SOIL SMaRTS

Specific **M**anagement **a**nd **R**esources **T**rainings for **S**oil Health in Tennessee

TRAINING CURRICULUM

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Southern SARE Sustainable Agriculture Research & Education

UT Extension Institute of Agriculture The University of Tennessee

USDA United States Department of Agriculture

This curriculum was developed through a Southern SARE grant and collaboration between Tennessee State University, the USDA-NRCS, and the University of Tennessee. The objective of this curriculum is to provide training on soil health and sustainable management practices for soil health to extension agents and local officials so that they may disseminate this information to their stakeholders.

Soil Smarts Training Curriculum

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MODULE 2. SOIL BIOLOGY

Learning objectives:

Participants will be able to:

- list at least six functions that soil microbes perform.
- define and describe the three broad functional groups used to categorize soil organisms and list a few key organisms for each group.
- identify and define biological hot spots in soil and key organisms living in each zone/sphere.
- describe how the soil health principles influence soil biology and soil function.

Materials:

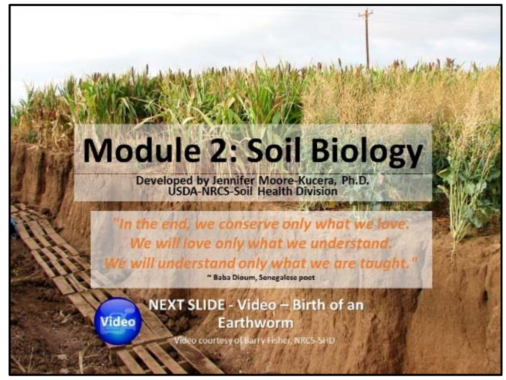
- PowerPoint® slides "Module 2: Soil Biology"
- Lesson guide: Use the notes in this lesson guide to present information for each presentation slide.
- Questions found at the end of this lesson guide can be used to test participants' knowledge at the end of the presentation. This can be combined with clickers to improve audience engagement and create discussion.
- An evaluation of the presentation can be found in this lesson guide following the lesson questions.

Topics:

Soil organisms as chemical engineers
Soil organisms as biological regulators
Soil organisms as ecosystem engineers
Optimal conditions
Litter layer (Detritusphere)
Earthworm and root channels (Drilosphere)
Pore space (Porosphere)
Aggregate surfaces (Aggregatusphere)
Root zone (Rhizosphere)
Benefits
Soil health principles

Slide 1

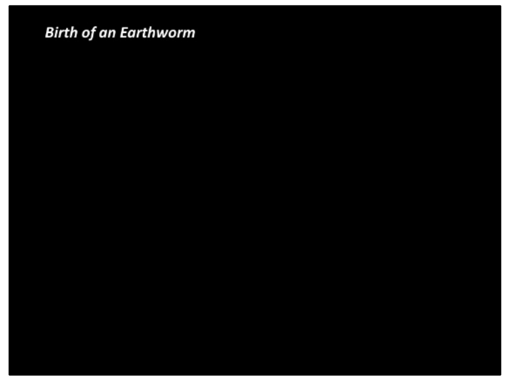
This module will focus on soil biology and its importance in achieving good soil health.



Slide 1

Slide 2

This slide is a video that shows the birth of an earthworm.



Slide 2

Slide 3

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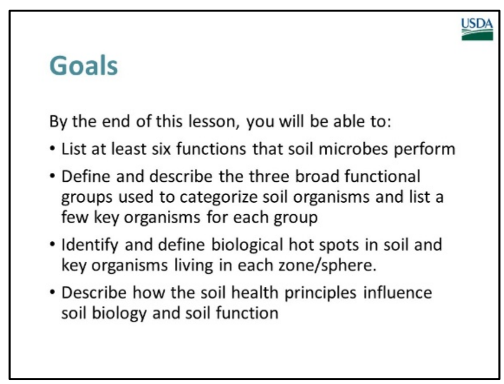
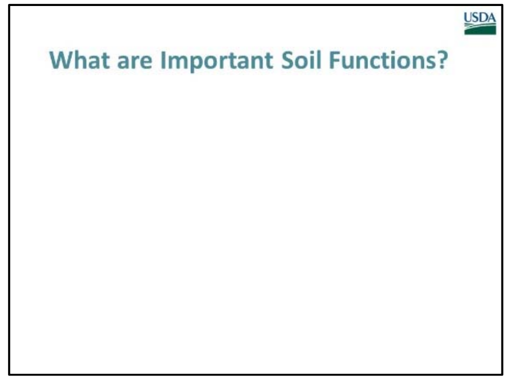


