of nitrate to gaseous N_2, nitrous oxide (N_2O) and/or nitric oxide (NO) by specialized bacteria (denitrifiers) under anaerobic conditions. Soil oxygen is depleted when soils are saturated and/or when microbial respiration is very high. Clay soils are more susceptible to denitrification than sandy soils. All the nitrate in a poorly-aerated soil may be lost to denitrification in two to three days during warm periods.

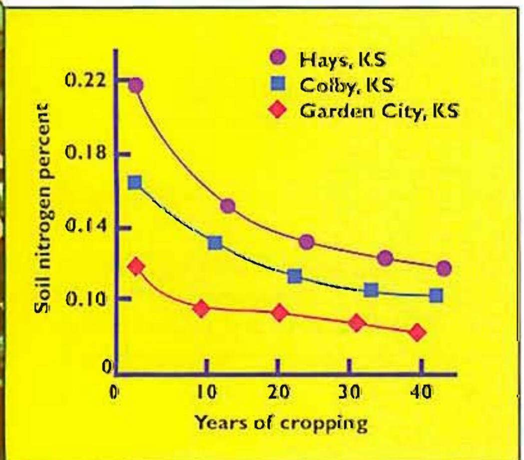
18 Despite 60 years of conservation programs, large amounts of soil nitrogen are still lost via **runoff and erosion**.



Source: M. Russelle, Journal of Production Agriculture, 1992.

Relative size of nitrogen pools

The pools of nitrogen are shown as circles in this diagram. The size of the circles reflects the size of the pools in a typical agricultural soil. Note that the organic nitrogen circle is 100 times as large as any of the other circles. Also, if atmospheric nitrogen were included as a circle, it would have a diameter of about 13 feet. The arrows represent nitrogen transformations. For clarity, not all arrows are labeled. The large square represents the boundary of the farm. Those arrows that cross this boundary represent nitrogen inputs and losses from the farm. Many nitrogen transformations result in nitrogen losses from the farm.



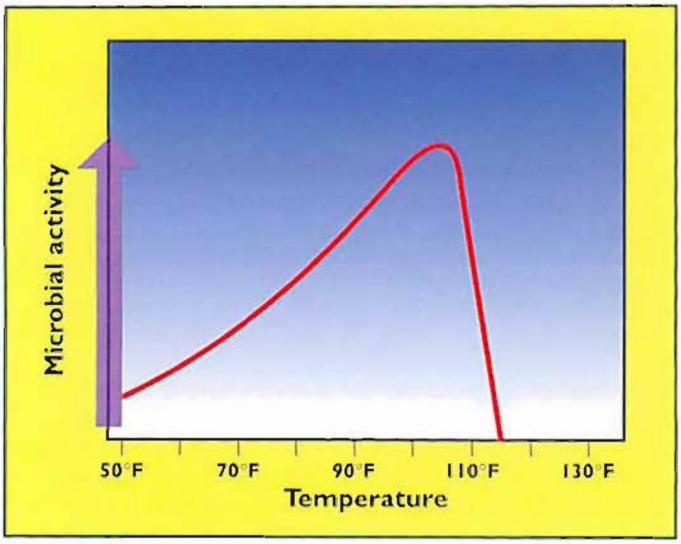
Nitrogen levels in farm soils have been reduced over time as a result of agricultural practices. This pattern is identical to that described for carbon in the previous chapter. Some of this nitrogen was removed in harvested crops. Some was lost by other means, potentially contributing to air and water quality problems, as discussed on p. 35.

Loss of soil nitrogen accompanying organic carbon losses in wheat-fallow rotations at three locations in Kansas, over 40 years.

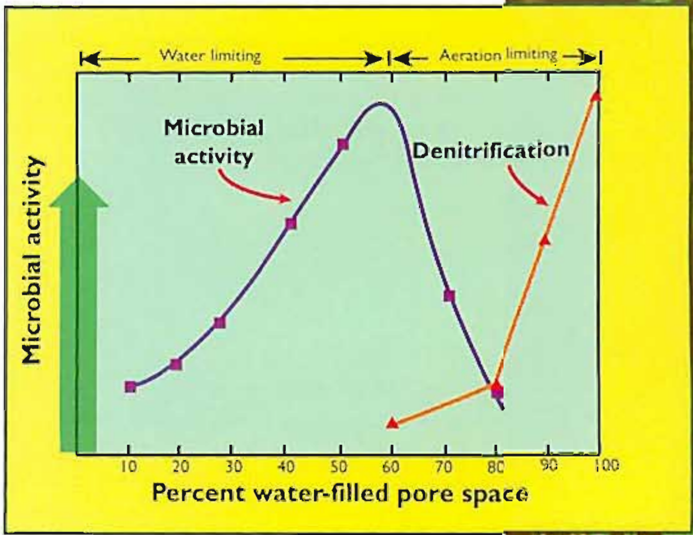
Source: USDA Technical Bulletin 1164, 1957.

Soil moisture, temperature and the nitrogen cycle

Seasonal temperature and moisture fluctuations influence the microorganisms that control the rates of many nitrogen transformations. The major transformations of soil nitrogen – mineralization, nitrification, immobilization and denitrification – can occur very quickly, especially during warm weather when the soil is moist.

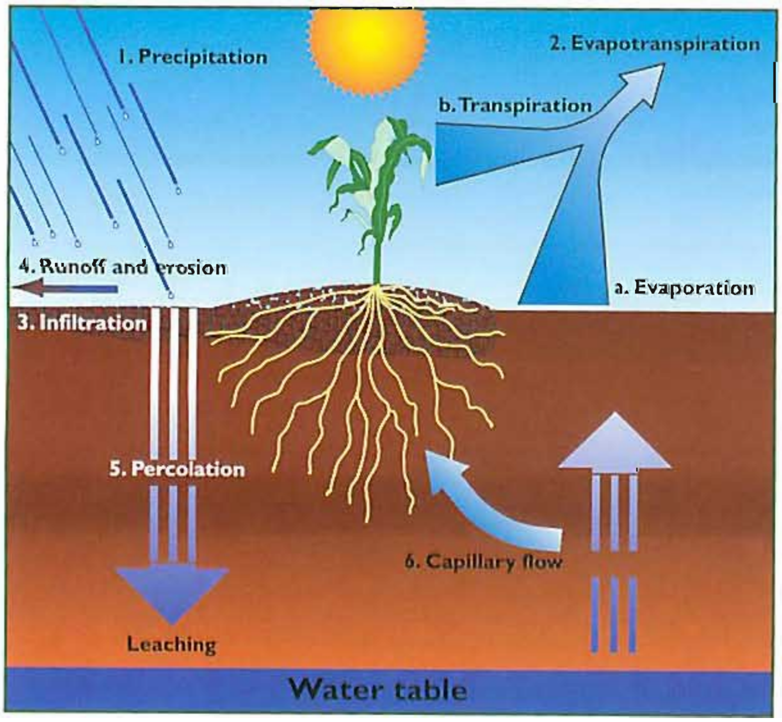


Microbial activity and nitrogen cycle process rates increase with temperature in the range commonly found in soils.



Source: Linn and Doran, Soil Science Society of America Journal, 1984.

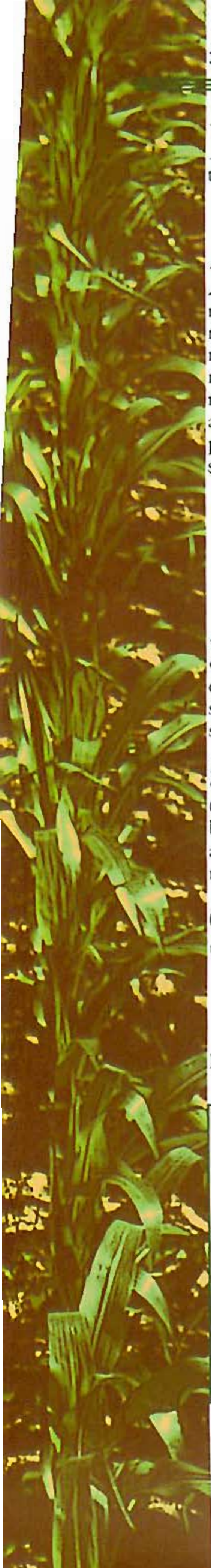
Microbial activity is limited at both low and high soil moisture, and is highest in moist, but not wet soils. The exception to this pattern is denitrification, which continues to increase with soil moisture.



Soil water cycle

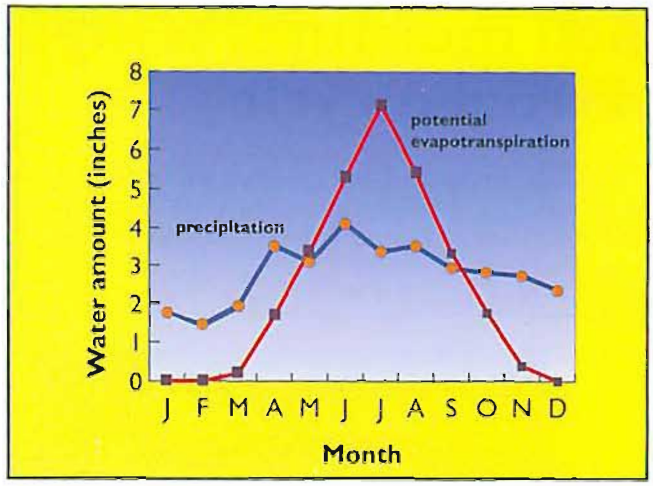
Nitrogen compounds move into and out of the soil depending on soil water cycle processes.

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



1 **Precipitation.** Michigan precipitation is plentiful and is often equally distributed throughout the year.

2 **Evapotranspiration** is water movement out of the soil by a combination of evaporation and transpiration. **Transpiration** is the removal of soil water by plant uptake and release to the atmosphere. Transpiration removes much more soil moisture than evaporation. Because actual evapotranspiration rates are difficult to measure, scientists measure **potential evapotranspiration (PET)** rates to study soil water cycles.



Monthly average precipitation and potential evapotranspiration rates for the years 1956 - 1986 at KBS. Though actual values vary across the state, this pattern is representative for major Michigan agricultural areas.

3,4 **Infiltration vs. runoff and erosion.** Whether precipitation enters the soil or runs off the surface depends on precipitation intensity and on the soil's infiltration capacity. Infiltration rates depend on soil texture, structure, compaction, freezing and saturation. Soils that are compacted, frozen or already saturated with water have very low infiltration rates and are prone to high runoff rates. Runoff and erosion are highest during early spring (snowmelt), fall and during intense or long rains throughout the year.

5 **Percolation and leaching.** The fate of water in soil depends on the soil's **field capacity**, water content and evapotranspiration rates. Sandy, poorly structured and low organic matter soils hold less water (have lower field capacity) than clay, well-structured and high organic matter soils. When soil moisture is below field capacity, added water will be stored in the soil. When soil moisture is at or above field capacity, added water will percolate through the soil profile, carrying any nitrate present with it. This is called **nitrate leaching**.

6 **Capillary flow** is the movement of soil water from wet to dry areas through very small soil pores as occurs in a sponge. In response to evapotranspiration, soil water from deeper, wetter horizons diffuses up through the soil profile.

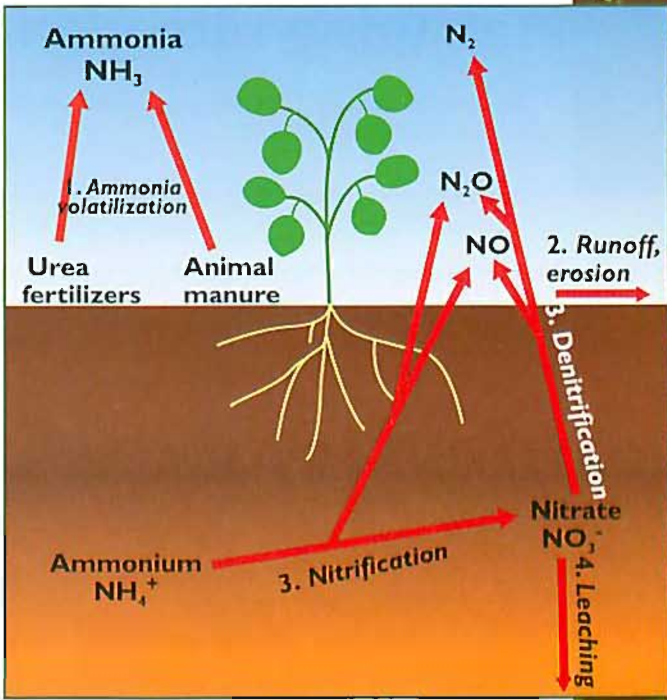
Nitrogen management requires consideration of a soil's texture. Coarser soils are prone to nitrate leaching and fine soils are prone to denitrification.

Soil hydrologic groups

Type	Infiltration capacity/ permeability	Leaching potential	Runoff potential
Deep, well-drained sands and gravels	high	high	low
Moderately deep to deep, moderately drained, moderately fine to moderately coarse texture	moderate	moderate	moderate
Impeding layer, or moderately fine to fine texture	low	low	high
Clay soil, soils with high water table, shallow soils over impervious layer	very low	very low	very high

Source: Cornell Extension Information Bulletin 218

Nitrogen and environmental quality



1. Ammonia volatilization: ammonia in the atmosphere

Ammonia volatilization from urea and manure can contribute to odor problems. Proper manure and fertilizer management can dramatically reduce ammonia volatilization.

2. Runoff and erosion: nitrogen in surface water

Nitrogen that is lost from agricultural systems via runoff and erosion is in both organic and inorganic forms. When this nitrogen and other nutrients in the runoff enter surface waters (lakes, ponds, rivers and streams), they can cause increased plant and/or microbial growth, increasing material decomposing in the sediments. Sediment decomposition increases the system's oxygen demand and reduces water quality for fish and other wildlife. The key to reducing nitrate contamination of surface waters is to minimize erosion and runoff as described in the carbon chapter.

3. Nitrification and denitrification: nitric and nitrous oxide in the atmosphere

A small portion of nitrogen that undergoes nitrification and denitrification can be converted to nitric oxide (NO) and nitrous oxide (N_2O). Nitric and nitrous oxides both contribute to stratospheric ozone destruction, which may result in increased skin cancer rates. Nitrous oxide is also a greenhouse gas, contributing to global climate change. Atmospheric concentrations of these gases have increased in recent years and inefficient nitrogen use in agriculture is commonly recognized as an important contributor. Our current knowledge of NO and N_2O production by nitrification and denitrification is not sound enough to allow us to suggest management practices to minimize it, but the strategies used to decrease nitrate leaching are likely to help decrease NO and N_2O emissions from agricultural soils.

4. Leaching: nitrate in groundwater

The federal standard for nitrate nitrogen in drinking water is 10 parts per million (ppm). Nitrate concentrations higher than this can cause methemoglobinemia, or "blue baby disease" in infants. Some livestock are similarly susceptible to nitrate. At higher concentrations (100-200 ppm), nitrate in combination with amines (portions of protein molecules), can form cancer-causing nitrosamines.

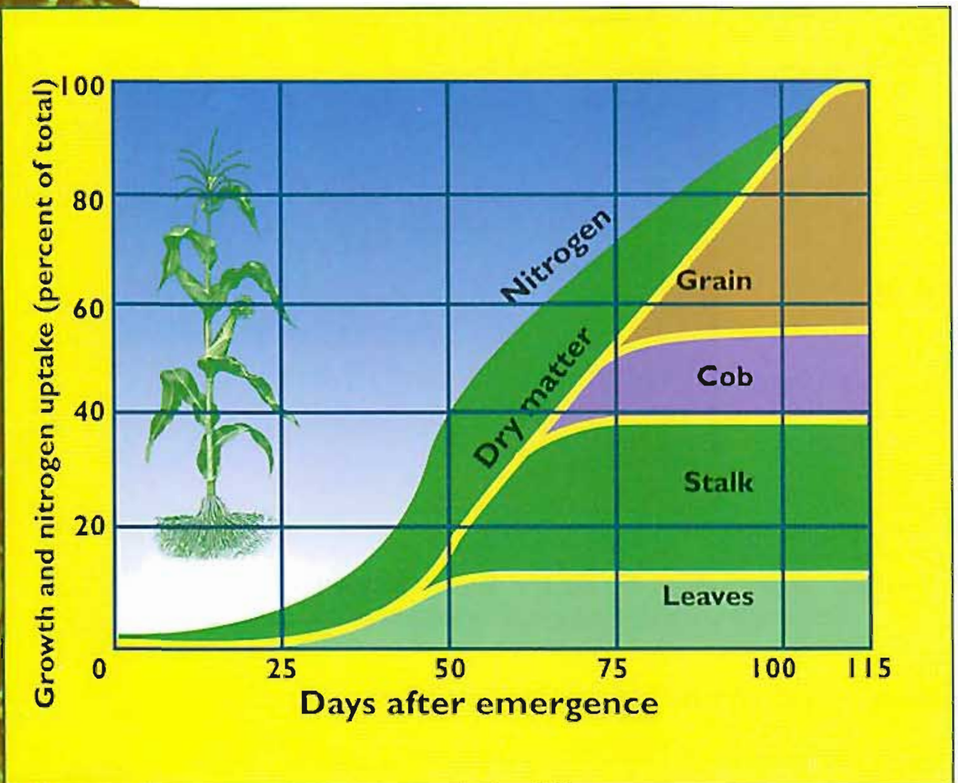
A 1984 study in one heavily agricultural Michigan county with sandy soils showed more than 10 ppm nitrate nitrogen in 34 percent of the tested wells. Though it is difficult to generalize about other areas of the state based on this study, it is clear that nitrate in groundwater is a serious environmental problem.

The key to reducing nitrate leaching is to minimize soil nitrate concentrations during times when precipitation exceeds evapotranspiration. PET and soil nitrate content can be manipulated using crop rotations and carefully managing fertilizer and other nitrogen sources.

Increasing nitrogen use efficiency will help solve these environmental problems and provide direct economic benefits to farmers. These strategies are discussed on the following pages.

Managing nitrogen

The goal of managing the nitrogen cycle is to minimize nitrogen losses by synchronizing soil nitrogen availability and plant uptake.



Source: Iowa State University Special Report No 48

Crop uptake

Plant nitrogen uptake is low during early plant growth stages, but increases exponentially along with dry matter (carbon) accumulation. In Michigan, exponential corn growth occurs between mid-June and the end of August. In order to reach crop yield potentials, it is important that nitrogen (usually in the form of nitrate) is available for uptake when demand occurs. This is the reason that side-dress applications are most efficient.

MSU nitrogen fertilization recommendations for continuous corn

Yield goal*	Nitrogen fertilizer recommendation
(bu/A)	(lb N/A)
100	110
125	140
150	180
175	210
200	250

*Yield goals must be realistic and achievable, meaning they are achieved at least two of five years. Choosing unrealistic or unachievable yield goals will lead to over- or under-fertilization. Expected yields are influenced by soil type and management.

Source: MSU Extension Bulletin, WQ06

Nitrogen fertility recommendations

The nitrogen cycle's dynamic nature makes it difficult to measure the amount of nitrogen available for crop uptake. Fertility recommendations are often based solely on crop yield goals and previous cultural practices. This table shows MSU's nitrogen fertilization recommendations for continuous corn when no legumes or manures are used on a soil with less than four percent organic matter.

When organic nitrogen sources are used, fertilizer recommendations are reduced based on the concept of "nitrogen credits," an estimate of the fertilizer equivalent of nitrogen supplied by organic sources. Nitrogen credits are subtracted from the fertilizer recommendations provided in this table. MSU nitrogen credit recommendations are included throughout this chapter.

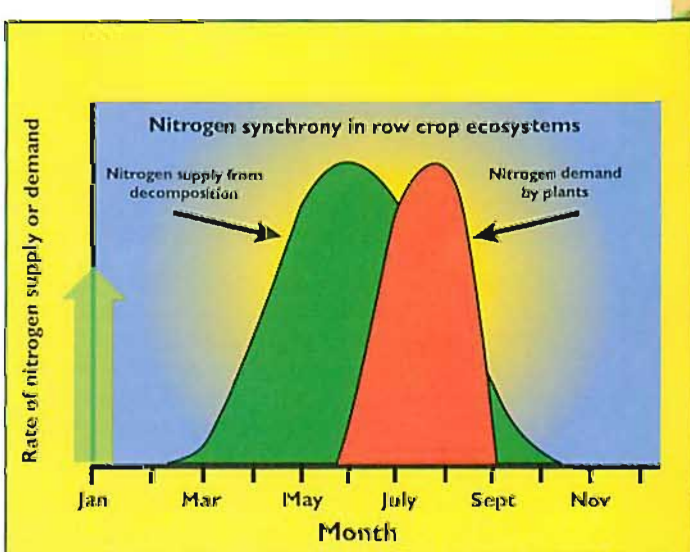
A second method of accounting for organic nitrogen sources is the **pre-sidedress nitrate test (PSNT)**. The PSNT measures the amount of soil nitrate in early June, about two weeks prior to side-dressing nitrogen fertilizer. Recent research by MSU scientists indicates that the PSNT is a good predictor of the amount of nitrogen that will be available to corn. The majority of fertilizer nitrogen should be applied only after this test is taken (i.e. **split applications**). It is important that test samples not be taken earlier than the recommended time so that only recently mineralized and nitrified nitrate are measured. Soil sample bags and information on taking soil samples for the PSNT are available from all MSU Extension offices or the MSU Soil and Plant Nutrient Laboratory.

Soil sampling.

Managing nitrogen: soil nitrogen

Michigan's mineral soils naturally contain 2,000-6,000 lb N/A, almost all of which is **organic nitrogen**. Like soil carbon, this nitrogen is present as a variety of compounds with different decomposition rates. Annually, only one to three percent (25-75 lb N/A) of soil organic nitrogen is converted to inorganic nitrogen. Thus, **total soil nitrogen** does not fluctuate during a crop year.

Inorganic, or plant-available nitrogen, fluctuates dramatically during the year. In response to increasing spring temperatures, mineralization and nitrification rates are high, providing a spring **pulse** of inorganic soil nitrogen. This peak may or may not be captured by plants. Manipulating this peak is one goal of efficient nitrogen management.



Source: Robertson, 1997.

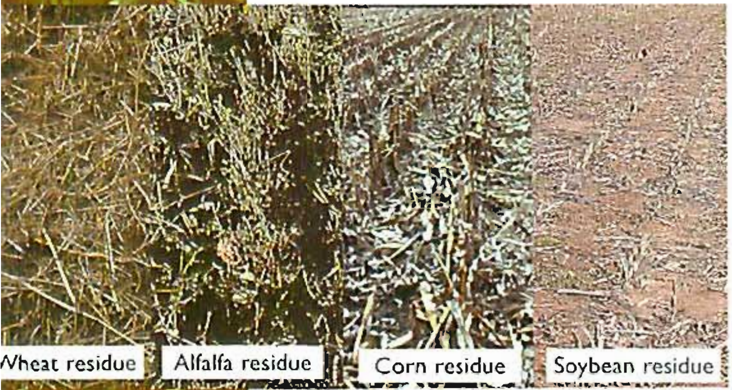
Nitrogen credits for soil nitrogen	
Soil organic matter	Nitrogen credit
(percent)	(lb N/A/yr)
0 - 4	0
4 - 8	20 - 40
organic soils (>8)	40 - 80

Source: MSU Extension Bulletin WO02S

Soil nitrogen mineralization's contribution to crop uptake is presented in this table. SOM levels tend to increase with the soil's clay content. As discussed in the carbon chapter, SOM levels can be increased over the long-term through appropriate management.

Managing nitrogen: crop residues, green manure/cover crops and crop rotation

Plants, especially legumes, can be used to "grow" nitrogen. The plant nitrogen that becomes available to succeeding crops is proportionate to the quantity and quality of residue produced and returned to the soil.



Crop residues

Crops differ greatly in the amount of nitrogen they contain. About 50-60 percent of the nitrogen in grain crops is harvested in the grain. The remainder is often returned to the soil as residue.

Yield and nitrogen content of common crops

Crop	bu or ton/A	lb/A	Nitrogen content
Alfalfa hay	6 ton	12,000	270
Corn, grain	150 bu	8,400	135
Corn, stover	4.5 ton	9,000	101
Soybean, seed	50 bu	3,000	188
Soybean, straw	2.5 ton	5,000	127
Wheat, grain	60 bu	3,600	75
Wheat, straw	2.5 ton	4,500	30

Source: North Central Region Research Publication No. 341

Green manures and cover crops

Legume/grass mixture being inoculated with nitrogen-fixing bacteria.

Green manures are crops grown to provide fertility (usually nitrogen) to succeeding crops. Cover crops are used to decrease runoff, erosion and leaching between cropping seasons. A single crop often serves both purposes, so the terms green manure and cover crop are often used interchangeably.

Legumes are usually used as green manures because of their ability to host nitrogen-fixing bacteria in root nodules. Legume seeds should be inoculated with the appropriate bacterial species just prior to planting. The bacteria provide the plant with readily available nitrogen by fixing atmospheric nitrogen; the plant provides the bacteria with energy in the form of carbon. When soil nitrate levels are high, this mutualism breaks down and plants save their carbon energy by taking nitrogen directly from the soil.

The amount of nitrogen fixed in legume nodules that will be available to a succeeding crop depends on legume species, variety, age, growth and soil conditions.

Nitrogen fixed in root nodules of common legumes

Legume species	N fixed (lb/A)
Alfalfa	50 - 150
Red clover	60 - 70
White clover	60 - 100
Hairy vetch	60 - 180
Soybean	30

Source: Managing cover crops profitably, Sustainable Agriculture Publications - USDA

C:N ratios of common crop residues

Residue	C:N ratio
Young legumes	12 - 20:1
Young grasses	20 - 40:1
Corn stalks	60:1
Small grain straw	80:1
Woody materials	400:1

Source: Laboratory manual for introductory soil sciences, 6th edition. Foth, Withee, Jacobs and Thien. ©1982 reprinted by permission of Wm. C. Brown Co Publishers, Dubuque, Iowa

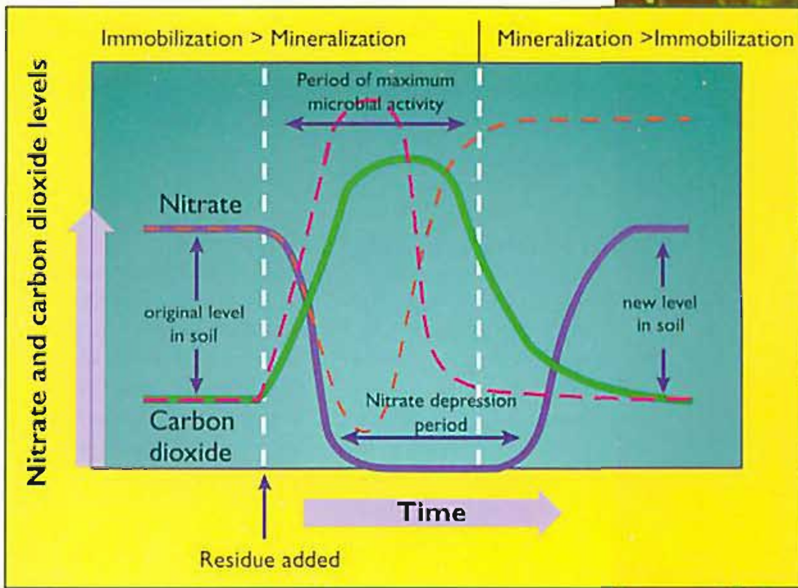
Residue quantity

The more residue of a particular kind returned to the soil, the greater the nitrogen returned.

Residue quality

Residue quality is even more important in controlling the fate and availability of residue nitrogen. The amount of crop or cover crop residue nitrogen available to succeeding crops is determined largely by the residues' carbon to nitrogen ratio (C:N ratio).

Residue C:N ratio



Source: Laboratory Manual For Introductory Soil Sciences, 6th Edition. Foth, Withee, Jacobs and Thien. ©1982, adapted by permission of Wm. C. Brown Co. Publishers, Dubuque, Iowa.

This figure shows the effect of residue C:N ratio on soil nitrate and microbial activity during and after decomposition.

Solid lines show the effects of high C:N ratio residues; dashed lines those of low C:N ratio residues.

When residues are added to soil, microbial activity increases (carbon dioxide production) and microbial uptake of nitrogen (immobilization) reduces soil nitrate levels.

As residue decomposition progresses, the amount of readily decomposable carbon declines, soil biomass gets smaller and the nitrogen in microbial cells is slowly released, making it available for crop uptake. At this point, mineralization is greater than immobilization. A soil's inorganic nitrogen level after decomposition depends on original residue C:N levels. Nitrate levels following decomposition are higher only if the original residue C:N ratio is about 20:1 or less.

Residues with high C:N ratios (>30:1)

Residues with high C:N ratios have too little nitrogen relative to carbon for rapid microbial growth, so organisms use ammonium and nitrate present in soil to supplement that in the residues. Soil nitrate levels are depleted following the return to soil of residues with high C:N ratios and no nitrogen is available for crop growth. This is one reason why adding nitrogen fertilizers may help increase decomposition rates.

Residues with low C:N ratios (<20:1)

Residues with low C:N ratios contain sufficient nitrogen for soil microorganisms so that depression periods are neither as severe nor as long-lasting. Nonetheless, primary field crops should not be planted immediately following the killing of cover crops. Decomposition processes and residue quality and quantity considerations are summarized in this table of nitrogen credits.

Nitrogen credits for previous crops when followed by corn

Previous crop	Nitrogen credit (lb N/A)
Corn and most other crops	0
Soybeans	30
Grass sod/pastures	40
Annual legume cover crop	40 - 80+
Perennial forage legume	60 - 140*

*Nitrogen credits can vary considerably based on plant species, stand density, growing conditions and harvest date. Values are calculated using 40 + 20x, where x = plants/sq ft.

Source: MSU Extension Bulletin WQ025 and Managing Cover Crops Profitably, Sustainable Agriculture Publications - USDA.

Managing nitrogen losses using cover crops and crop rotations

Nitrate leaching and denitrification can be reduced by maintaining continuous plant cover using either cover crops or perennial crop rotations.

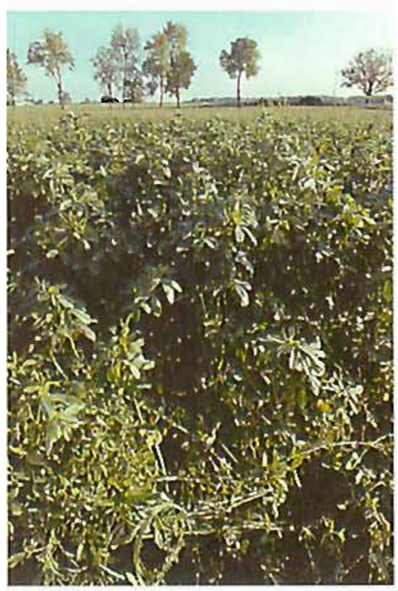
Following corn's physical maturation (or that of any warm season crop), significant residual nitrate leaching can occur, especially on sandy soils if no cover crop is used. On finer-textured soils, nitrate loss is more likely to occur as denitrification. Cover crops, especially grasses (e.g. annual ryegrass) and oilseed radish, have successfully been used to take up residual nitrogen following corn without decreasing the succeeding corn crop's yield.

Annual ryegrass cover crop.

Winter wheat as a cover crop.

A winter wheat crop affects soil nitrogen like a cover crop/green manure. When wheat is planted, transpiration reduces soil moisture and plant uptake reduces soil nitrate concentrations, reducing fall and winter nitrate leaching. Nitrate leaching may occur following wheat maturation since transpiration is very low at this time, though frost-seeding red clover into wheat can alleviate this problem. After wheat harvest, rapid clover growth reduces soil moisture and nitrate levels. MSU studies have shown first-year corn yield in a corn-corn-soybean-wheat rotation are highest when a red clover green manure crop is included.

Perennial crops (e.g. alfalfa) exhibit much lower nitrate leaching than annual crops because water and nitrate uptake occur over a longer growing season. Nitrate leaching can occur, however, after the crop is killed and before a succeeding crop is established. It is important to synchronize killing a perennial crop with the succeeding crop's nitrogen uptake.



Alfalfa.

Managing nitrogen: animal manures

Total soil nitrogen levels may be increased over time by repeated manure application.

Typical nitrogen content of manures from selected animals

Animal type	lb N/ft³ manure
Dairy cattle	0.30
Beef cattle	0.35
Swine	0.42
Sheep	0.73
Horse	0.36
Poultry	0.83

Source MSU Extension Bulletin E-2344

Nitrogen loss

Nitrogen losses from manure can also be high. **Volatization**, for example, can reduce surface-applied manure's nitrogen content by more than 70 percent. Incorporating manure immediately can decrease volatization losses to less than five percent. **Denitrification** losses can be as high as 20 percent of manure nitrogen. **Leaching** losses will be high for manure applied during periods of high leaching potential.

Ammonium nitrogen volatization losses for surface applied solid and semi-solid manures

Days before incorporation	Percent lost
0 - 1	30
2 - 3	60
4 - 7	80
>7	90

Source MSU Extension Bulletin E-2340

Application timing

In addition, the timing of manure application relative to crop growth affects the amount of nitrogen available for crop uptake. This figure summarizes the amount of nitrogen available from manure and urine, as effected by application timing and storage.

Source: Cornell Cooperative Extension SFS Fact Sheet, Page 101.

Nutrient content

Animal manures, compost and industrial by-products are notoriously variable in nutrient content. Manure's nitrogen content varies with animal species, age, diet, gender and reproductive stage, bedding and manure storage and handling procedures.

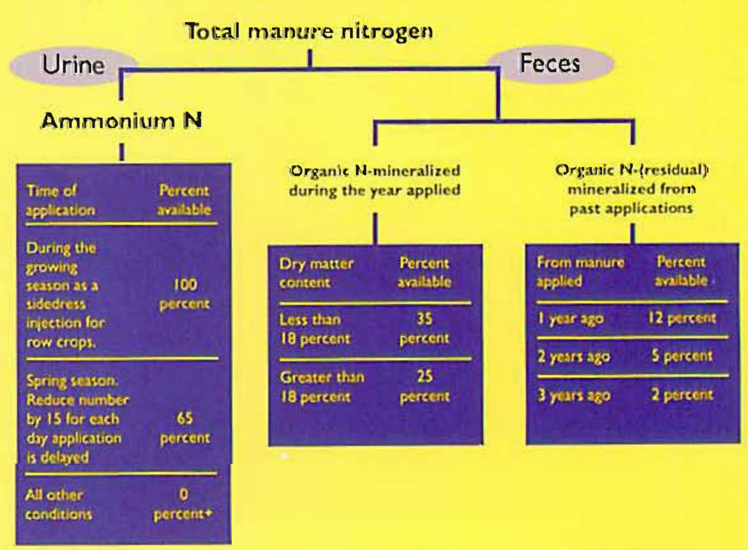
It is important to analyze manures and other organic matter sources for nutrient content to give appropriate nutrient credits and not over fertilize. Also, because phosphate levels in many Michigan soils are very high due to a history of high manure applications, manure nutrient concentrations should be monitored for two years to determine expected nutrient levels.

Nitrogen losses during manure handling and storage

Manure type	Handling system	Nitrogen lost (percent)
Solid	Daily scrape and haul	15 - 35
	Manure pack	20 - 40
	Open lot	40 - 60
	Deep pit (poultry)	15 - 35
Liquid	Anaerobic pit	15 - 30
	Above-ground	10 - 30
	Earth storage	20 - 40
	Lagoon	70 - 80

Source: Midwest Plan Service, 1985.

Effect of application timing and storage on manure nitrogen availability



Aerobic manure **composting** can increase nitrogen stability, decrease manure volume and decrease the compost's C:N ratio.

Composting at KBS.

Managing nitrogen: synthetic fertilizers

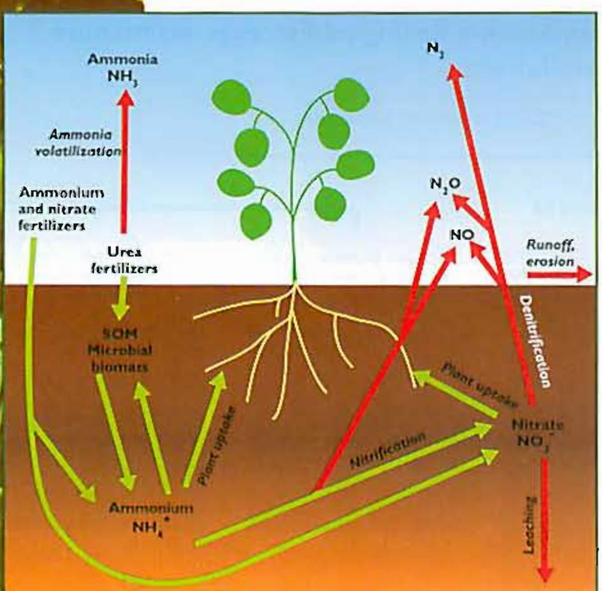
Many forms of synthetic nitrogen fertilizers are used in Michigan field crop agriculture. Some commonly used nitrogen fertilizers are grouped by type in this table.

Nitrogen content of fertilizers

Fertilizer type	Percent nitrogen	Source of nitrogen (percent) Urea	Ammonia/Ammonium	Nitrate
Urea	46	100		
Anhydrous ammonia	82		100	
Aqua ammonia	21		100	
Ammonium phosphates	3 - 21		100	
Ammonium sulfate	21		100	
Urea-ammonium nitrate	28 - 32	50	25	25
Ammonium nitrate	34		50	50
Calcium, sodium and potassium nitrates	13 - 16			100

Volatilization

Surface-applied urea fertilizers are susceptible to large nitrogen losses via ammonia volatilization during dry conditions, especially if pH > 7.9. One-half inch of rain is sufficient to move surface-applied urea into the soil and essentially eliminate volatilization. Without rain, however, 75 percent of urea can be lost by volatilization in less than five days. Like manure, urea should be incorporated soon after application.



Leaching and denitrification

Under warm and moist conditions, virtually all properly applied urea- and ammonium-based fertilizers are converted to nitrate in less than two weeks. Nitrogen loss from agricultural systems occurs primarily after nitrogen undergoes nitrification, since nitrate is so mobile and prone to loss. To avoid nitrate loss by leaching, denitrification or runoff, it is important to coincide fertilizer application with crop uptake. This means that nitrogen fertilizers shouldn't be applied in the fall. Although nitrogen fertilizers are usually cheaper when purchased at this time, nitrogen losses from fall-applied fertilizers range from 10 to 20 percent on fine-textured soils, and 30 to more than 50 percent on coarse-textured soils. If it is necessary to apply in the fall due to wet spring conditions, apply non-nitrate fertilizer after soil temperatures have dropped below 50° F and consider using nitrification inhibitors. Nitrification inhibitors have proven effective in Michigan only on fine-textured soils when nitrogen applications are slightly below recommended levels.