Slide 3

<u>Slide 4</u>

Time required: ~10 min….write these on a whiteboard or flipchart

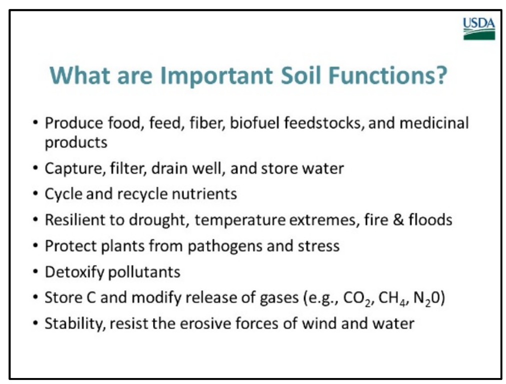


Slide 4

Ask participants to make a list of soil functions important for agriculture/range/forest production. Given that this module follows the Soil Health Basics presentation, they should come up with something in line with the following functions of healthy soils (**this is a good review/recap of important soil functions):

Produce food, feed, fiber, biofuel feedstocks, and medicinal products
Capture, filter, drain well, and store water
Maximizes internal nutrient cycling
Resilient to drought, temperature extremes, fire and floods
Protects plants from pathogens and stress
Detoxifies pollutants
Stores C and modifies release of gases (e.g., CO2, CH4, N20)
Stable, resisting the erosive forces of wind and water

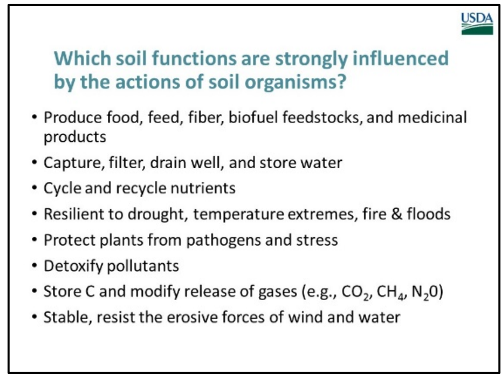
<u>Slide 5</u>



Slide 5

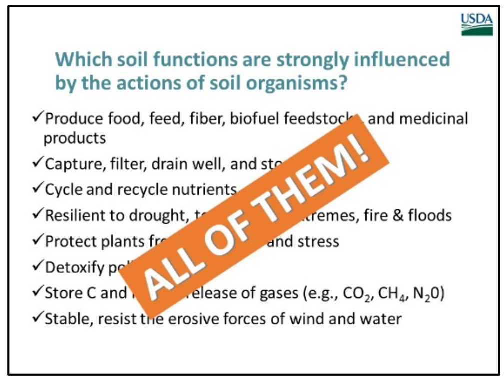
Slide 6

After the list is created, ask them to put a star next to the functions that are driven by the actions and interactions of soil organisms. All of them should have a star next to them!



Slide 6

Slide 7



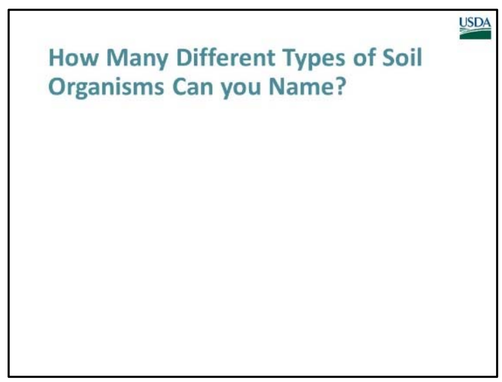
Slide 7

Slide 8

Regardless of how we define diversity and measure it, soils are home to vast abundance and types of organisms. Likely you already are familiar with many of them.