Nitrate-based fertilizers should never be applied in the fall in Michigan due to the potential for immediate loss by leaching and/or denitrification.

Apply nitrogen in split applications. Starter fertilizer applied at corn planting is followed by larger amounts when corn is three to four inches high based on nitrogen credits and/or PSNT results. Applying nitrogen fertilizers in split applications has a number of advantages. First, it allows nitrogen fertilizer adjustments for weather conditions prior to crop uptake. Second, using the PSNT allows a measure of the amount of nitrogen released from soil, plant residues and manures. Finally, yields are not affected using split applications, but nitrogen use efficiency increases.

Tillage and the nitrogen cycle

Tillage stimulates nitrogen mineralization and nitrification. Therefore, fall tillage without planting a cover crop should be avoided whenever possible.

Michigan no-till soils warm up slower than tilled soils, so mineralization and nitrification occur later in the spring under no-till than conventional tillage. Surface residues can also increase immobilization of inorganic nitrogen.

Cover crops

Dale R. Mutch and Todd E. Martin

Key concepts and questions

- What are cover crops?
- How do cover crops influence carbon and nitrogen cycles?
- How do cover crops influence pest management?
- How do cover crops influence weed management?
- Which cover crops can be used in each part of a corn-corn-soybean-wheat rotation in Michigan?
- How economical are cover crops?
- What are the long-term benefits of using cover crops?

Additional reading

Sustainable Agriculture Research and Education Program. Managing Cover Crops Profitably. Sustainable Agriculture Publications - USDA, Washington, D.C. 20250-2200.

What are cover crops?

A cover crop is a crop that is not harvested but is grown to benefit the soil and/or other crops in a number of ways. Cover crop benefits include: reduced soil erosion; improved soil quality; reduced weed pressure; reduced insect, nematode and other pest problems. Cover crops are grown during or between primary cropping seasons. They are versatile and easily adapted to conventional, low-input and organic field crop ecosystems.

There are many cover crop species. **Legume** cover crops fix atmospheric nitrogen into a form plants and microorganisms can use. **Non-legume** species recycle existing soil nitrogen and can reduce the risk of excess nitrogen leaching into groundwater.

Cover crop species

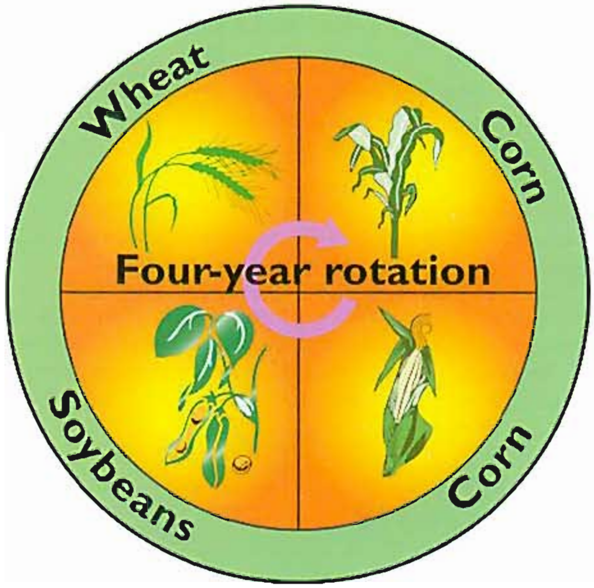
Species	Life cycle[a]	Nitrogen value[b] (lb/A)	Seeding rate (lb/A)	Seeding depth (inches)
Legumes				
Annual medic	SA	40 - 100	10 - 39	1/4 to 1/2
Berseem clover	SA	60 - 90	9 - 20	1/4 to 1/2
Crimson clover	SA	50 - 60	12 - 20	1/4 to 1/2
Field peas	SA	30 - 100	70 - 150	1 to 2
Hairy vetch	WA	60 - 180	25 - 40	1/2 to 2
Mammoth red clover	B	60 - 70	8 - 15	1/4 to 1/2
Sweetclover (SW)[c]	B	70 - 90	8 - 15	1/4 to 1/2
Alfalfa	P	50 - 150	9 - 25	1/4 to 1/2
White clover	P	60 - 100	5 - 7	1/4 to 1/2
Medium red clover (RC)	P	60 - 70	10 - 15	1/4 to 1/2
Alsike clover	B/P	60 - 70	4 - 10	1/4 to 1/2
Birdsfoot trefoil	P	40 - 100	5 - 10	1/4 to 1/2
60/40 mix (RC/SW)	B/P	60 - 90	8 - 15	1/4 to 1/2
Non-legumes				
Buckwheat	SA	NA	36 - 60	1/4 to 1/2
Forage turnips	SA	NA	3 - 5	1/4 to 1/2
Oats	SA	NA	34 - 68	1 to 2
Oilseed radish	SA	NA	15 - 25	1/4 to 1/2
Rape	SA	NA	3 - 8	1/4 to 1/2
Annual ryegrass	WA	NA	15 - 25	1/4 to 1/2
Barley	WA	NA	48 - 96	1 to 2
Rye	WA	NA	28 - 112	1/2 to 1
Triticale	WA	NA	60 - 120	1/2 to 1
Wheat	WA	NA	60 - 120	1/2 to 1

[a] Life cycles: P = perennial; WA = winter annual; SA = summer annual; B = biennial
[b] Nitrogen values vary depending on cover crop densities
[c] Yellow-blossom sweetclover

Source: Managing Cover Crops Profitably, Sustainable Agriculture Publications - USDA.

Cover crops and crop rotation

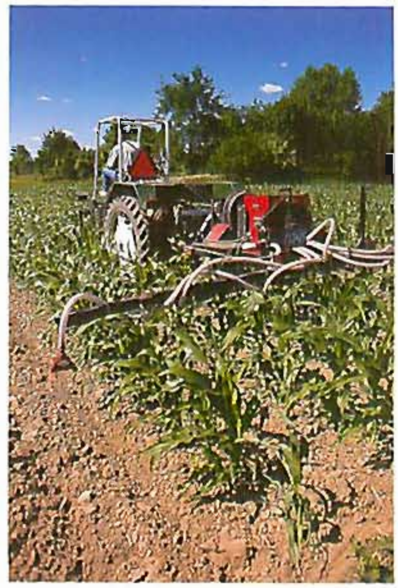
Because every aspect of farm management is linked to other aspects, it is important to consider the entire system when planning a field crop scheme. Rotating crops is an important practice that has repeatedly proven to be an excellent pest management tool. Rotation also provides an opportunity for seeding cover crops. The corn-corn-soybean-wheat rotation many Michigan farmers use offers several possibilities for incorporating cover crops.



Common field crop rotation in Michigan

Growers can incorporate cover crops into their cropping systems by overseeding, frost seeding, aerial seeding or spreading.

Aerial seeding. Source: Howell, NRCS.

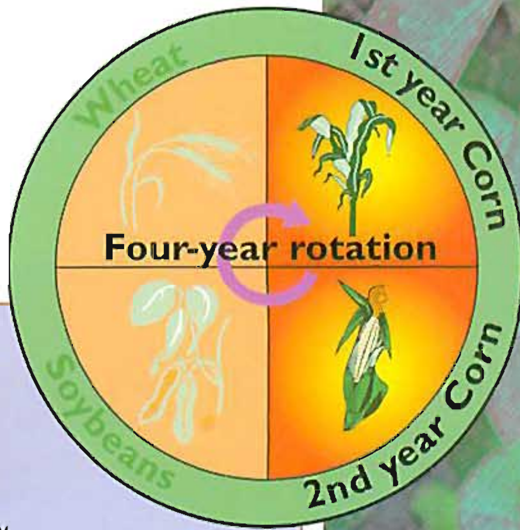


Overseeding (above), bulk spreading (below).

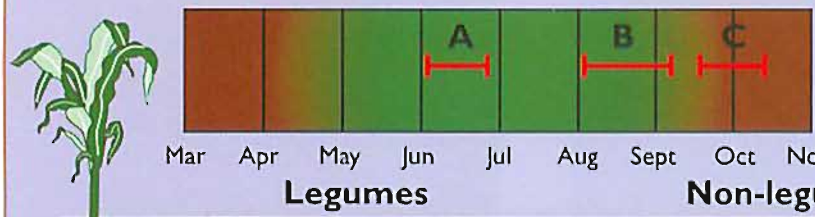
Frost seeding.

Cover crops in corn

Researchers at KBS have adopted a corn system that includes a 10-inch band herbicide treatment followed by two cultivations. Cover crops are overseeded at the second cultivation. Several cover crop species have been successfully established this way, including crimson clover, mammoth red clover, annual ryegrass, hairy vetch and a 60 percent red clover/40 percent sweet clover plowdown.

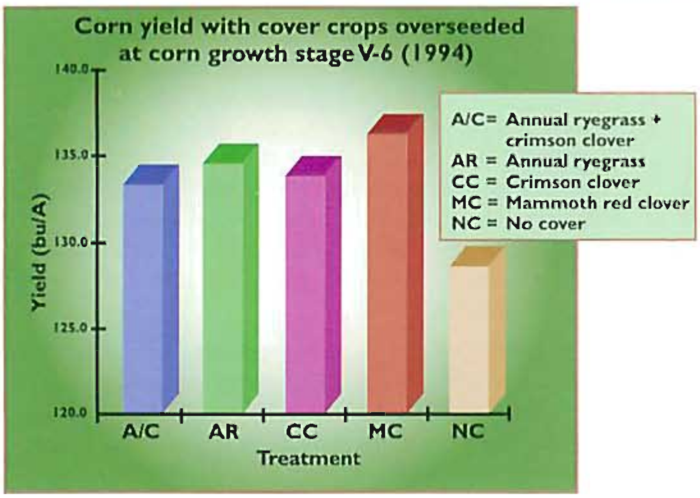


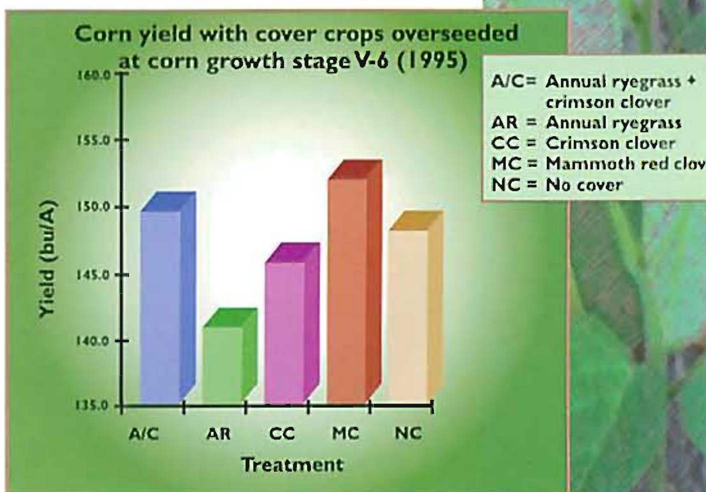
Cover crop options for corn



Legumes		Non-legumes	
A	Berseem clover	A†, B†	Annual ryegrass
A, B	Crimson clover	C	Barley
A, B	Mammoth red clover	A, B	Buckwheat
A, B	Medium red clover	B	Oats
A, B	Sweet clover	B	Oilseed radish
A, B	White clover	B	Rape/Turnip
A, B	60/40 mix	C	Rye
A†, B†	Hairy vetch	C	Triticale
A	Medic annual	C*	Wheat

A = Overseed corn at vegetative stages V4 - V8
B = Overseed corn by air or highboy
C = Overseed corn by air or highboy
* = After Hessian fly-free date
† = Not recommended if being planted to wheat





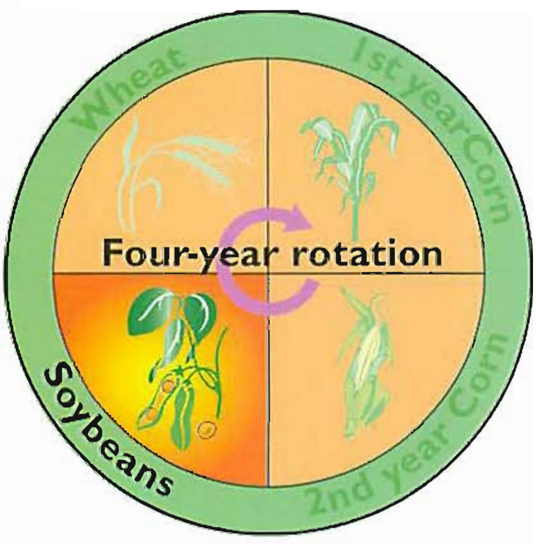
Timing is very important to successfully establishing a cover crop by overseeding. It is extremely important to seed when there is enough light to germinate and establish the cover crop, yet late enough so it will not compete with the corn crop for water, nutrients or light. Two years of research data have shown that legume covers should be seeded between corn growth stages V-4 and V-6, while annual ryegrass should be seeded at V-6 to V-8. With good weed control, cover crops overseeded between the corn rows have not shown a corn yield reduction compared to a broadcast/no cultivation herbicide treatment. For best ground cover after corn harvest, adequate rainfall must occur during the growing season.

Crimson clover and annual ryegrass in corn stubble.

Hairy vetch in corn.

Many Michigan producers apply broadcast herbicide treatments without cultivation. These farmers can still use cover crops by seeding cover crops aerially or with highboy applicators. These seedings can begin when the corn crop begins drying. As the plant dries, sunlight penetrates to the soil, allowing cover crops to germinate and establish. Farmers have been very successful seeding cereal grains, particularly cereal rye.

Annual ryegrass in corn stubble.

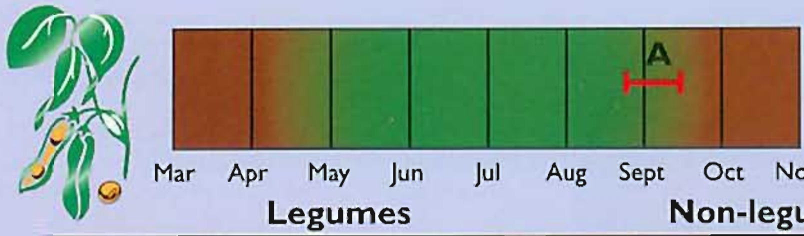


Cover crops in soybeans

Soybeans leave very little residue following harvest, thus following soybeans with wheat is an environmentally beneficial rotation. Not only will the wheat benefit from the nitrogen produced by the soybeans, but seeding after soybean harvest generally offers a good seedbed for drilling wheat. Wheat also provides farmers perennial weed control. Michigan soybeans are often harvested following the Hessian fly-free date, providing a nice fit in the crop rotation scheme.

One alternative to rotating to wheat is to follow soybeans with cover crops planted at soybean leaf drop. KBS cover crop researchers have successfully overseeded red clover, wheat, cereal rye and forage rape into soybeans.

Cover crop options for soybeans



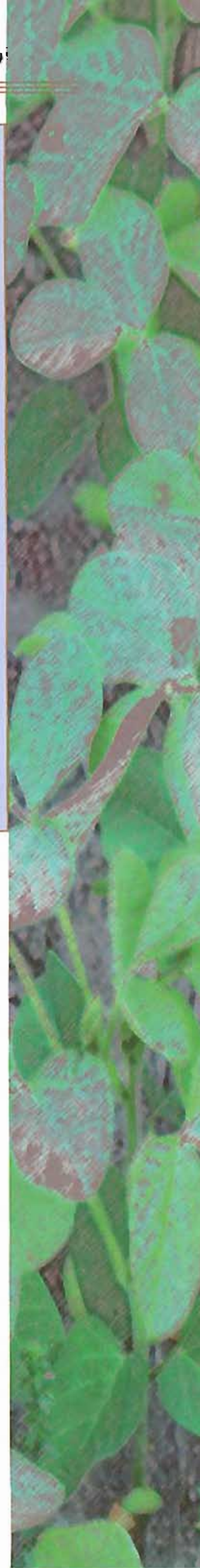
Legumes		Non-legumes	
NR	Berseem clover	A†	Annual ryegrass
A	Crimson clover	A	Barley
A	Mammoth red clover	NR	Buckwheat
A	Medium red clover	A	Oats
A	Sweet clover	A	Oilseed radish
A	White clover	A	Rape/Turnip
A	60/40 mix	A	Rye
A†	Hairy vetch	A	Triticale
NR	Medic, annual	A*	Wheat

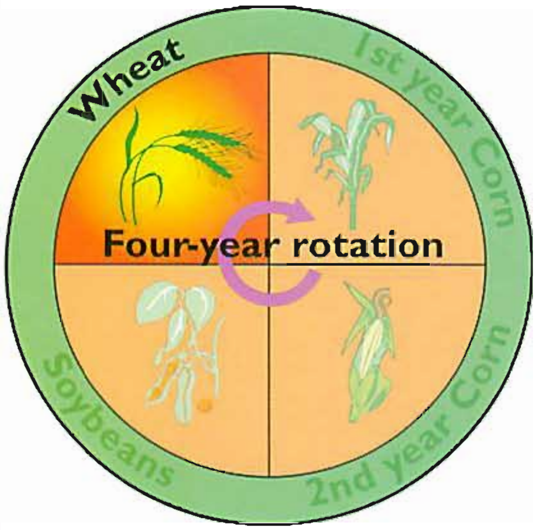
A = Overseeding at leaf drop
NR = Not recommended
† = Not recommended if being planted to wheat
* = After Hessian fly-free date

Wheat seedlings emerging in soybean stubble (corn stubble from previous year).

Rye seeded into soybeans.

Red clover seeded into soybeans.



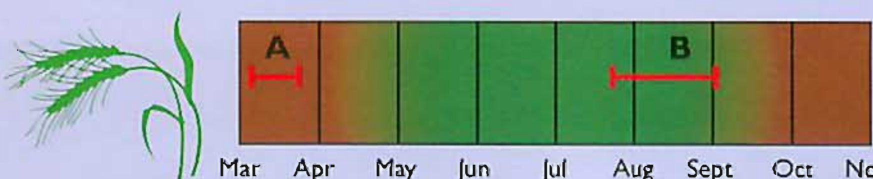


Cover crops in wheat

Wheat offers several cover crop seeding alternatives. Mammoth red clover can be successfully frost-seeded into wheat when spring nitrogen fertilizer is applied. This usually occurs mid-March to mid-April, depending on location. Nitrogen is not necessary for the cover crop, but combining activities reduces the number of trips across the field.

After wheat harvest, farmers have a large window of time for establishing cover crops and managing perennial weed problems. Several cover crops can be successfully drilled into wheat stubble.

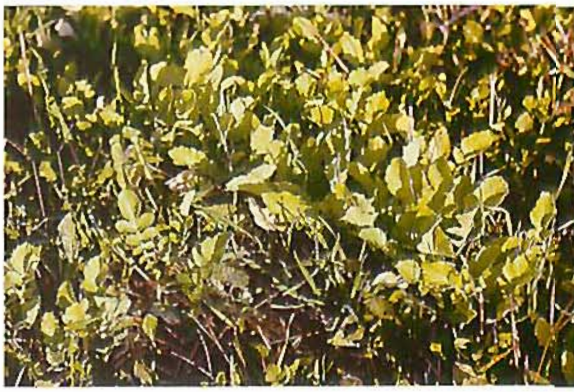
Cover crop options for wheat



Legumes		Non-legumes	
B	Berseem clover	B	Annual ryegrass
B	Crimson clover	B	Barley
A, B	Mammoth red clover	B	Buckwheat
A, B	Medium red clover	B	Oats
B	Sweet clover	B	Oilseed radish
B	White clover	B	Rape/Turnip
A, B	60/40 mix	B	Rye
B	Hairy vetch	NR	Triticale
B	Medic, annual	NR	Wheat

A = Frost seed
B = Seed after harvest
NR = Not recommended

Red clover in wheat.



Oilseed radish in wheat stubble.

Cattle grazing oats sown into an early harvested potato field.

Oats and forage rape in harvested seed potato field.

Once farmers begin incorporating cover crops into their farming systems, they will discover innovative cover cropping strategies. Cover crops fit well with short-season specialty crops (early harvest potatoes, carrots, cucumbers, snap beans, sweet corn and seed corn). In southwest Michigan, farmers have shown that early harvested potato fields can be seeded to cover crops and grazed by livestock.

Economics

What are the economics of using cover crops in field crop systems? Initial studies conducted at KBS compared continuous corn to first-year corn following frost-seeded red clover in wheat. These studies have shown a $40/A gross return minus costs when cover crops were incorporated into a crop rotation.

Costs and returns of first-year corn in a rotation compared with continuous corn*

First-year corn following wheat and red clover cover crop

	Yield or quantity	Price ($)	Dollars/A
Gross returns	158 bu	2.35/bu	371.30
yield @ 15 percent moisture			
Variable costs			
Seed Corn	26,000 seeds/A		24.00
Ryegrass	25 lb	0.30/lb	7.50
Red clover	15 lb	1.00/lb	15.00
Fertilizer	409 lb	0.11/lb	43.28
Bladex 4L	0.5 qt	3.10/qt	1.55
Dual II	0.5 pt	7.01/pt	3.50
Atrazine	0.25 pt	3.051/pt	0.76
Drying			10.00
Fuel	5.42 gal	0.9/gal	4.88
Repairs			6.01
Operating interest			10.00
Total variable costs			126.48
Gross margin (gross return minus costs)			244.82

Continuous corn (no cover crop)

	Yield or quantity	Price ($)	Dollars/A
Gross returns	139 bu	2.35/bu	326.65
yield @ 15 percent moisture			
Variable costs			
Seed Corn	26,000 seeds/A		24.00
Fertilizer	596 lb	0.105/lb	61.78
Bladex 4L	0.5 qt	3.10/qt	1.55
Dual II	0.5 pt	7.01/pt	3.50
Atrazine	0.25 pt	3.05/pt	0.76
Drying			10.00
Fuel	5.42 gal	0.9/gal	4.88
Repairs			6.01
Operating interest			10.00
Total variable costs			122.48
Gross margin (gross return minus costs)			204.17

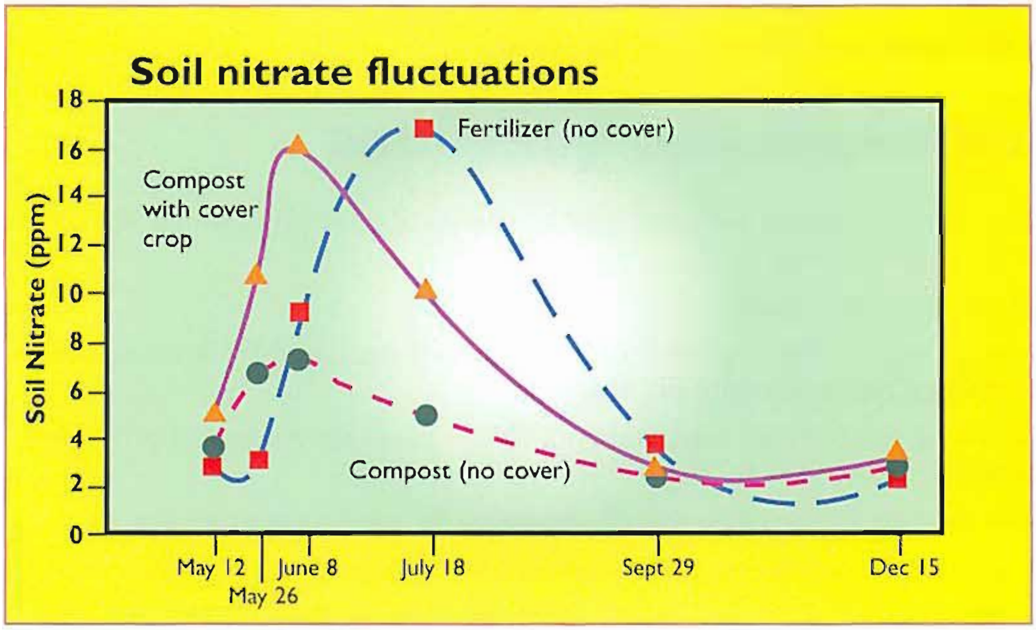
*Third year of rotation study, KBS, 1995

Source: Jones, M., 1996, Ph.D. dissertation, MSU.

KBS studies on corn showed no yield differences between banded herbicide with two cultivations and overseeded cover crops versus broadcast herbicide and no cultivation. The reduced herbicide system requires two cultivations and is more labor intensive, but it also decreases herbicide costs by 67 percent. These savings can often compensate for the added cost of cover crop seed. The long-term economic benefits of cover crops have not yet been calculated, but the value of increased soil biotic diversity, soil quality, soil organic matter, soil erosion control, insect and nematode biodiversity, soil water-holding capacity, aeration and water percolation is certainly important.

Cover crops, soil nitrogen and soil quality

Recent KBS research has shown a dramatic influence of cover crops on soil nitrate dynamics when used in conjunction with composted dairy manure.



Source: Living Field Laboratory, KBS, 1995.

This figure shows that when synthetic fertilizer was applied according to PSNT recommendations, a sharp increase in soil nitrate levels followed. Corn yields were 152 bu/A. Adding a clover cover crop to this system resulted in a slightly earlier increase in soil nitrate and only a slight increase in yield (158 bu/A, curve not shown). When composted dairy manure was the sole added nitrogen fertility source, nitrate levels peaked earlier in the season, but maximum levels were much lower than with synthetic fertilizers, and corn yields were similarly lower (140 bu/A). When cover crops and compost were the only nitrogen sources added to the manure treatment, maximum nitrate levels were much higher than with manure alone, and equal to those with fertilizer. Peak nitrate concentration occurred five weeks earlier and corn yields were higher (169 bu/A).

This effect was not just due to nitrogen, since adding fertilizer earlier in the season does not result in this type of yield increase. The earlier nitrate peak, resulting from mineralization of manure and cover crop nitrogen, may be an indication of soil quality. The cover crop's active roots may have provided a "priming effect," in which microorganisms growing on or near live roots increased manure and soil nitrogen mineralization more than without a cover crop. This possibility is currently being investigated by MSU researchers.

Further progress toward increasing nitrogen efficiency in Michigan row crop ecosystems will require more research on integrated systems, and will involve cooperative efforts between farmers, MSU Extension and research scientists. Incorporating cover crops will undoubtedly be an important component of high-production, nitrogen-efficient agricultural systems in Michigan.

Crimson clover and oats, early December.

Pest ecology and management

George W. Bird and Michael F. Berney

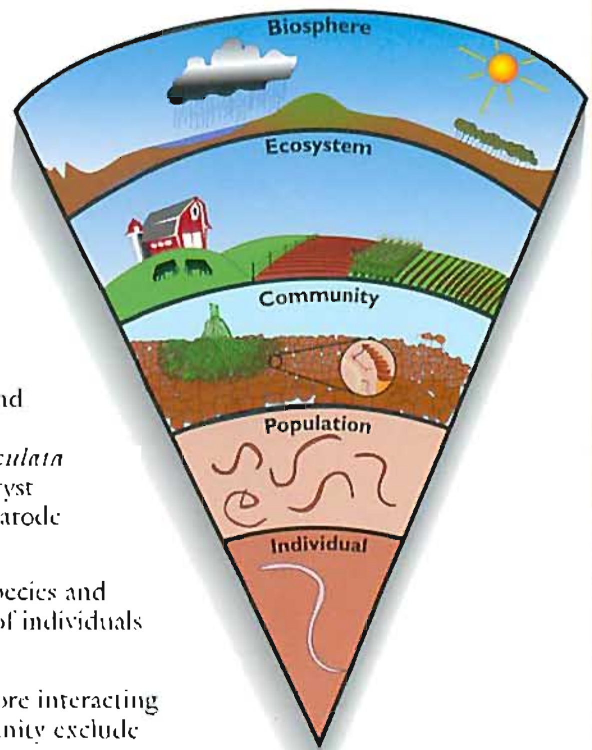
Key concepts and questions

- What is pest ecology? How are species, populations, communities, ecosystems and the biosphere related?
- What is carrying capacity?
- How is the population growth of a pest species regulated by limiting factors such as resource limitations and predation?
- What is integrated pest management (IPM)? How are ecological principles applied in IPM?
- How can the release of beneficial organisms be used to manage pests?
- How can crop biodiversity and crop rotation be used to influence pest ecology?

Additional reading

Bird, G. W., T. Edens, F. Drummond and E. Groden. 1990. Design of pest management systems for sustainable agriculture. In C.A. Francis, C. B. Flora and L. D. King (eds.). Sustainable Agriculture in Temperate Zones. John Wiley & Sons, Inc., New York.

Pest ecology



Ecological pest management is heavily dependent on knowledge of pest biology and ecology. A short introduction to population and community ecology concepts is provided here. Biology specific to insects and nematodes is provided in the following chapters.

Species, populations, communities and ecosystems

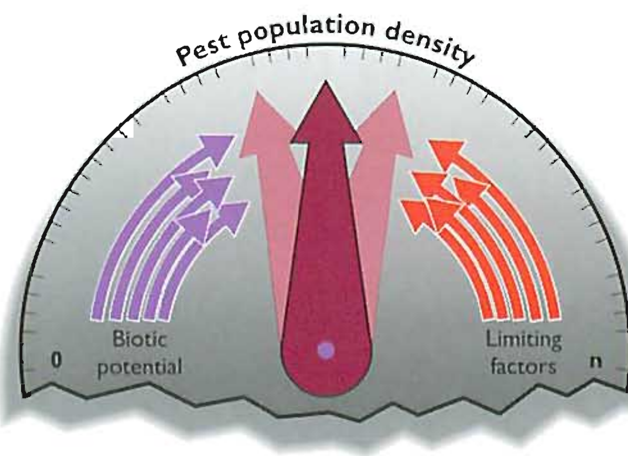
In nature, those organisms capable of reproducing and producing viable offspring are members of the same **species**. The twelve-spotted ladybug (*Coleomegilla maculata lengi*) is an example of an insect species. The soybean cyst nematode (*Heterodera glycines*) is an example of a nematode species.

Populations are groups of individuals of the same species and are often expressed as **population densities** (number of individuals per area or volume).

Populations usually exist in **communities**, two or more interacting populations. The definitions of population and community exclude associated abiotic (nonliving) factors. The abiotic system components are included in the concept of **ecosystem**. The **biosphere** includes all the world's ecosystems.

Carrying capacity and population density

Carrying capacity is a species' population density that an ecosystem can support over a long period of time. The carrying capacity of an ecosystem is determined by the species' **biotic potential** (reproductive rate, ability to migrate, ability to invade new habitats, defense mechanisms and ability to cope with adverse conditions) and the resource availability in the ecosystem. Actual **population density** is almost always lower than carrying capacity due to the constraining effect of **limiting factors** (lack of food, nutrients, water or suitable habitat; or ability to cope successfully with predators, disease, parasites or competitors).



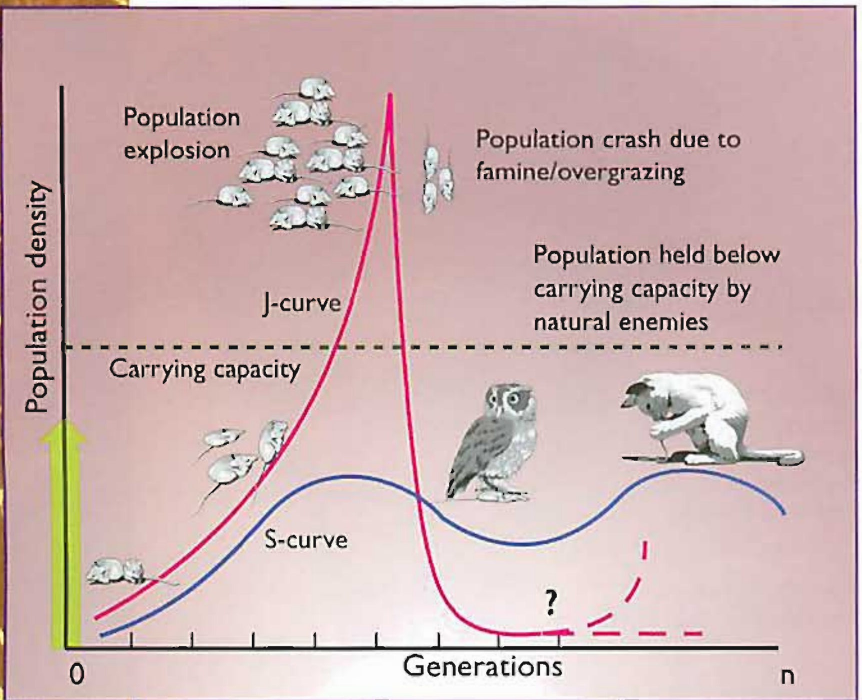
Biotic potential

- Reproductive rate
- Ability to migrate (animals) or disperse (seeds)
- Ability to invade new habitats
- Defense mechanisms
- Ability to cope with adverse conditions

Limiting factors

- Lack of food or nutrients
- Lack of water
- Lack of suitable habitat
- Adverse weather conditions
- Predators
- Disease
- Parasites
- Competitors

Source: Environmental Science, 5th Ed., B. J. Nebel, R. T. Wright. © 1996, adapted with permission of Prentice-Hall, Inc., Upper Saddle River, N.J.



Growth limits

When an organism lives in an optimal environment with no limiting factors, its population growth potential depends on its **biotic potential** and can be represented by a **J-shaped curve**. When the population exceeds carrying capacity, a population crash may occur. This situation rarely occurs in nature. A specific organism's population growth potential is usually constrained by one or more limiting factors including predators or resource limitations. In this case, population growth is represented by an **S-shaped curve**.

In natural ecosystems, herbivores spend their time searching for food. In field crop ecosystems, the crop provides a plentiful and readily available resource for pests because humans concentrate production in large fields for efficient harvesting.

This situation favors pests that normally have high reproductive potential. The carrying capacity of field crop ecosystems for these pests is very high and pests can reach numbers that can cause economic damage.

Approaches to pest management

Pest biology was reasonably well understood by the 1920s. Biological, cultural, chemical, physical, genetic and regulatory pest control procedures were used. Research activities associated with both World Wars led to the discovery, development and common use of synthetic organic pesticides. There were, however, unexpected consequences associated with increasing pesticide use, including:

- Development of pest resistance to pesticides
- Chemical contamination of the environment
- Acute and chronic human health risks
- Harm to non-target beneficial organisms
- Pesticide-induced evolution of new key pests
- Pest population density resurgence

As a result, the U.S. Council on Environmental Quality reviewed these phenomena in a 1972 publication entitled "Integrated Pest Management." **Integrated Pest Management (IPM)** was defined as, "A systems approach to reduce pest damage to tolerable levels through a variety of techniques, including predators and parasites, genetically resistant hosts, natural environmental modifications, and when necessary and appropriate, chemical pesticides." IPM consists of designing, using and continually evaluating pest control procedures. It requires a thorough understanding of each pest and its associated ecosystem.

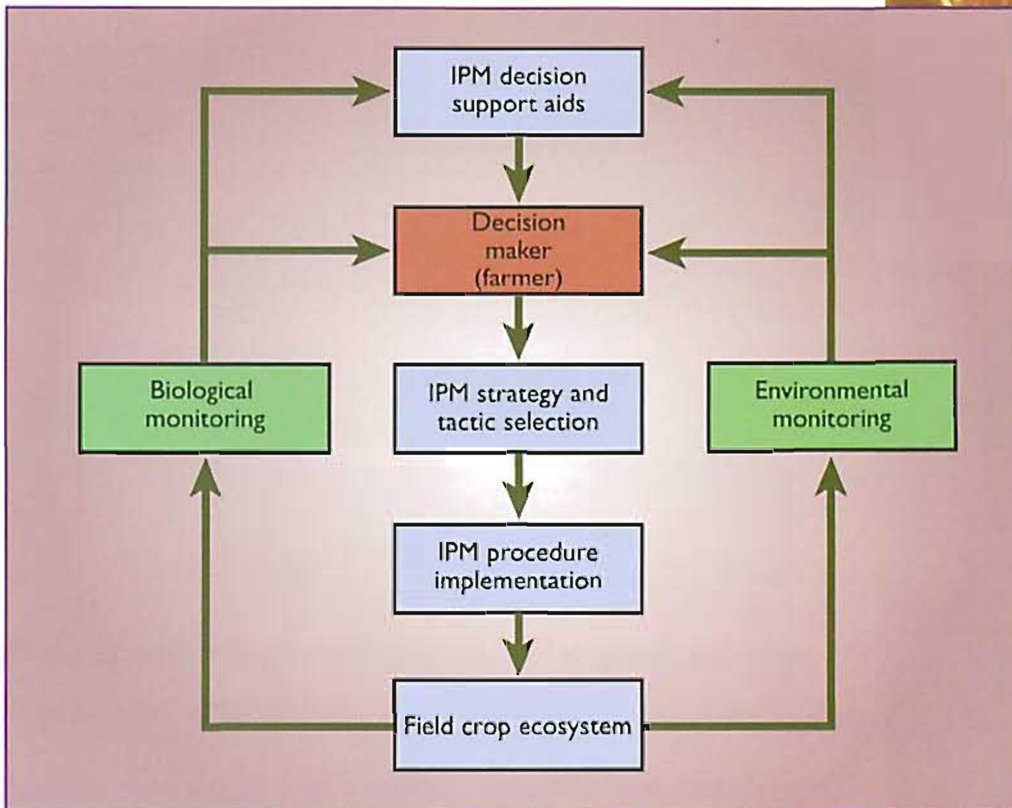
In June 1993, the President pledged "to help agricultural producers implement IPM methods on 75 percent of total crop acreage by the year 2000," and on December 14, 1994, the United States Department of Agriculture announced a "National Plan to Increase the Use of IPM."

The IPM process

IPM can be described as a cyclical process comprising seven interactive components.

The field crop ecosystem

The field crop ecosystem consists of all of the components and interactions discussed in the chapters on Field Crop Ecosystems and Soil Ecology.



Production system manager/decision maker (farmer)

The production system manager or decision maker is responsible for overall system quality and the success or failure of IPM programs.

Biological monitoring

Biological and environmental monitoring are essential knowledge intensive components of the IPM process. Biological monitoring, also called scouting, consists of comprehensively evaluating pest presence and population density, determining crop or livestock status and analyzing the nature and population density of associated beneficial organisms.