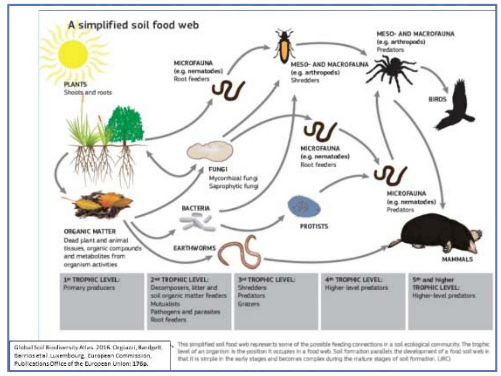
Ask participants to name soil organisms they know and write on board/flipchart or simply take notes and then read the combined list at the end. This should take only 1-3 minutes.

Answers may include: bacteria, fungi, algae, ants, beetles, mites, spiders, nematodes, earthworms



Slide 8

Slide 9



Slide 9

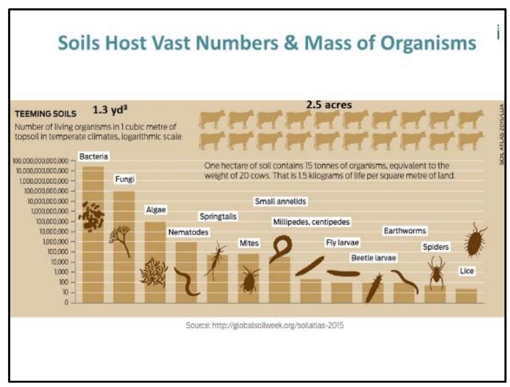
Historically, soil biodiversity was studied by mapping the soil food webs. This approach details the chain of energy transfer in soil and is based on grouping organisms according to their trophic role and food preferences. In a very simplistic manner, the food web is fueled by plants and photosynthetic bacteria that fix C from the atmosphere through photosynthesis. Other organisms then obtain their energy by breaking down plant residues and organic compounds or by consuming other organisms. During decomposition and consumption, nutrients are converted from organic to inorganic forms and made available to plants and other soil organisms (Paraphrased from Turbe et al., 2010).

Pros of the food web approach: Very useful for understanding nutrient cycling and energy flows and provided the foundation to study functional soil biodiversity.

Limitations: overlooks other important processes not based on feeding relationships, such as soil structure development, parasitism and pathogenesis. Relies on biomass and species composition, whereas activity provides a better understanding of soil biological function.

Slide 10

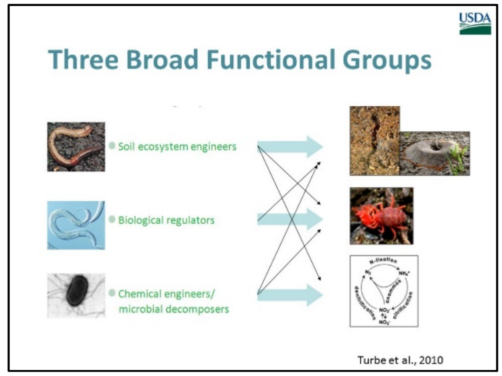
2.5 acres contains the weight of 20 cows of microbes in the soil. This is equivalent to about 3 lbs per square yard of soil. Source: Global soil biodiversity Atlas.



Slide 10

Slide 11

Soil organisms have coevolved for hundreds of millions of years and interact in positive (mutualistic) and negative (e.g. predator versus prey) ways. Conserving biodiversity also translates to conservation of important functions or services that the biological community provides. Keeping in mind that soil, soil biodiversity, and soil functions are complex interactions between inherent soil properties, climate, management, and the life within the soil, a simplistic view is to categorize soil organisms into the following broad functional groups. These include the soil ecosystem engineers, the biological regulators, and the chemical engineers (aka microbial decomposers).



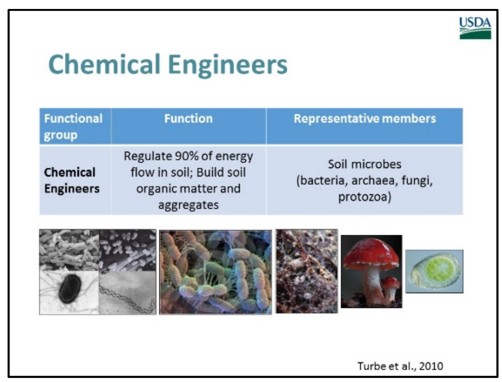
Slide 11

The following slides will explain:
what these groups are primarily responsible for, key representatives will be identified and a brief overview of specific functions, where they are found in soils, and their abundance

The arrows crossing among and between the different groups are an indication that the groups are not exclusive to certain members and multiple members can be influential on other functions but in order to follow some structure and help us understand key groups, we will go through them by identifying the dominant players.