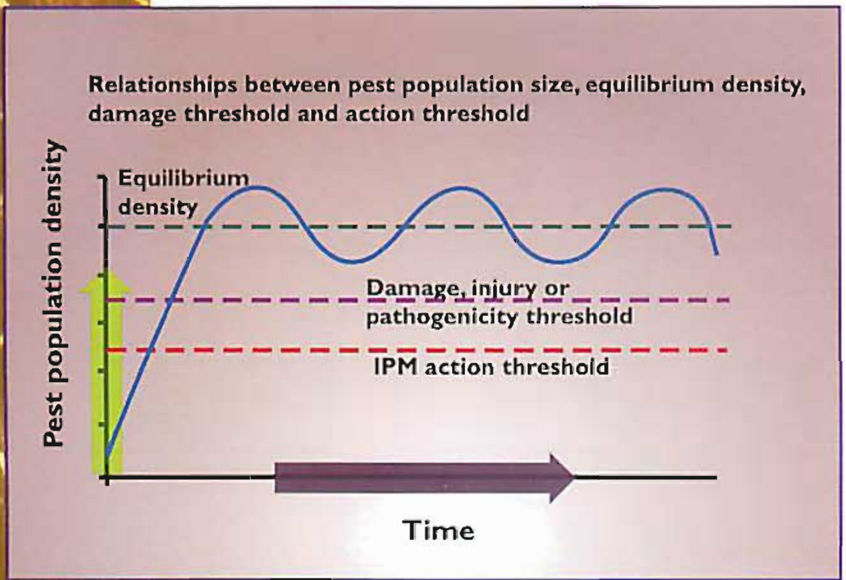
Environmental monitoring

Since the system's biotic components are driven by its abiotic elements, comprehensive environmental monitoring is imperative. Temperature, rainfall and relative humidity are examples of abiotic components of the environment monitored in IPM programs.

Decision support aids

Biological and environmental data are either directly available to the farmer or available through various IPM decision-support systems. Examples of IPM decision support aids include pest scouts, crop consultants or a computer program.

Trap/field monitoring.



The concept of **thresholds** is a fundamental IPM aspect. If the population density exceeds the **damage, injury** or **pathogenicity threshold**, crop loss will already have taken place. The **IPM action threshold**, therefore, is at a lower pest population density, and designed to prevent crop loss if tactics are implemented in an appropriate and timely manner.

IPM strategy, tactic selection and procedure implementation

Data from biological and environmental monitoring are used to select appropriate IPM strategies and tactics and determine the most appropriate implementation procedures.

IPM strategies consist of the way the production system manager or decision maker approaches a potential or existing pest problem. Fundamental IPM strategies can be divided into the following four categories:

- Pest avoidance or exclusion
- Pest containment or eradication
- Pest population reduction
- No action at the present time

A diversity of pest management tactics are available for use under the first three IPM strategies. Particular tactics are specific to the pest of interest and are addressed in more detail in the following two chapters. In general, tactics can be classified into one of the following five categories:

- Biological
- Genetic
- Chemical
- Cultural
- Regulatory

Because the IPM process is **cyclical**, once an IPM tactic has been implemented, biological and environmental monitoring must be continued to determine if the implemented action resulted in the desired ecosystem response, or if an additional IPM tactic is required.

The following chapters on insects and nematodes are designed to provide a basic understanding of the biology of these organisms in relation to their associated ecosystems, potential as pests and possible implementation of the practices, systems and concepts of IPM, especially those focused on managing field crop biodiversity and crop rotation.

Pests, with which humans have always competed for food, feed and fiber, include weeds, vertebrates, arthropods, nematodes, fungi, bacteria and viruses. Due to limited space, we present only information about insect and nematode biology in this document, but the principles of IPM are applicable to all pest types.

The Insect Community

Manuel Colunga-G., Stuart H. Gage and Lawrence E. Dyer

Key concepts and questions

- Some insects are herbivores, some are predators, and others are parasitoids. How do these different components of the insect community interact with other ecosystem components?
- What are beneficial insects? How do predators differ from parasitoids?
- How do weather and management influence insect populations?
- What are the different scales of complexity in field crop ecosystems? How do plant architecture, growth, succession, diversity, crop rotation, landscape structure, function and change affect beneficial insect activity?
- How can management of structural complexity and diversity favor beneficial insect activity?

Additional readings

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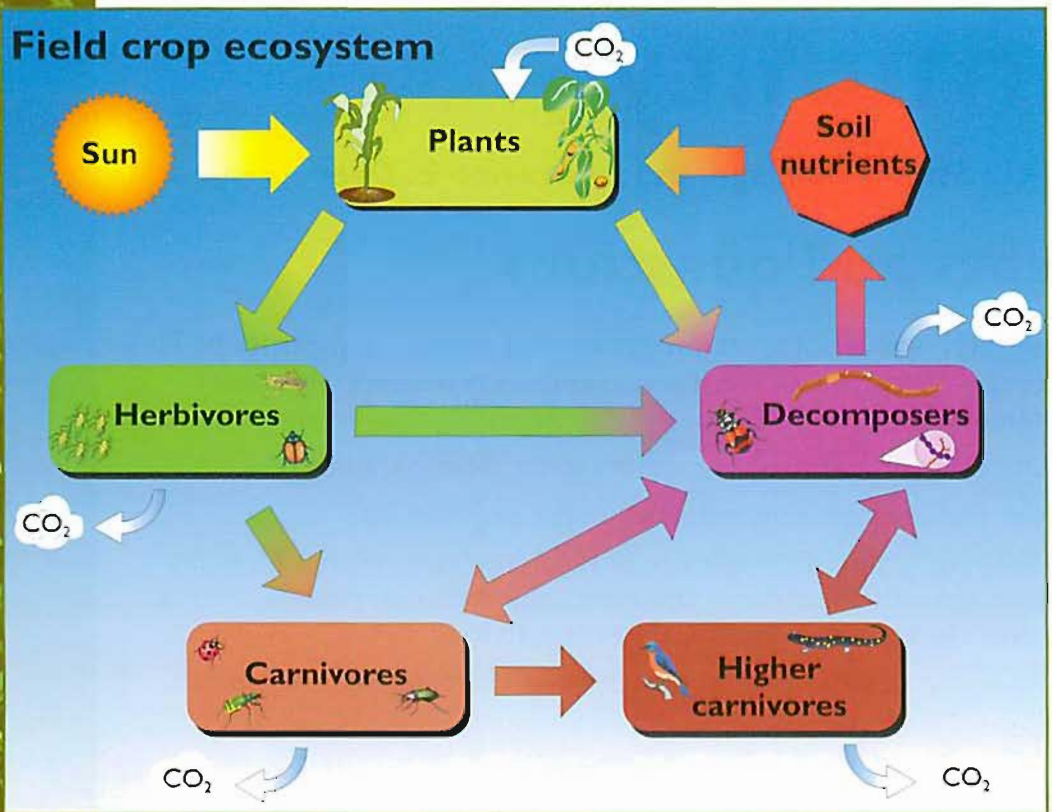
Why are insects important?



The basic components and interactions within field crop ecosystems are outlined in this diagram.

Insects are six-legged organisms that play an important role in the function of many ecosystems. More than one million insect species exist worldwide. The majority are **beneficial** in human-managed ecosystems and only a small fraction are pests.

In agricultural ecosystems, farmers are very familiar with insects, primarily because of the economic damage that some pest species can cause. Volumes of information have been produced regarding plant resistance, importation, augmentation and release of beneficial insects. Descriptions of these and other pest management practices are found in other MSU Extension bulletins.

In this chapter, we focus on the implications for the insect community of biologically managing field crop ecosystems. Practices such as **crop rotation** and **cover crop** use increase the **complexity** of crop ecosystems with a subsequent impact on insect/plant interactions.

Navy beans.

Source: Howell, NRCS.

Plants

In the energy flow that occurs within the trophic system, plants are important to insects because they provide them with both **habitat** and **food sources**.

Herbivores

In field crop ecosystems, herbivores may be vertebrates (rodents, birds), **invertebrates** (mites, insects) or **pathogens** (virus, bacteria, fungi). In most cases, herbivores share crop resources with farmers without causing significant damage. In fact, most herbivores are not considered pests, and in some cases, they can be beneficial since they feed on weeds. There are, however, a few cases when herbivores can reduce yields significantly. When herbivores are economically important they are called **pests**, and management schemes aimed at reducing their population density need to be implemented.

Tarnish bug (above). Corn rootworm adults (r).

Carnivores: beneficial predators and parasitoids

Many carnivores are well known to farmers. Carnivores such as eagles, owls, hawks, foxes and coyotes help maintain the equilibrium of ecosystems by regulating the numbers of herbivores such as mice, rats and groundhogs.

In field crop ecosystems, there are organisms less well known to farmers that feed on insect herbivores. These natural enemies prevent pests from reaching outbreak levels. These beneficial organisms are classified into two major groups: **predators** and **parasitoids**. Both groups are biological control agents that are important in regulating herbivore numbers in the field. There are, however, some major differences in the biology and behavior that separate predators and parasitoids. These are highlighted in the boxes below.

In agricultural ecosystems, natural enemies are at a disadvantage because the pests have a readily available food source (crop), while natural enemies have to search through the plants to find their prey (pests). A thorough understanding of how natural enemies interact within the field crop ecosystem can allow farmers to introduce management practices that encourage beneficial insect activity.

Predators

In most species, both immature and adult predators feed on prey.

One individual feeds on many prey during its life time.

Most predator species are generalists (feed on many different prey species).

Ground beetle.

Parasitoids

In most parasitoid species only immature stages feed on prey.

One individual (the larva) feeds on one prey during its lifetime. The adult, however, leaves many prey parasitized during its lifetime.

Most parasitoid species are specialists (feed on a limited range of species).

Weather and management influence insect populations

Weather system moving through the Great Lakes region.

Source: ©1997, reprinted by permission of The Living Earth, Inc./Earth Imaging, Santa Monica, CA 90404.

Weather

Weather regulates biological activity and has important effects on field crop ecosystems. **Temperature** and **precipitation** influence crop growth and development and, therefore, the timing of planting, harvesting and other agricultural practices. **Wind** affects the timing of pesticide applications and influences evapotranspiration (which can reduce the availability of water for plants).

Insects, too, are affected by weather. Warm temperatures increase insect activity and speed up their development. In an unusually warm summer, the number of insect herbivore generations will be high and may result in decreased crop yields. On the other hand, very cold winters, precipitation and wind can cause high insect mortality. Wind also helps disperse insects. The potato leafhopper, an important pest of alfalfa, migrates on atmospheric currents from the Gulf Coast to Michigan every spring.

Alfalfa harvest.

Potato leaf hopper, nymphs and adult.

Source: Marc Sulc, Ohio State University

Pesticide application in second year corn.

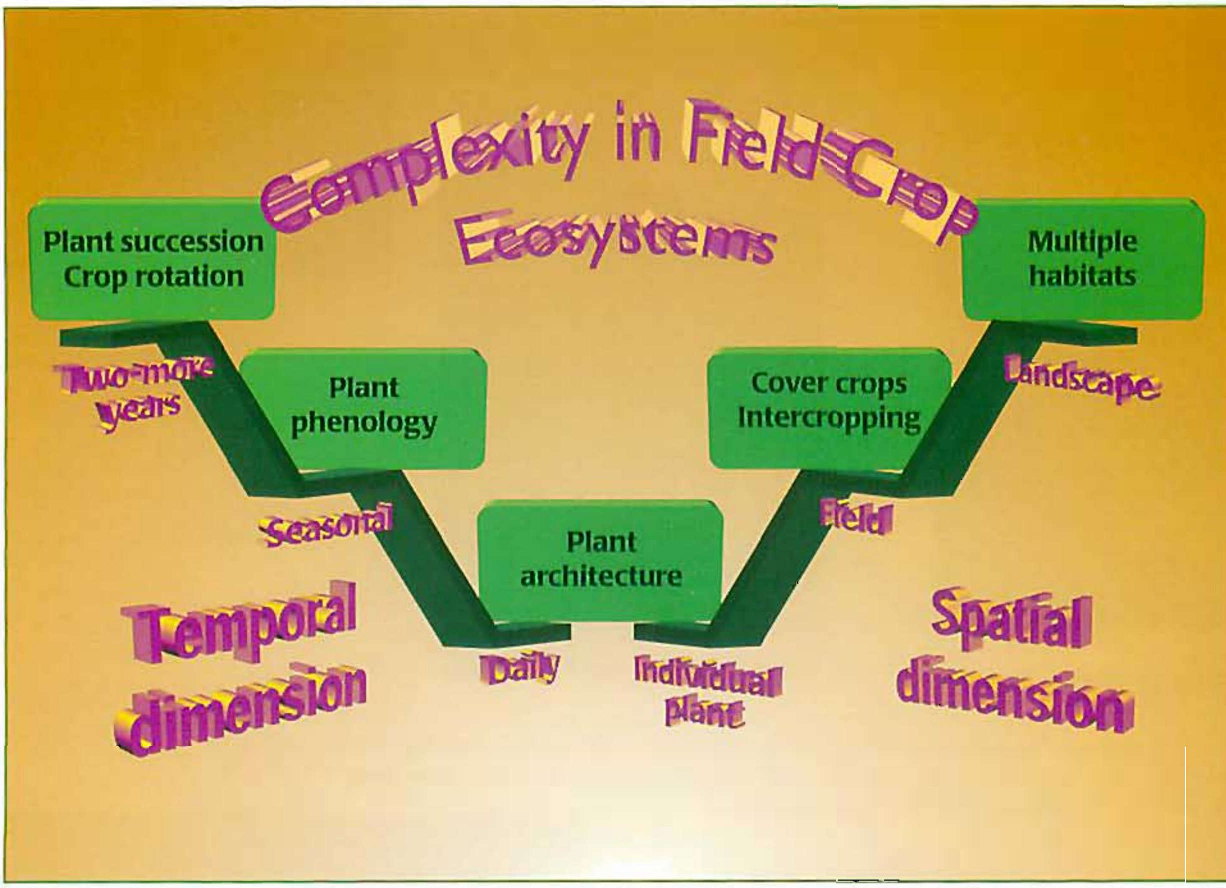
Management

While farmers depend upon weather and other natural processes, management also influences insect populations. Management has both **direct** and **indirect** effects. For example, if a farmer applies pesticides to control an insect pest, a direct result is that insects die. What may be less obvious is that only susceptible individuals in the population die, leaving pesticide-resistant survivors. A pesticide application may also kill beneficial organisms, such as natural enemies or pollinators. Beneficial insect numbers are also reduced when trees and fencerows are removed, since vegetation provides shelter and alternate food sources.

It is important to design pest management strategies that minimize negative impacts on the field crop ecosystem, yet allow farmers to meet their economic goals.

Scales of complexity and the insect community

Management has a large influence on field crop ecosystem complexity. Ecologically based field crop ecosystem management increases diversity and focuses on interactions between system components that improve ecosystem stability and resilience. The system's diversity and structural complexity have important implications for the insect community. The next five pages will address different scales of complexity that we find in ecologically managed systems, and will emphasize management decisions that favor the natural regulation of insect pests using beneficial insects.

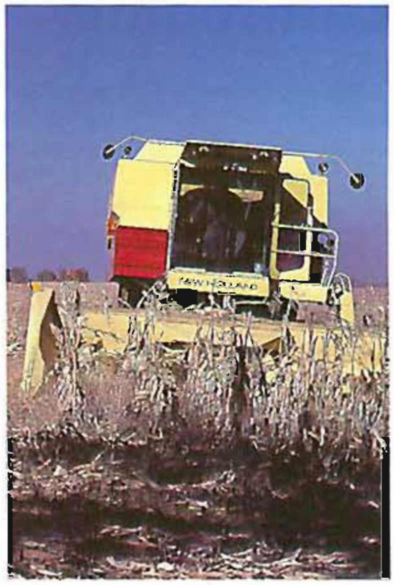


Plant architecture

A plant's structure and chemical composition significantly affect which insect will eat it. Insects that live in trees are different from those that live in bushes or those that inhabit grasses. In agricultural crops, the plant can deter or attract insects. The selection and use of resistant varieties in field crop ecosystems is based on this fact. For example, alfalfa varieties with long, glandular hairs are more resistant to alfalfa weevil.

Plant growth

As crops grow and change during the season, so do insects. Insects synchronize their development with the development of the plants they prefer. Examples of management strategies that take this into consideration include: 1) monitoring for important pests such as the European corn borer or the corn rootworm at critical times, 2) cutting alfalfa when the alfalfa weevil egg stage peaks, 3) releasing purchased beneficial insects during a pest's susceptible stage and 4) changing wheat planting time to minimize Hessian fly impact.



Plant diversity

If plant growth changes the vegetational structure of the field over time, plant diversity changes the structure of the field in space. Significant changes can occur within a field if another plant species is added into the system.

Hairy vetch.

This additional plant could be another crop (intercropping), a cover crop or single companion weed. Cover crops that are used to add nitrogen to the soil can also serve as an important refuge for beneficial insects. Planting grasses in alfalfa, for example, can deter potato leafhopper.

Crop rotation

Some important pests have a special preference for particular crops. The **corn rootworm**, for example, deposits eggs in the soil in corn fields. The eggs overwinter and hatch the next season. Planting the same crop in a field year after year fosters higher numbers of rootworms. Crop rotation reduces rootworm numbers since succeeding generations will not find their preferred host in the same field. They must either disperse to new fields or die.

Some beneficial insects, such as the **twelve-spotted ladybird beetle**, are more abundant in corn than in soybeans. In this case, rotation will make the number of this species fluctuate every year. As discussed in the Field Crop Ecosystems chapter, rotation also has beneficial effects on many other system components.

Landscape diversity

In farm fields, interactions occur between plants, pests, beneficial insects and the weather. However, the population dynamics of most insects are influenced by factors that extend beyond the boundaries of individual fields. For those insects, the landscape and not the field is their domain. If we zoom out and look at the landscape level, we see that adjacent to crop fields there are rivers, lakes, other crops, forest patches, abandoned fields and houses. Three landscape characteristics are important to ecosystems: structure, function and change.

Landscape

A land area composed of a cluster of interacting ecosystems.

Landscape structure	Landscape function	Landscape change
The spatial relationships among the distinctive ecosystems or elements present.	**The interactions among the spatial elements.**	**The alteration in the structure and function of the ecological mosaic over time.**

Landscape structure

Agricultural landscapes are usually highly fragmented, with non-agricultural patches interspersed among crop fields. Surrounding vegetation plays an important role in the dynamics of a field's insect community. Many pests move readily from one field to another so that pest management success may depend on what is in nearby fields. Pest management practices should therefore consider landscape structure.

Source: Howell, NRCS.

Landscape function

Beneficial insects can also move from field to field. For example, ladybird beetles, key beneficial insects in field crop ecosystems, occur early in the season in alfalfa or wheat, and later move to corn or soybeans. Nearby patches of non-crop vegetation are especially important for beneficial insects because many spend some stage of their life cycle in areas outside crops. Uncultivated patches present alternate food sources. Some insects, including ladybird beetles, use these patches during the winter and return the next year to crop fields.

Landscape change

All landscapes have seasonal changes that are regulated by weather, though the structure of agricultural landscapes is highly dynamic due to intense human activity. Planting, cultivating, harvesting, plowing and spraying all change landscape structure and function.