Slide 12

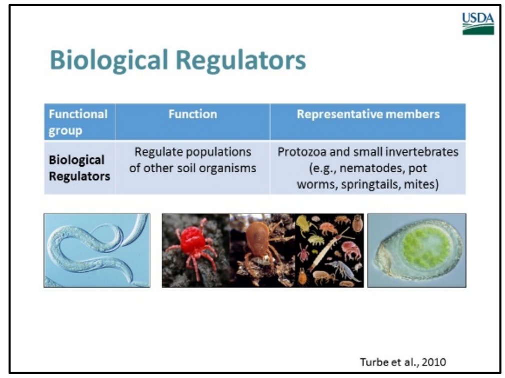
Chemical engineers involve soil microbes, regulate 90% of energy flow in soil and are responsible for decomposition of plant organic matter into nutrients that are available for plants. Soil microbes are also responsible for stimulating plant growth, plant protection and the production of multiple antibiotics used for human and animal health.



Slide 12

Slide 13

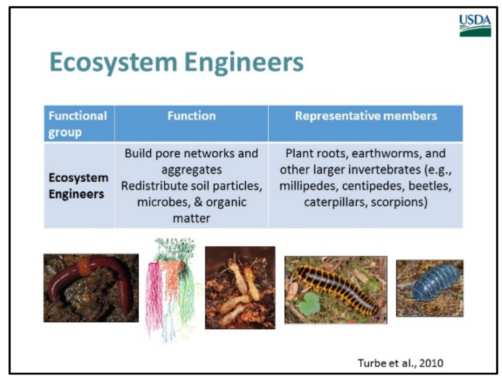
Biological regulators include small invertebrates such as protozoa, nematodes, pot worms, springtails, and mites. Through grazing, predation or parasitism, these organisms regulate populations of other invertebrates and microbes.



Slide 13

Slide 14

Ecosystem engineers are the larger organisms such as earthworms, ants, termites, etc. as well as plant roots that modify or create their own habitat and, in doing so, create biopores that channel air and water, mix organic materials during burrowing, and help build resistant soil aggregates. By regulating resources and redistributing and regulating access to resources, these organisms create 'hotspots' that support high numbers of microorganisms.



Slide 14

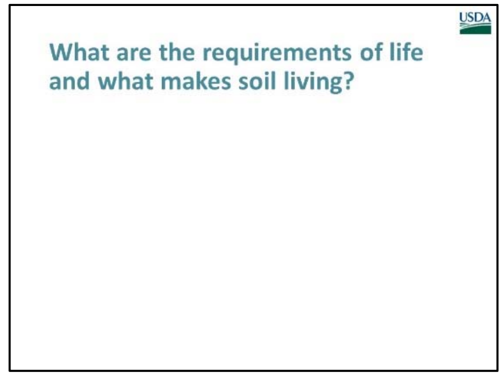
A large source that fuels the entire soil system relate to the impacts of plant roots, which is the first group of ecosystem engineers to discuss. Plant roots can cause physical weathering as they grow and expand inside cracks in the rocks. Roots and decaying vegetation also produce organic compounds such as solvents, acids and alkalinity that enhance the actions of percolating rainwater.

The two main types of root systems are fibrous and taproot. Fibrous roots are the traditional structures formed by primary and secondary roots branching in all directions in the soil. By contrast, taproots are characterized by a single firm root growing straight down, with minor roots developing on either side. Other specialized roots do exist; for example, the tuberous roots of sweet potato are modified for the storage of nutrients and water.

The number of known plant species has been estimated to be around 400,000.

Slide 15

Reiterate the definition of soil health…"The continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans". Then ask participants to compile a list of what it takes to be considered alive on a chart or white board (ALL PROCESSES BELOW CAN BE DIRECTLY RELATED TO THE BIOLOGICAL HOT SPOTS)

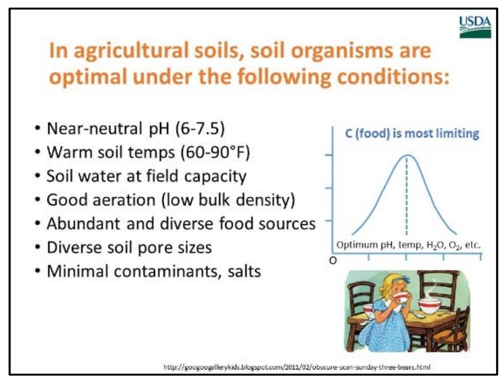


Slide 15

Should include:
Breathing—respiration/gas exchange
Shelter—aggregates/pores
Food source—detritus layer
Reproduction—pores/water films
Elimination—nutrient cycling
Death

Slide 16

There are numerous factors that influence biodiversity and activity of soil organisms. Although microbes can exist in the most extreme environments possible, most agricultural soils benefit from the following conditions:
Near-neutral pH (6-7.5)
Warm soil temps (60-90°F)
Soil water at field capacity (moist with no excess water draining out)
Good aeration (low bulk density)
Abundant and diverse food sources
Diverse soil pore sizes
Minimal contaminants, salts

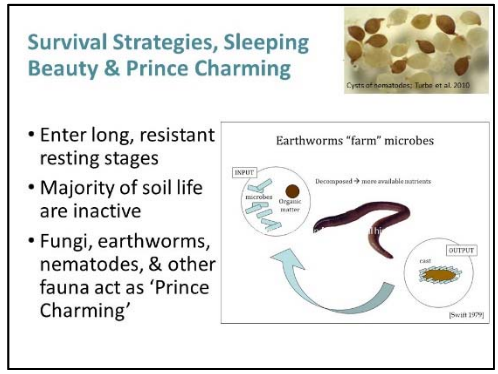


Slide 16

Equate these conditions to Goldilocks, needs to be "just right".

Slide 17

The majority of life in soil is not in an active state but often remain in a resting stage that allows them to stay alive when conditions are not conducive but rebound quickly when conditions improve.



Slide 17

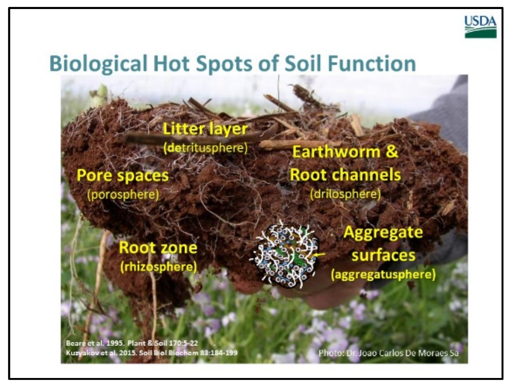
For example, over 90% bacteria in soil are inactive because they have not been able to move towards an organic substrate to use but spring to life quickly upon rewetting of soil to redistribute soluble organic C and nutrients.

If we want to encourage a diverse and healthy habitat for microorganisms we must provide food, nutrients, proper aeration, pH, water, etc.

Protists and nematodes form cysts, bacteria form endospores, fungi form spores, bacteria and fungi change cell chemistry, microarthropods can enter a state of 'crytobiosis' (suspended metabolism to survive extreme temperatures or dryness)

Slide 18

A hierarchical view of biodiversity as it influences the diversity in structure and function of ecosystems.



Slide 18

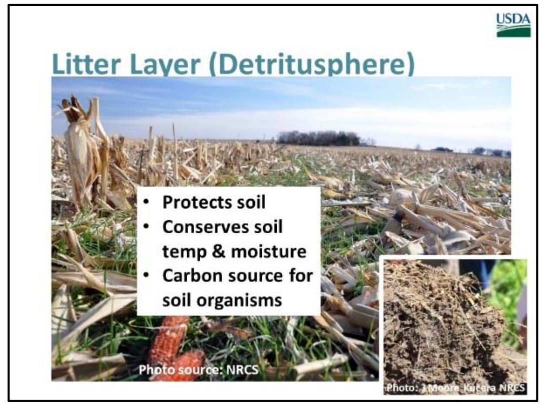
Activity idea: Collect soil from different management practices and give to different groups to identify the zones of biology within the management

The slide illustrates the places where microbes live—if any are missing then soil health is degraded. To begin to understand how to evaluate the health of a soil from a biological perspective, we need to change our view of how soil functions. Instead of looking at profiles and texture, we need to look at the biological processes or spheres of influence that are taking place working in concert together. The following slides will run through each of these independently.