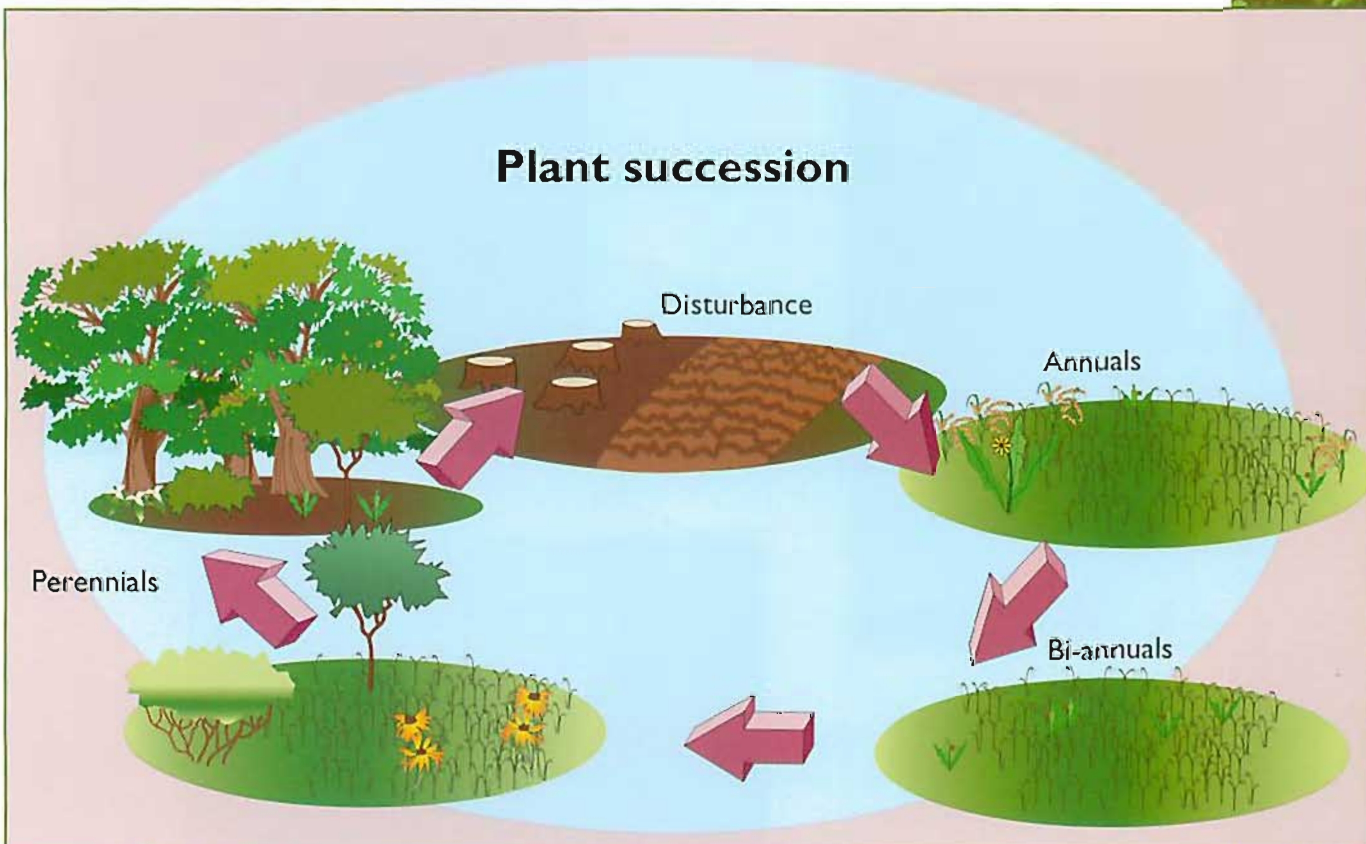
Although the complexity that emerges from landscape diversity may seem overwhelming, its impact cannot be ignored. Managing a landscape requires cooperation between farmers, scientists and government agencies. For example, public and private organizations monitor insect pest populations and activities in numerous locations. Farmers can use this information to guide their management decisions.

Source: Howell, NRCS.

Plant succession

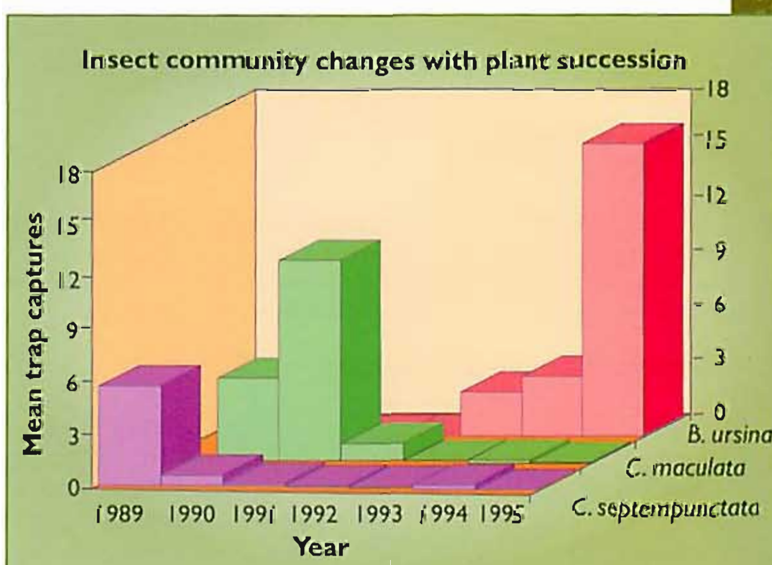
Landscape structure changes with crop development and crop rotation. Landscape structure is also affected by the changes that occur in non-agricultural patches. For example, old field and forest patches also change with the seasons and across years. Change in plant species composition that occurs with time is called plant succession.

In early succession, species that rapidly colonize disturbed areas predominate. These are mostly annual herbs and grasses. As succession proceeds, herbaceous perennials, shrubs and small trees prevail. Later stages are dominated by large, long-lived trees (oak, hickory, maple and others).



The insect community also changes as succession takes place. For example, the species of ladybird beetle that dominates a poplar habitat changes as the stand develops. The first year that trees are planted, *Coccinella septempunctata* is the dominant species. *Coleomegilla maculata lengi* dominates the following three years. Finally, *Brachiacantha ursina*, a species typical of woodlots, becomes the dominant species.

Therefore, the successional stage of ecosystems within the landscape will influence population densities of beneficial insects.



Successional fields are important to the beneficial insect community. The plants in these fields are inhabited by insects that provide alternate food for beneficial insects, and the plants themselves can provide nectar and pollen. Non-crop sites provide shelter for beneficial insects after a disturbance in the field crop ecosystem (e.g. harvest, herbicide application, etc.), so maintaining edges of uncultivated habitats in the landscape is important for regulating pest populations.

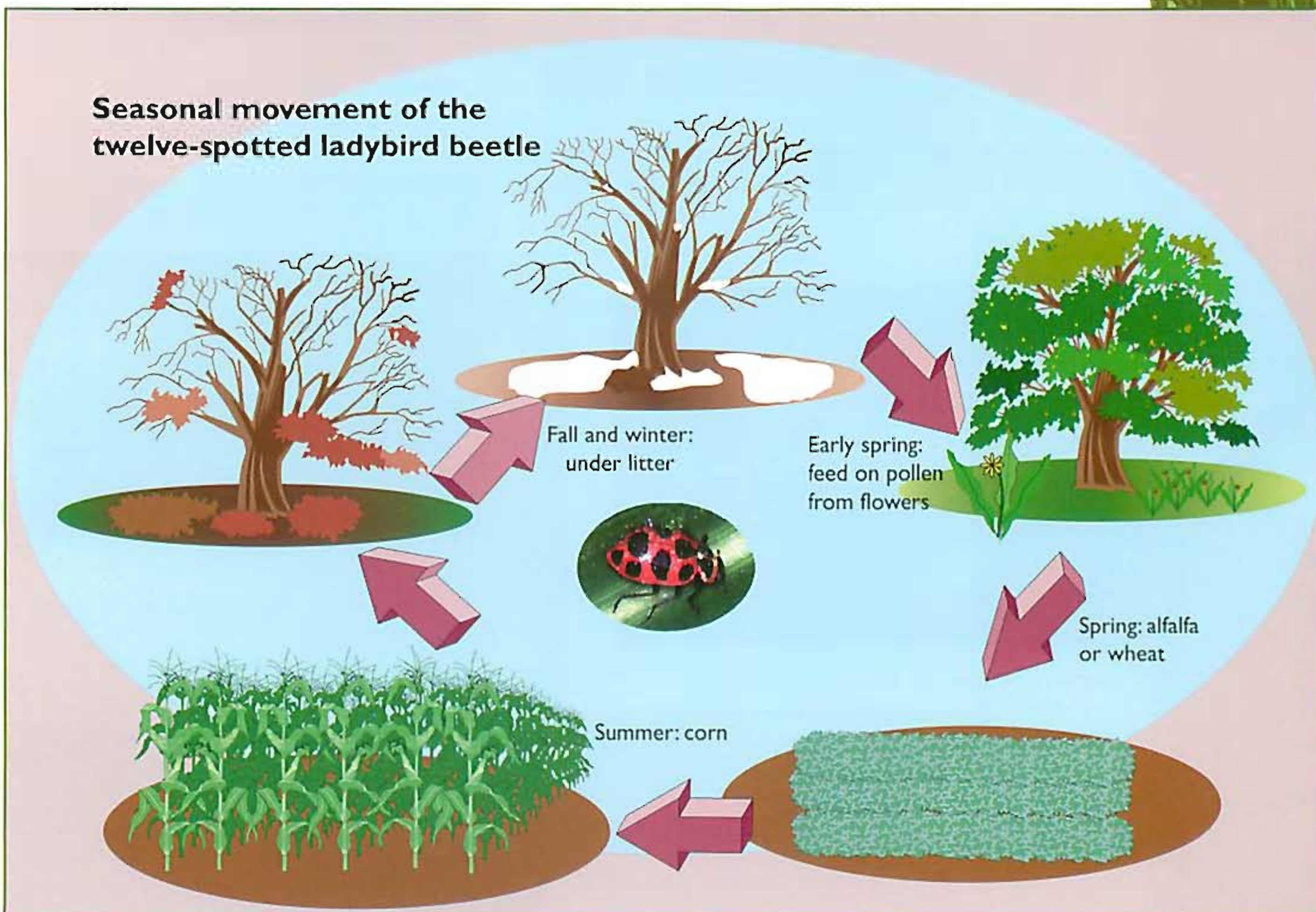
Examples

Uncultivated habitats such as forest patches and undisturbed field borders are important to beneficial insect dynamics. Current information does not yet allow us to determine the number of trees or uncultivated patches that maximize biological control. Nevertheless, we do know that these resources are important components of field crop ecosystems and landscapes.

Twelve-spotted ladybug

The twelve-spotted ladybug *(Coleomegilla maculata lengi)* is an important Michigan ladybird beetle species. It is present in most field crops and feeds on aphids during its larval and adult phases. If prey is scarce, adults can also feed on pollen from other plants, such as corn.

When fall arrives, adults of this ladybird beetle species move to hibernation sites in forest patches, clusters of trees or even individual trees. They aggregate in colonies of hundreds of individuals under the litter, which protects them from the cold. Snow insulates them further. When spring arrives, the insects become active and feed on the pollen produced by spring flowers in nearby hibernation sites. In Michigan, dandelion is a dominant plant at this time of the year, and it is an important food source for the adults. As the weather warms up, adults disperse to agricultural fields and reproduce. Adult and larval stages feed on early pests in crops.



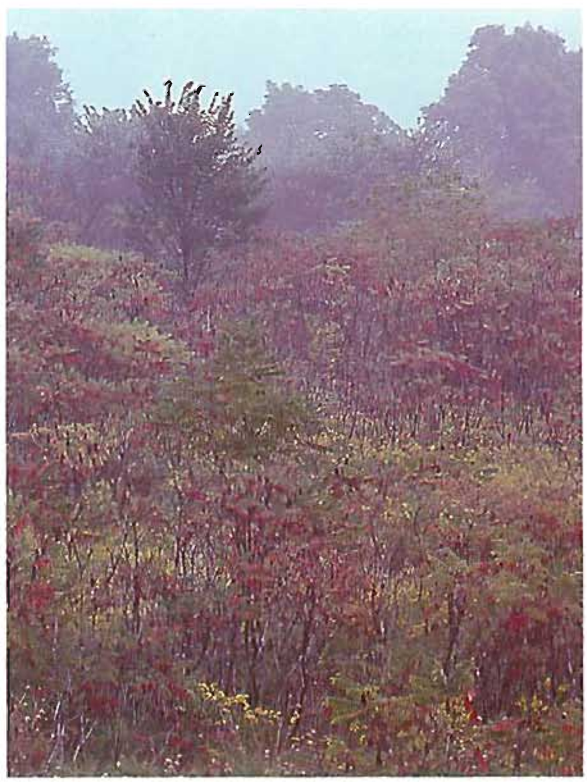
Trees that provide shelter are very important for the survival of this species during the winter. Pollen from spring flowers, such as dandelion, is a critical food source prior to dispersal to crop fields. In some cases, when crop fields are adjacent to forest patches, dandelion flowers close to the trees are destroyed during spring plowing. This destroys an important food source for beneficial insects.

A parasitoid wasp, *Eriborus terebrans*

Eriborus terebrans, a parasitoid wasp, is one of the natural enemies of the European corn borer in Michigan landscapes.

For *E. terebrans*, as well as for other parasitoids, the larval stage is the only one that feeds on herbivores. The adult searches for its preferred host (in this case, European corn borer larvae) and deposits an egg inside the larva. This egg hatches and the parasitoid larva feeds on the pest larva. The adult, however, does not feed on the pest. Instead, adults feed on nectar produced by wild flowers. Adults also need shelter for protection from high summer temperatures. Both food and shelter are provided by forest patches located at corn field edges.

Nectar, produced by flowers such as the Queen Anne's lace, constitutes prime food for parasitoid adults.



Clearly, leaving forest patches within the agricultural landscape will help the population size of the twelve-spotted ladybug and *Eriborus terebrans* and could help control aphids and European corn borer, respectively.

Nematodes

Michael F. Berney and George W. Bird

Key concepts and questions

- What are nematodes and what impacts do they have on humans?
- What are the different types of nematodes? What roles do nematodes play in ecosystems?
- What is the difference between ectoparasites, migratory endoparasites and sedentary endoparasites?
- What are necrotic, hypoplastic and hyperplastic disease symptoms caused by plant-parasitic nematodes?
- How can plant parasitic nematode damage be avoided and managed?
- How can field crop biodiversity and crop rotation influence plant parasitic nematode population sizes?
- How can soybean cyst nematode damage severity be reduced using field crop ecosystem biodiversity and crop rotation?

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Mai. W. F., 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, New York. 227 pp.

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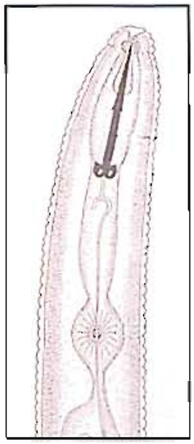
What are nematodes?

Nematodes are roundworms that interact directly and indirectly with humans and other animals, plants and microorganisms. They are classified in the animal phylum Nemata, and are best known for causing infectious disease in plants and animals, but they also play an important role in soil and crop ecology. Nematodes are present on all farms in soils, plants and animals. Nematodes feed on and interact with many soil-borne microorganisms, such as fungi, bacteria and protozoa. Many beneficial nematodes serve as biological pest control agents in managed systems and others play important roles in regulating natural ecosystems and nutrient cycles.


Source: R. Ingham.

Head region of a plant parasitic nematode (herbivore).

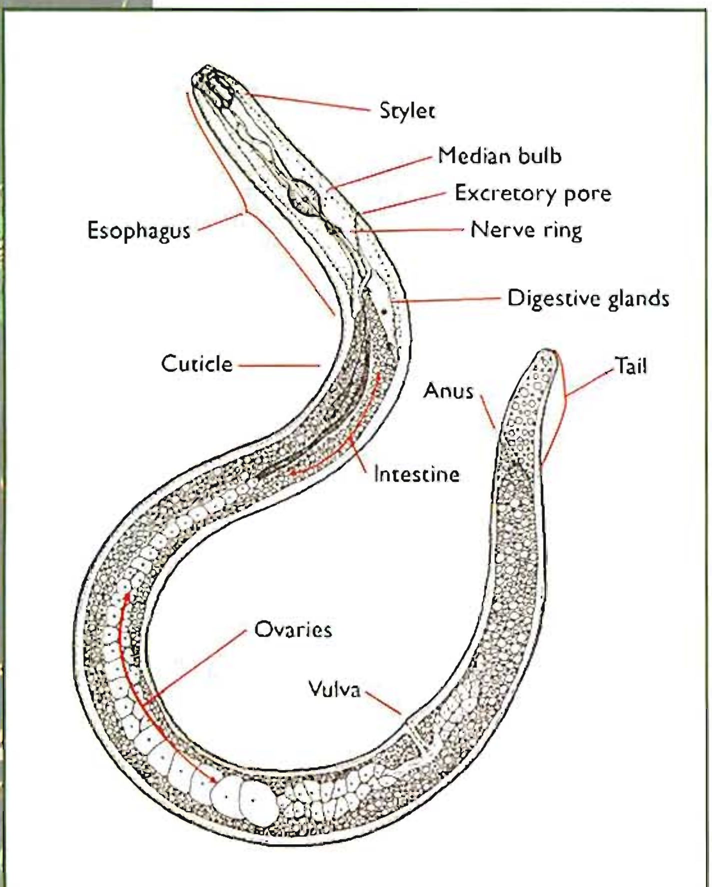
Impact on humans

Nematodes impact humans directly by causing infectious diseases, or indirectly by damaging crops, livestock, and other plants and animals, such as pets and ornamentals.

Direct impacts

Trichinosis is probably the most widely known human disease caused by nematodes. Although most people know the danger of eating raw pork, few understand that this is to avoid an infectious disease caused by a nematode.

Hookworms are nematodes that cause infectious human diseases. On a global basis, these diseases rank among the four most important factors contributing to human suffering.



Indirect impacts

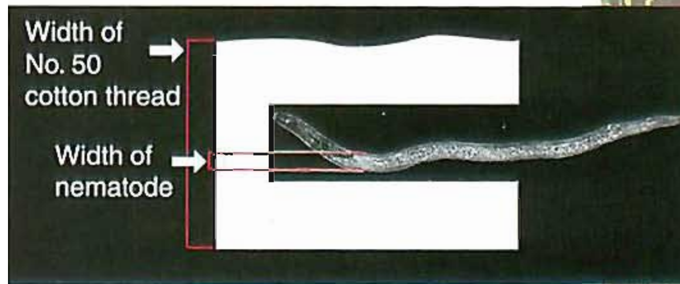
Nematodes impact agriculture by parasitizing crops and livestock, preying on bacteria, fungi and protozoa, and vectoring plant pathogenic viruses. As plant or animal parasites, nematodes cause infectious diseases. Two important examples in Michigan are the soybean cyst nematode and the dog heartworm. When they prey on other soil organisms, nematodes help accelerate rates of decomposition and nutrient cycling. Some entomopathogenic nematodes (insect pathogens) harbor bacteria found only in their intestines. These bacteria produce chemicals that are highly toxic to insects.