- Soils can be viewed as being composed of a number of biologically relevant spheres of influence that define much of their spatial and temporal heterogeneity.
- They are formed and maintained by biological influences that operate at different spatial and temporal scales. Although not mutually exclusive, each sphere has fairly distinct properties that regulate the interactions among organisms and the biogeochemical processes that they mediate.
- Probably more than any other biological factor, the composition and structure of plant communities determine, directly or indirectly, the physical, chemical and biological properties of soils. Individual plants can have markedly different zones of influence in soils.

Slide 19

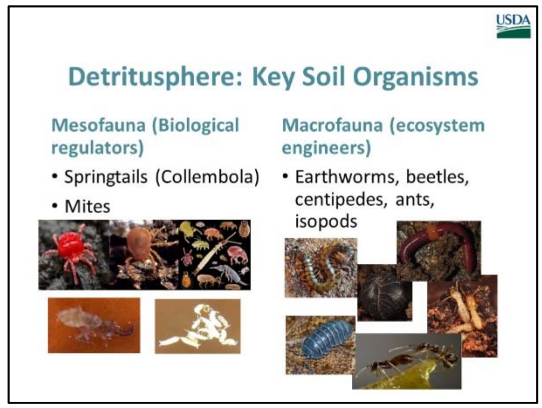
This is the zone above the mineral soil surface.
It contains recognizable plant and animal detritus undergoing decay
It contains high concentrations of saprophytic fungi, mites, nematodes and some macrofauna (e.g., beetles, centipedes, etc.)



Slide 19

Slide 20

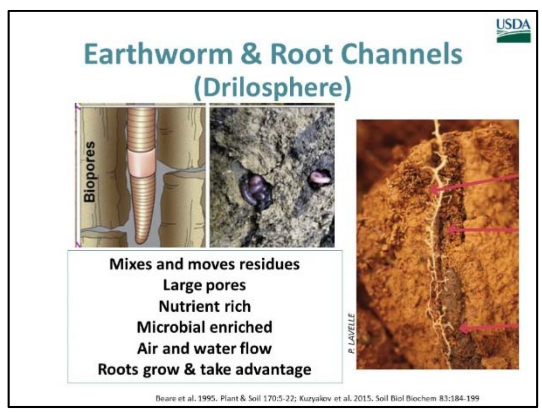
Springtails and mites are tiny arthropods that eat bacteria and fungi associated with decaying vegetation.
The macrofauna help to shred, mix, and fragment residues at the surface. This increases surface area for saprophytic fungi and bacteria to release specialized enzymes that breakdown residues. They also disperse microbial spores and influence microbial activity and nutrient cycles.



Slide 20

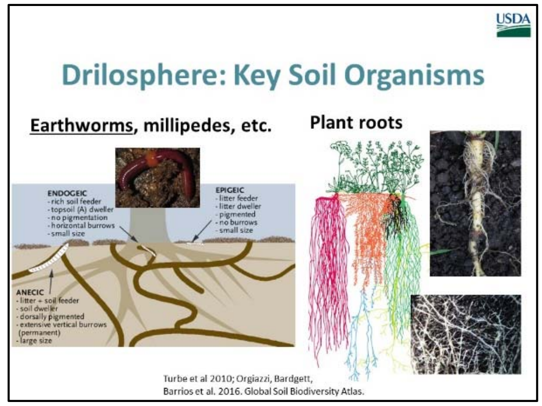
Slide 21

Earthworms ingest labile (easily moved/broken down) and recalcitrant (not easily moved/broken down) organics and processes them within the hindgut of earthworms and other soil organisms (mainly invertebrates) at various depths
Redistribute plant litter "carbon" throughout the soil the profile
Enrich soils with N, P, and humified organic matter
Increase water infiltration
Provide a biopore for plant roots
Homogenize the soil surface
Increase biodiversity in soils