Nematode biology

Nematodes have a head (anterior end) and a tail (posterior region). They have well-developed nerve and reproductive systems, and are considered the most primitive animal with a complete digestive system.

Size

The adults of most nematode species remain microscopic, while others grow to more than a foot in length.

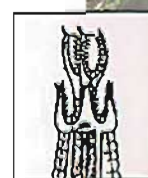


Habitats

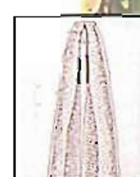
Nematodes live in water. Any ecosystem containing water can be a suitable environment for nematodes, including plant tissue, animal tissue, decomposing organic matter, soil, lakes, streams, rivers and oceans.

Feeding

Nematodes live as **herbivores** or **carnivores** (both predators and parasites). As predators, they feed on other organisms, such as bacteria, protozoa, fungal spores, small invertebrates and other nematodes. As **parasites**, nematodes feed on most plant and animal species, including humans. Some feed as ectoparasites and attach themselves to the outside of a host. Others feed as endoparasites and live within their host.



Head region of a bacterial-feeding nematode (bacterivore).

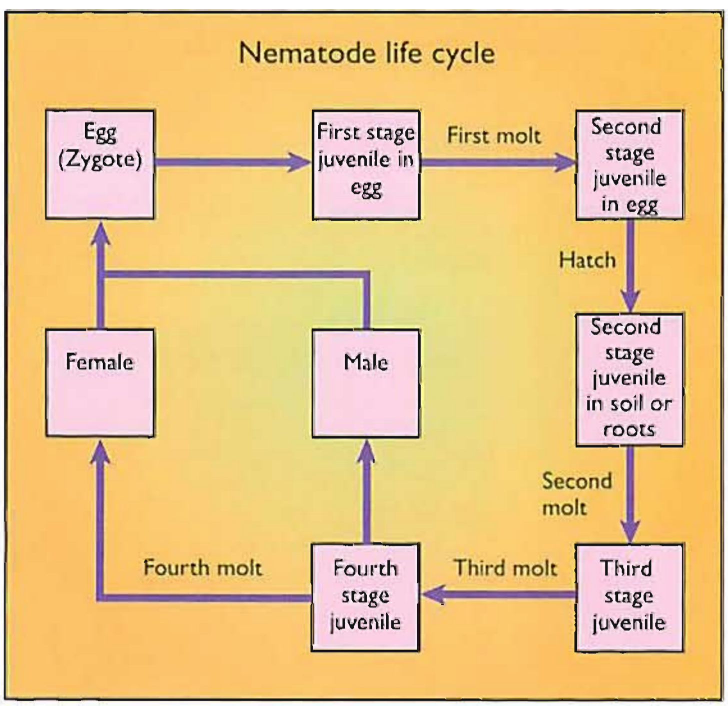


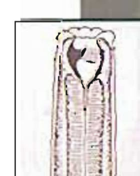
Head region of a fungal-feeding nematode (fungivore).

Source: R. Ingham

Reproduction

Many nematode species reproduce sexually, while others reproduce through a variety of alternative mechanisms. The general life cycle of a nematode consists of the zygote or fertilized egg, four juvenile stages and adult males and females. Nematodes molt or shed their exterior skin (cuticle) four times, once between each of the life stages.





Head region of a predacious nematode (carnivore).

Source: R. Ingham

Ecology

If a nematode community is diverse and contains many species, there is a high probability that no one species will be at an extremely high population density. This is considered a balanced and **biologically diverse community**. An old field that has not been disturbed for many years and is in the process of succession is likely to have this type of nematode community structure. If few nematode species are present, it is likely that one or more of these will exist at a high population density.

Research has found that nematode community structure varies among different cropping systems. The ratio formed by dividing non-plant parasitic nematode numbers by plant parasitic nematode numbers was highest for a transition organic rotation of corn, corn, soybeans and wheat. The ratio was lowest for a conventional system involving the same crops. The nematode community structure index was intermediate for two other systems with intermediate biological diversity. These results suggest that the ratio of non-plant parasitic to plant parasitic nematodes may be a useful indicator of ecosystem health, with high ratio numbers indicating a more healthy ecosystem. This research is on-going and future results will help determine if this pattern is consistent over time.

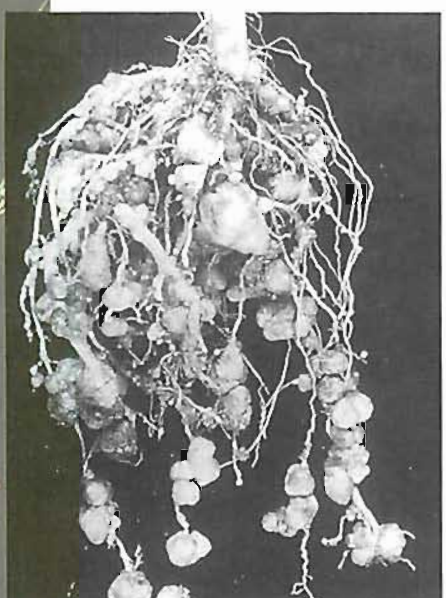
Nematode community structure index*

System	Ratio
Conventional tillage system	1.70
Integrated fertilizer	2.42
Integrated compost	5.66
Transition organic	7.33

* Population density of non-plant parasitic nematodes/population density of plant parasitic nematodes on May 26, 1996 at the Living Field Laboratory, KBS.

Plant parasitic nematodes

Most plant parasitic nematodes feed on root tissue. A few species feed on shoot tissue. They have a stylet that is inserted into plant cells during feeding.



Root galls (hyperplastic symptom) induced by root-knot nematodes (sedentary endoparasite).

Symptoms

Infectious disease symptoms caused by plant parasitic nematodes generally fall into three categories: necrotic, hypoplastic and hyperplastic.

Infectious disease symptoms

Symptom	Definition	Example
Necrotic	breakdown of cells, tissues or organs	necrotic lesions, yellow foliage
Hypoplastic	retarded growth and development in cells, tissues or organs	stunted roots or shoots, low crop yields
Hyperplastic	over growth or development in cells, tissues or organs	root galls, swollen root tips, excessive root branching

There are three types of plant parasitic nematodes: ectoparasites, migratory endoparasites and sedentary endoparasites.

Ectoparasites

Ectoparasites inject their stylets into plant cells and feed from the surface of root or shoot tissue. The most important ectoparasitic nematode in Michigan field crop production is the **corn needle nematode** (*Longidorus breviannulatus*). This nematode's feeding causes swollen root tips, extensive plant stunting, barren ears and greatly reduced grain yields. This species is limited to coarse, sandy soils. It is a serious problem on seed and irrigated corn. The needle nematode species *L. elongatus* can be a limiting factor in Michigan celery production.

The **dagger nematode** (*Xiphinema americanum*) is commonly associated with Michigan tree fruit and vineyard crops. It is mentioned here because in addition to being an important pathogen, this species can transmit plant viruses. In Michigan, *X. americanum* carries the tomato ringspot virus that causes peach rosette mosaic virus disease in grapevines, cherry tree stem pitting and apple tree union necrosis.

Cyst nematode on soybean roots.
Source: Iowa State University

Migratory endoparasites

Migratory endoparasites penetrate host tissue and migrate throughout the plant. The most common and significant migratory plant parasitic nematode species in Michigan is the **root-lesion nematode** (*Pratylenchus penetrans*). This species is not only an important pest in potato, corn, alfalfa, small grains, strawberries, mint, celery and orchard crops, but in some cases it interacts with fungi to cause even more serious disease. The root-lesion nematode penetrates into root tissue and migrates throughout the cortex, causing cell necrosis and decreasing water and nutrient uptake and transport efficiency.

A second migratory endoparasite, the **bulb and stem nematode** (*Ditylenchus dipsaci*) feeds on shoot tissue and can be a major pest in Michigan onion and ornamental production systems. In other parts of the world, various races of this nematode are serious alfalfa pathogens.

Another foliage-feeding migratory endoparasite is the **pinewood nematode** (*Bursaphelenchus xylophagus*). This species is unique because it is transmitted from infected trees to healthy pine trees by long-horned beetles. The pinewood nematode can kill a mature, healthy pine tree in a few months.

Stunted corn growth (left) by plant parasitic nematodes.

Sedentary endoparasites

Sedentary endoparasites penetrate host tissue and establish a feeding site where the females spend the rest of their lives. The two most important sedentary endoparasitic nematodes in Michigan agriculture are the root-knot and cyst nematodes. Both types cause plants to form complex hyperplastic symptoms at the nematode feeding sites. These nematodes alter normal plant metabolism by redirecting plant resources for nematode reproduction.

The **root-knot nematode** female deposits eggs outside her body in an egg mass. The egg mass is protected when root galls are formed. Although the **northern root-knot nematode** (*Meloidogyne hapla*) is an important pest in Michigan vegetable and ornamental systems, it is not known to be a major problem in field crop production systems. Another root-knot nematode species, *M. naasi*, is known to exist only in Michigan.

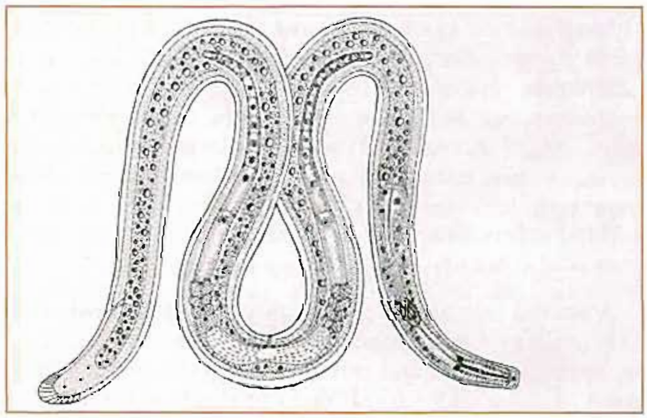
Cyst nematode on soybean roots.
Source: Iowa State University

Reduced plant growth due to soybean cyst nematodes.

Female cyst nematodes retain most of their eggs within their bodies. Some species also produce an external egg mass. When the female dies, her body becomes a cyst that protects the eggs in the absence of a suitable host for as long as ten years.

At least seven cyst nematode species affect Michigan agriculture. The two most important to Michigan field crops are the sugarbeet cyst nematode (*Heterodera schachtii*) and the soybean cyst nematode (*H. glycines*). The clover cyst nematode (*H. trifolii*) and the cereal cyst nematode (*H. avenae*) are also present. Michigan is the only reported U.S. location for the carrot cyst nematode (*H. carotae*).

Avoiding and managing plant parasitic nematodes



Most conventional Michigan farming systems maximize crop yields using purchased system inputs. This frequently limits biological diversity and results in an extensive food supply for plant parasitic nematodes with very few factors to limit their population potential. When a plant parasitic nematode's population exceeds a threshold level, an **infectious disease** occurs. In certain situations this will limit profitable crop production.

Ecologically managed farming systems are designed to foster **biological diversity**. Consequently, nematode problems are rare in these systems.

Nematode management process

Nematode management involves using information about an ecosystem's status, predicting a probable future nematode problem and selecting an appropriate strategy to keep plant parasite populations below disease threshold levels.

The monitoring system must provide information about nematode population density, cropping history, proposed site use, soil texture, soil nutrition and other existing factors that limit or enhance the nematode's biotic potential.

Since most farms are not equipped to process soil and tissue samples for identifying nematodes, Michigan State University and several private testing laboratories provide this service.

Farmers and crop consultants use information from the monitoring system to select an appropriate nematode management strategy: **avoidance-exclusion, containment-elimination, control** or **doing nothing**.

Nematode management strategies

Avoidance-exclusion

Avoidance-exclusion is by far the best way to prevent nematode problems. It is always easier to prevent a nematode problem than to manage an established problem. Some nematode management tactics that can be used under this strategy include:

- Designing a field crop ecosystem for biodiversity
- Rotating crops
- Enhancing potential limiting factors
- Using nematode-free seeds and transplants
- Implementing a soil erosion control program
- Using a water management system
- Keeping farm equipment nematode-free
- Maintaining good farm sanitation

Containment-elimination

Containment-elimination is also an important nematode management strategy. Once a nematode species is established in a site, it is very important to prevent it from spreading to other sites. This can be achieved, in part, by reducing the population density in the infested site and using avoidance-exclusion to prevent its spread to new locations. It is usually not possible to eliminate a nematode species from a system once it has become established.

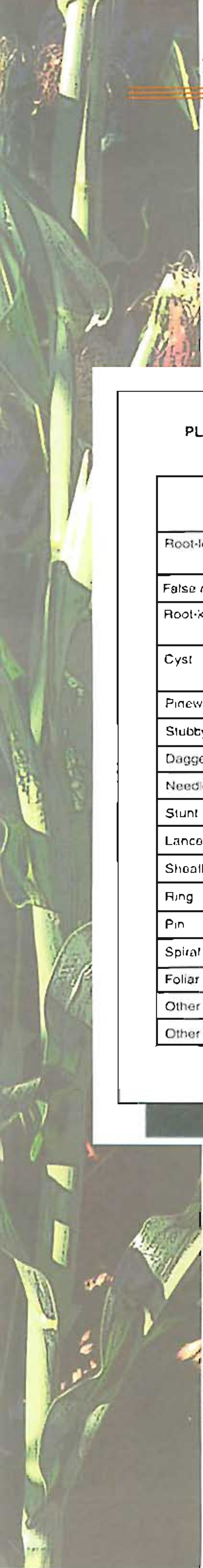
Nematode control

When a nematode's population density exceeds a crop's threshold, some type of control is used. Nematode control reduces the population density to a level that is below the disease threshold, and attempts to maintain it at this new equilibrium. Nematode control tactics include:

- Manipulating soil structure
- Manipulating soil water potential
- Manipulating soil humus content
- Using organic amendments
- Rotating with non-host crops
- Enhancing existing limiting factors
- Releasing natural enemies
- Introducing bionematicides
- Using synthetic chemical nematicides

Doing nothing

Doing nothing is sometimes the most appropriate strategy. For example, when a plant parasitic nematode's population is declining and looks as though it will continue to decline without using another management strategy, then doing nothing is the most appropriate strategy.



Soybean cyst nematode: case studies

Conventional field crop ecosystem

Soybean yield in an 80-acre field has been declining annually for the past three years. Plants in various locations are stunted, appear yellow during the growing season and have very few nitrogen-fixing root nodules. Yield losses are estimated to be 60 percent of the site potential. Although corn, wheat and soybeans are produced on this farm, soybeans have been grown in this field for the past five years. The following are the results of a soil and root tissue sample submitted to MSU for identification of the problem.

PLANT PARASITIC NEMATODE POPULATION DENSITIES AND RISK INDEX

Nematode	Population Soil[1]	Population Root[2]	Risk Index[3]
Root-lesion ☐ Penetrans ☐ ________	12		1
False root-lesion			
Root-knot ☐ Northern ☐ ________			
Cyst ☒ Soybean ☐ Sugarbeet ☐ Oat ☐ Clover	4,850	420	5
Pinewood			
Stubby-root			
Dagger			
Needle			
Stunt			
Lance			
Sheath			
Ring			
Pin			
Spiral	8		0
Foliar			
Other			
Other			

OCCURRENCE OF BENEFICIAL NEMATODES

Saprophagous Nematodes FW
Predaceous Nematodes NN
Endomycorrhizal Fungi FW
Nematode Trapping Fungi NN

NN = none AB = abundant
FW = few EX = extreme
CM = common

DIAGNOSIS:

- Nematode problem site ☒
- Disease complex problem site ☐
- Possible problem site ☐
- Future problem site ☐
- No problem detected ☐

GENERAL RECOMMENDATION

- Action advisable ☒
- Employ tactic on a trial basis ☒
  - Refer to MSU Ext. Bulletin No. E-2200 pages 1-6
  - ________ pages ________
- No action strategy available ☐
- Submit root sample ☐ ________
- Submit additional soil sample ☐ ________
- No action required at this time ☐

[1]Nematodes/100 cm^3 soil
[2]Nematodes/1.0 g root
[3]Risk Index
0 = None Detected
1 = Low
2-3 = Moderate
4 = High
5 = Severe

Analysis of the soil and root tissue indicates that the low yields are caused by the soybean cyst nematode (*Heterodera glycines*). It is strongly recommended that this field be placed in a long-term rotation designed to decrease population densities of the soybean cyst nematode and increase crop productivity. The rotation should consist of three, three-year cycles. The first two years of non-host crops (corn, wheat, potato, etc.) in the first cycle should be followed in the third year with a nematode-resistant soybean cultivar from a known resistance source. The non-host crops planted in the first two years of the second three-year cycle should be followed with one year of a nematode-resistant soybean cultivar from a different resistance source than the one used in the first three-year cycle. After two years of non-host crops in the third three-year cycle, a nematode susceptible soybean cultivar should be planted. The above recommendation is designed to lower population densities of the soybean cyst nematode and conserve host-plant resistance. It should also be noted that very few beneficial nematodes and fungi were associated with the sample from this field.

Organic field crop ecosystem

An organic farmer, in the process of transitioning a 40-acre field from a conventional system to a certified organic system, submitted a soil and root tissue sample for nematode analysis. This analysis was designed to use the types and population densities of nematodes and associated fungi to indicate overall soil quality, with special reference to the concept of a "living soil." The farm produces specialty small grains, specialty beans, corn and a variety of forage legumes. When the sample was taken, the site was planted to wheat with an over-seeded clover.

PLANT PARASITIC NEMATODE, POPULATION DENSITIES AND RISK INDEX

Nematode	Population		Risk Index[3]
	Soil[1]	Root[2]	
Root-lesion ☐ Penetrans ☐ ______	3	1	1
False root-lesion			
Root-knot ☐ Northern ☐ ______			
Cyst ☐ Soybean ☐ Sugarbeet ☐ Oat ☐ Clover	0	0	0
Pinewood			
Stubby-root			
Dagger			
Needle			
Stunt	8		1
Lance			
Sheath			
Ring			
Pin	6		1
Spiral	14		1
Foliar			
Other			
Other			

OCCURRENCE OF BENEFICIAL NEMATODES

Saprophagous Nematodes AB
Predaceous Nematodes CM
Endomycorrhizal Fungi EX
Nematode Trapping Fungi CM
NN = none AB = abundant
FW = few EX = extreme
CM = common

DIAGNOSIS:
Nematode problem site ☐
Disease complex problem site ☐
Possible problem site ☐
Future problem site ☐
No problem detected ☒

GENERAL RECOMMENDATION
Action advisable ☐
Employ tactic on a trial basis ☐
Refer to MSU Ext. Bulletin No.______
______pages______
______pages______
No action strategy available ☐
Submit root sample ☐______
Submit additional soil sample ☐______
No action required at this time ☒

[1]Nematodes/100 cm^3 soil
[2]Nematodes/1.0 g root
[3]Risk Index
0 = None Detected
1 = Low
2-3 = Moderate
4 = High
5 = Severe

Although five types of plant parasitic nematodes were recovered from the soil and root tissue, none were at high enough population densities to be considered as a current or potential problem in relation to crop productivity. There was a high ratio of non-plant parasitic to plant parasitic nematodes. The overall beneficial organisms analysis indicated diverse fungal and bacterial feeding nematodes, an above average population density of predacious nematodes, a very high population density of mycorrhizal fungi spores and the presence of nematode-trapping fungi. Based on the results of this sample, the soil would definitely be classified as a "living soil," one important component of an overall soil quality audit.