Slide 21

Slide 22



Slide 22

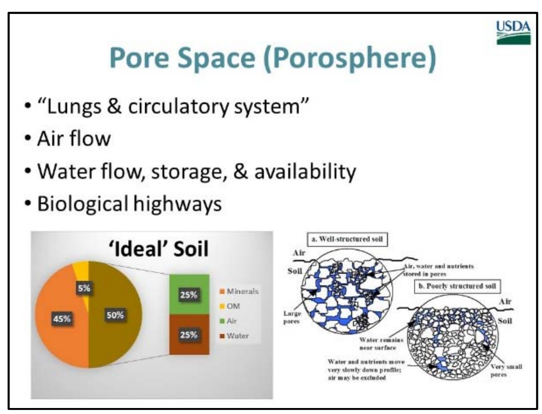
Zone of influence by earthworms and other microarthropods & millipedes
Function: shred and redistribute plant litter from the detritusphere throughout the soil profile
Earthworm Functions:

- Decompose & relocate organic matter
- Stimulate & move microbial community
- Increase available N and P
- Create stable aggregates
- Consume and redistribute seeds
- Invasive in northern forests
- Creates large pores important for water infiltration and air exchange
- Transport of soil microbes and labile and recalcitrant materials

<u>Epigeic</u> earthworms are those that live in the superficial soil layers and feed on undecomposed plant litter.
<u>Endogeic</u> earthworms forage below the soil surface in horizontal, branching burrows. They ingest large amounts of soil, showing a preference for soil that is rich in organic matter. Endogeics may have a major impact on the decomposition of dead plant roots, but are not important in the incorporation of surface litter.
<u>Anecic</u> earthworms build permanent, vertical burrows that extend deep into the soil. This type of worm comes to the surface to feed on manure, leaf litter, and other organic matter. This class of earthworms, such as the night-crawlers, have profound effects on organic matter decomposition and soil structure.

- Most common are members of the family Lubricidae (220 species)
- May account for 50% of total soil faunal biomass in grasslands and up to 60% in some forests
- 10-50/ft^2 to 200/ft^2 in pastures with several thousand species

Slide 23

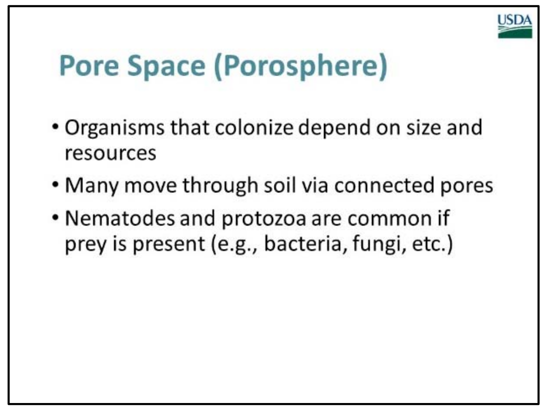


Slide 23

The lungs and circulatory system of the soil:
Regulates water and air flow
Impacts N, P mineralization
Impacts soil organism biomass and diversity
Site of nutrient exchange
Site of mycorrhizal entanglement and sequestration of water and nutrients
Root interface
Part of the water cycle

Plant roots, earthworms and other arthropods can rearrange soil particles to create smooth, cylindrically shaped macropores (biopores)
Biopores can extend a considerable distance in the soil, forming channels for preferential flow of water and nutrients
Good air exchange in the soil creates habitat in which aerobic organisms can thrive
Poor air exchange leads to anaerobic conditions, organisms that can tolerate this habitat tend to be those that cause disease and produce byproducts that inhibit root growth, e.g. alcohols
A mix of different sized pores is important
Collapse of space and large pores disrupts air, water, nutrient flows, and biological highways