Directions for farm change: Bringing it all together

Richard R. Harwood

Learning objectives

- How can a holistic approach be used to bring social, regulatory, environmental and economic objectives into harmony with family and business goals?
- How can patterns of crop diversity be designed to reach the multiple objectives of soil quality, pest management and high yields?
- How can the tradeoffs between high yield, profit and adverse environmental impact be minimized?

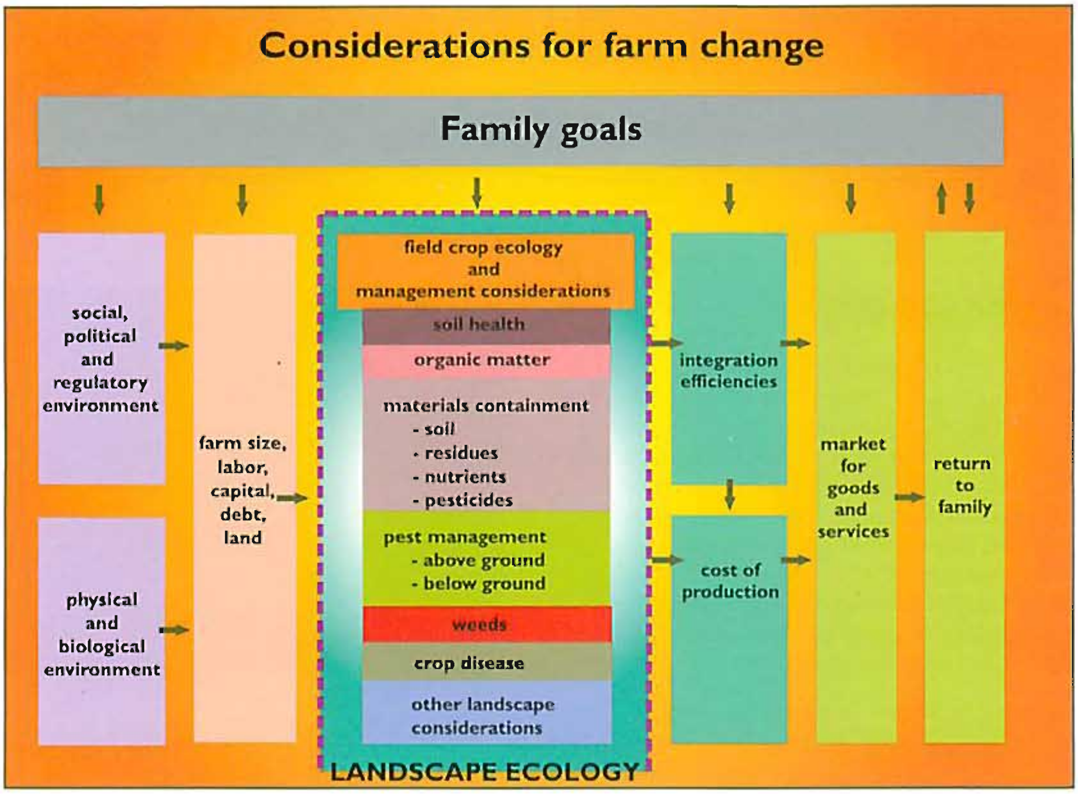
Additional reading

G. Hegyes and C. A. Francis (eds.). 1997. Future horizons: Recent literature in sustainable agriculture. Extension and Education Materials for Sustainable Agriculture: Volume 6. Center for Sustainable Agricultural Systems, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln.

Considerations for farm change

A holistic approach

Most farms are operated with a careful eye toward the off-farm environment, and blend family goals with business objectives. It's as important to plan for the evolving social, political and regulatory environment as it is to plan a cropping season. Have family goals for the farm been realistically established and put on paper? Does the family understand and share those goals? Given the most likely patterns of change in the local community and in regulatory processes, what implications are there for farm size and structure? What changes are likely in markets, and what new opportunities are probable for providing high value goods and services? What implications does all of this have for how the farm landscape is managed? How should the "social contract" evolve with neighbors and with the local community? How can a farmer be proactive in that social agreement in order to head off conflict or, worse yet, more regulation?



We have not examined many of these broader issues because they are beyond the scope of this volume. The preceding chapters have given insight into many of the more critical field crop ecosystem processes important to agricultural landscape aesthetics, field crop ecosystem soundness, environmental protection and economic efficiency.

Those chapters impress the need for taking a holistic viewpoint which considers biology along with economics, engineering and human well-being. But what are the priorities and where do we start?

We have learned that the best ecological methods for influencing biological organisms are managing their habitats (sometimes at the landscape level, within a field or in the soil) or managing their food source, which means managing plants and crops, organic inputs and their residues.

What changes should producers make in the crops they grow, where they are planted, their timing and their management practices? It's logical to begin by listing key determinants of **productivity** and **system sustainability**.

Landscape design

Getting a view of the farm landscape can help a producer identify potential "socially sensitive" areas. What special considerations should be given to nearby homes? Are they upslope or downslope from our fields? What travel patterns to and from fields could be changed to avoid populated or congested areas? Where are the neighbors' wells? How deep are they and how rapid is nearby soil leaching?

Are field shapes, sizes, grassways and other surface water management practices consistent with good erosion control? Are grassways managed for beneficial insect habitat? Are our field borders, headlands or non-arable field areas managed for wildlife and predator habitat? These are a few of the questions a farmer needs to ask himself/herself to provide the best landscape design.

Design for soil quality

Soil quality and productivity are major priorities. On the best soils it may be enough to use modest to low tillage on a simple summer crop rotation such as corn and beans or soybeans, while carefully monitoring inputs and managing crop residues. Minimal **rotation** is adequate for controlling corn rootworm and plant parasitic nematodes. These soils are characterized by low slope and a texture, clay type and depth profile that normally provide good aggregation, internal water movement and moderate to low leaching potential.

If a soil has a tendency to compact, crust or have low water infiltration, a more aggressive crop rotation is suggested. Controlled traffic patterns, tillage and drainage systems may also be necessary. These soils generally require greater **crop diversity** and longer **root growth duration**. This requires managing soil habitat, crop residue quality and soil organisms. A two-crop summer rotation has active crop rooting (from crop emergence to dry down) of about 115 days, which is less than one-third of the year. Including a winter crop such as wheat (which roots for about 300 days), brings the active rooting period to 57 percent for a two-year bean and wheat rotation, and 92 percent if a cover crop is used following wheat.

A beans-wheat-cover crop-corn rotation has active rooting 72 percent of the time over a three-year period and includes four species if a monoculture cover crop is used. Including a legume hay crop in the rotation for two or three years adds even more aggressive **soil conditioning**.

If a system's major crop has great economic value (i.e. potatoes or sugar beets), management revolves around optimizing the soil and environment for that crop and balancing the need for soil conditioning, pest and disease management with its planting frequency. With sugar beets, the choice is either a three- or four-year rotation. Given the heavy machinery traffic, at least one winter crop is needed (either a winter cereal or an aggressive cover crop after beans). Wheat, followed by an aggressive legume cover, followed by corn is an excellent sequence, but generally takes four years with beans, unless the beets are out early enough for fall wheat planting.

These options for increasing rooting duration and crop and residue diversity have a major impact on increasing soil organism abundance and diversity, which in turn impacts soil quality.

Rotation	Rotation years	Active rooting period	Number of species
Corn-soybeans	2	32	2
Soybeans-wheat	2	57	2
Soybeans-wheat/cover	2	92	3
Corn-soybeans-wheat/cover	3	72	4
Beets-wheat-corn	3	76	3
Beets-beans-wheat/cover-corn	4	65	5

Designing for reduced nutrient leaching

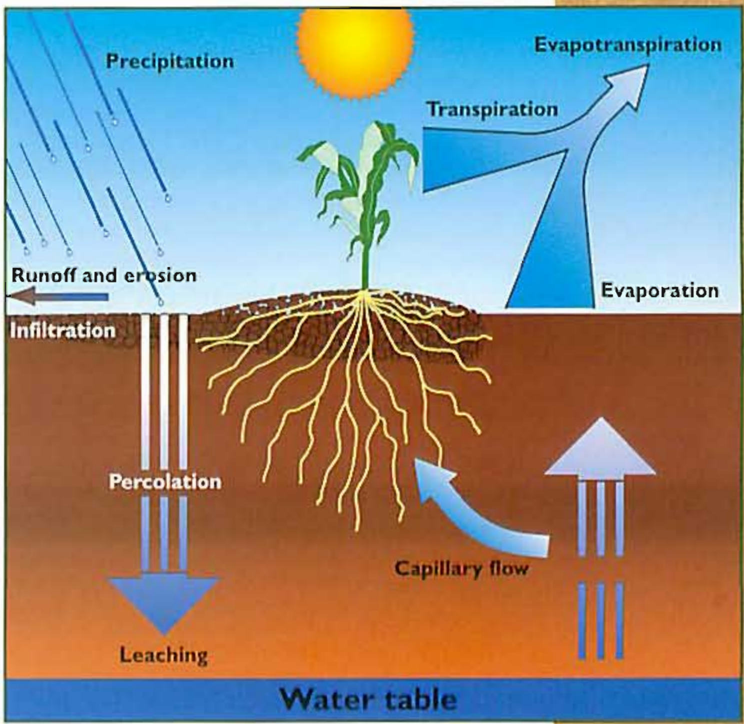
Water is added to cropland as snow, snowmelt and rain. In a typical field, most of this water eventually evaporates back to the atmosphere (66 percent from April to October). About 25 percent of it will run off the soil surface to streams, creeks, drains, lakes and ponds.

The remaining nine percent of this water enters the soil (infiltration). This soil water can percolate through the soil to groundwater, be stored as soil moisture or transpire by plants back to the atmosphere. Groundwater replenishes the soil water table (shallow aquifers), percolates to deep aquifers or flows back to surface waters such as streams and creeks.

The fate of irrigation water, particularly with overhead sprinkler systems, is similar to that of falling precipitation. The main difference is that water is taken from local surface or ground water sources. Taking or wasting too much water is a risk when supplies are low.

If a soil has a course texture a farmer must consider nitrogen use efficiency and leaching potential. Nitrate leaching in mineral soils is governed by the soil nitrate concentration and the amount of excess water (rainfall plus irrigation minus evapotranspiration).

One way of looking at nitrogen loss to groundwater is to consider the landscape-level impact. If a neighbor's well is shallow and near a soil with a high leaching rate, even a single season with a large nitrogen pulse (100 or so pounds per acre) may cause a short-term problem. In a more slowly leached soil, or where the well is either deeper or a greater distance from the fields, assessing three- to four-year nitrate leaching averages is probably more meaningful. KBS data show that nitrate leaching loss depends on crop rotation and season.



Most leaching occurs during the winter following a fertilized crop. The rotations shown here followed long-term alfalfa, so leaching was higher than would normally be expected for all crops. In 1994, a wet May-June caused heavy leaching under soybeans, showing that there is a period of vulnerability early in the crop season. A 1996 summer drought left sidedressed nitrogen unused, causing all corn to lose more than 100 pounds nitrogen per acre the following winter. On average, corn in rotation lost 70 to 80, soybeans 48 and wheat 24 pounds nitrogen per acre per year. Vulnerability in the high-leaching years brought overall nitrogen loss in the rotation to a level similar to that under continuous corn. Applied nitrogen averaged 85 pounds per acre per year and 150 pounds per acre per year for the continuous corn.

Annual nitrogen leaching (pounds N per acre) at the Living Field Laboratory, 1993-1997, KBS

Year (April - April)	Soybean	Wheat	1st year corn	2nd year corn	Rotation average	Continuous corn
1993-94	49	49	75	70	61	72
1994-95	54	16	45	38	38	24
1995-96	11	17	59	63	38	18
1996-97	76	15	100	151	86	103
crop (system) average	48	24	70	81	56	54

If a farm of 640 acres has 80 percent arable land (512 acres) and 56 pounds of nitrogen leached per acre, the farm would contribute 28,672 pounds of nitrogen into groundwater from cropland. Additional amounts may come from housing areas (lawns, septic systems) and other sources. Careful nitrogen management is critical, regardless of the crop system. We hope many farmers can do better than our KBS systems. After carefully managing applied nitrogen, we believe a winter cereal crop or rye cover is most effective for reducing overall nitrogen loss. Avoid early fall nitrogen mineralization by leaving a high-nitrogen legume or cover crop in place while the soil is still warm.

A plant's efficiency at taking up soil nitrogen and applied fertilizer seems linked to the rate of late spring soil nitrogen mineralization. This can be estimated using the rate of spring soil nitrate buildup (the presidedress nitrate lost). This rate is enhanced by a history of long-duration crop rooting, crop diversity and by a modest amount of green legume cover crop residue left in the spring. This fresh residue seems to "spike" bacterial reproduction in the soil. Spring-applied animal manure multiplies the cover crop effect. These nitrogen soil sources appear correlated with overall soil quality and high corn yields. Such nitrogen "pulsing" is obviously not desirable ahead of beans or soybeans, as it would increase the leaching potential. We don't know how this early season "pulsing" affects nitrogen loss during the following winter.

Designing for disease management

Ecologically based disease control requires a knowledge of pathogen biology and pathogen crop interaction. Does a pathogen leave residue in the soil, crop residue or field borders? Does it have alternate hosts? How, under what conditions and when is inoculum produced? Is crop genetic resistance available? Does crop vigor, nutrition or timing impact infection and disease development? With soil-borne pathogens such as potato scab or sugar beet root rot, rotations of three years or more can effectively reduce inoculum levels. Disease is a prime consideration when planning crop rotations, with soil quality and nematode control secondary factors.

With wheat scab, which leads to a mycotoxin buildup in the grain, alternating hosts such as corn and weedy species ensures a plentiful inoculum supply. Spores are produced on crop residues in the spring, though wheat is susceptible to infection only during the flowering period. Since spores move for some distance, scientists debate how effective it is to bury springtime crop residue. A lack of corn residue might reduce one fungus species' inoculum, but it would not affect alternate host production of several other disease-causing species.

With soybean white mold, spores disseminate from the soil under the crop canopy. Plant pathologists believe that a cover crop or crop residue might help reduce inoculum dispersal. The same rotation and cover crop tools used for soil quality and fertility benefits may also apply to disease control, but disease management must be pathogen specific.

Managing for insect and nematode control

Insect pest management is more complex than disease control and requires knowledge of specific pests and their predator relationships. Managing habitat for both pests and predators is important. It is importrant to remeber that insect habitat is effected by landscape-scale crop diversity, quality of field borders and crop timing. Cool-season crops, such as wheat or alfalfa, often provide an early season source of aphids and other food for such predators as ladybird beetles. This helps build their populations ahead of aphid infestations in warm-season summer crops. European corn borer is preyed upon primarily by *Eriborus*, a parasitic wasp. *Eriborus* needs habitats adjacent to corn fields for early season shelter and food. In annual crop agriculture, perennial habitats adjacent to crop fields may be necessary to provide the structure, stability and resource needs for the successful conservation of natural enemies and effective biological control.

The ratio of nematode types in a community may be an indicator of soil quality. A well-planned crop rotation, planned crop diversity and use of cover crops can enhance habitat for beneficial organisms, make carbon and nitrogen flow more efficiently and lead to improved soil quality and yield.

Biological pulsing

Crops have differing levels of net primary productivity, or total biomass accumulation and return to the soil. Corn returns more carbon to the soil than any of our other field crops, including harvested hay crops or any of the cover crops we have described. Beans and soybeans return far less carbon, but have a much lower C:N ratio. Young, cool-season legume covers have a very high-quality, readily decomposable biomass, so they spike the system.

A wheat-clover rotation has a 22-month period of diverse root growth. The combination of soil conditioning, followed by high-quality substrate incorporation prior to first year corn provides the highest soil activity pulse in the rotation. A good rotation effectively causes seasonal highs and lows of soil biological activity. For those highly responsive crops like corn, sugar beets or potatoes, periodic pulsing is a critical part of the design. Early spring pulsing is desirable for the non-legume crops. Beans, soybeans and other legumes should be placed in rotation in the "low pulse" years.

Crop integration efficiencies

There are several types of crop integration efficiencies. The major benefits in reducing inputs and increasing yield are shown in the accompanying table. Yield increases depend on effectively using "conditioner" crops. Those crops, when combined with landscape-level effects, can add to significant cost savings.

Michigan corn, soybean and wheat rotation efficiencies

Corn-after-corn (control)

Corn-after-beans
- 30 lbs/A N credit
- no rootworm scouting or control costs
- 6 to 10 percent yield advantage

Corn-after-soybeans/dry beans and wheat (Michigan, 2nd, 3rd year of rotation)
- no N credit
- no rootworm control costs
- window for perennial weed control (either mechanical or chemical)
- greater than 10 percent yield advantage

Corn-after-wheat plus frost-seeded clover
- 40 lbs/A N credit (60-70 lbs/A with PSNT)
- no rootworm control costs
- at least 15 percent yield advantage
- 30 to 50 percent yield advantage if the farm is organic, where corn-after-corn is not advisable

Economic returns

The biological interactions outlined in the previous pages and chapters have obvious economic implications. Those that improve soil quality, harvest greater yield and nutrient use efficiency benefits and reduce the need for additional nutrient or pesticide inputs. Landscape-level pest-predator interactions may have major impact, though the economics have not been determined. Benefits are likely to be in the range of a few dollars per acre per crop.

Net economic return, Living Field Laboratory, KBS 1995 (dollars per acre)

	Compost		Fertilizer	
	Cover crop	No cover	Cover crop	No cover
First year corn	315	274	251	257
Second year corn	232	249	202	227
Continuous corn	217	223	192	211

These small-plot yields do not include landscape-level effects.

Source: Jones, M. 1996.

KBS research shows that first-year corn has higher net economic return than second-year or continuous corn. Adding compost and cover crops maximized both soil biological activity and first-year corn yield. That advantage drops off rapidly in second-year corn. High-value crops dominate economic analyses of crop rotations. The rotation's overall profitability depends greatly on relative crop prices.

In a limited Michigan farm survey sample, gross margin for continuous corn was $84 per acre, whereas a multi-crop rotation achieved a gross margin of $103 per acre. When manure was added to the rotation, the margin was $115 per acre. These farm data include landscape-level effects and presumably long-term rotation equilibrium. The integration effects held over a wide price range for corn, soybeans and wheat.

Visible indicators of sustainability

Michigan's farms must not only be economically and environmentally sustainable, they should look that way to an informed public. Rural residents are increasingly concerned about environmental soundness and stability. They must better understand and appreciate the environmental services that a healthy agriculture provides. Visible good management indicators should include crop diversity patterns, good winter residue cover, patches of green fields in the late fall and early spring, grass strips and white (rather than brown, due to blowing soil) snow along windy winter roadsides. Biologically integrated practices make good economic, environmental and aesthetic sense.

Michigan Field Crop Ecology

During the many planning sessions for this publication, priorities were determined based on a logical learning sequence, availability of Michigan data, farmer priorities and space.

Several topics had to be deferred to subsequent publications including:

- Social/political linkages and social contract
- Weed ecology
- Pathogen management
- Mycorrhizae management
- Tree and forest management
- Wildlife issues
- Livestock and manure residue management.

Companion Bulletin: Michigan Field Crop Pest Ecology and Management. Michigan State University Extension Bulletin E-2704.

Additional information: http://www.canr.msu.edu/misanet/

MICHIGAN STATE UNIVERSITY EXTENSION