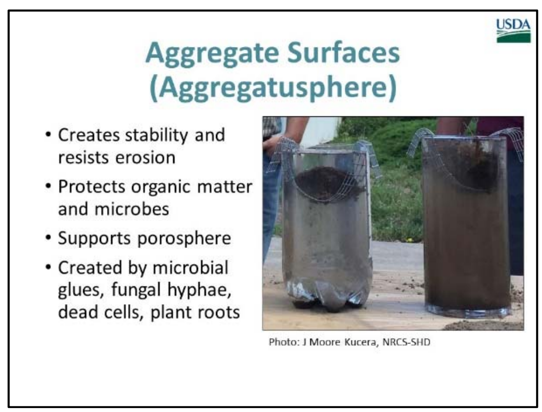
Slide 24
Related to biopores but includes medium, small, and micropores
Regulates H_2O & air flow
Pore networks help redistribute microorganisms, nutrients, etc.
Different sizes house and protect organisms and promote a diverse habitat
Bacteria, protozoa, fungal hyphae, nematodes, etc.
Most sensitive to disturbances
Protects microbes from larger predators



Slide 24

Slide 25
Lack of good soil aggregation results in compacted soils that:

- Restrict root growth
- Provide poor root zone aeration
- Have poor drainage

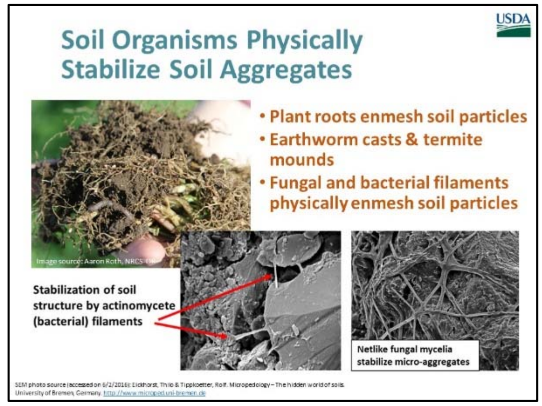


Slide 25

Soil compaction has always been thought of as a physical soil problem caused by excessive tillage and heavy equipment squeezing the soil pore space.
Compaction is actually due to a loss of soil organic matter and destruction of soil aggregates. These need to be replaced in the soil in order to provide a stable soil base in which to produce food & fiber
Soil compaction is a biological problem related to decreased production of polysaccharides and glomalin in the soil and a lack of living roots and mycorrhizal fungus in the soil.

Slide 26

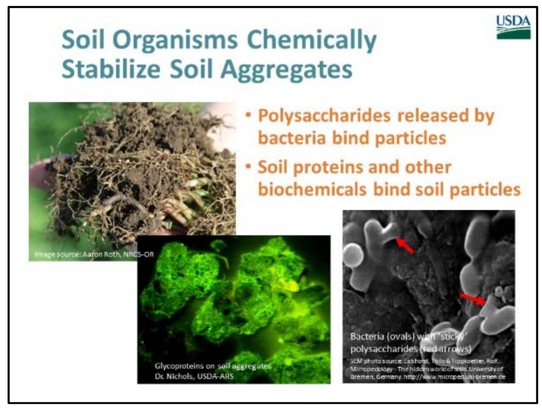
Follow material on presentation slide.



Slide 26

Slide 27

Tillage tends to reduce overall numbers of soil organisms, especially fungi that form hyphae and earthworms, important for soil aggregation and other soil functions. It also tends to favor increased bacterial populations and their predators (Protists and nematodes shift to bacterial-feeders). In contrast, no-till or reduced till favors higher overall populations, especially fungi and earthworms and nematodes shift to fungal-feeders.



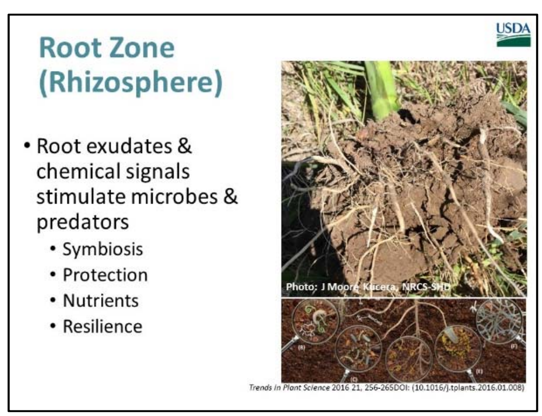
Slide 27

Forming soil aggregates requires both biological and physical actions:

- Need conditions that will allow for Arbuscular Mycorrhizal Fungi (AMF) colonies to be established
- AMF release glues as hyphae work their way out through the soil
- Hyphae entangle soil particles, realign them
- Create alternating wetting/drying cycles helping to bind particles together

Slide 28

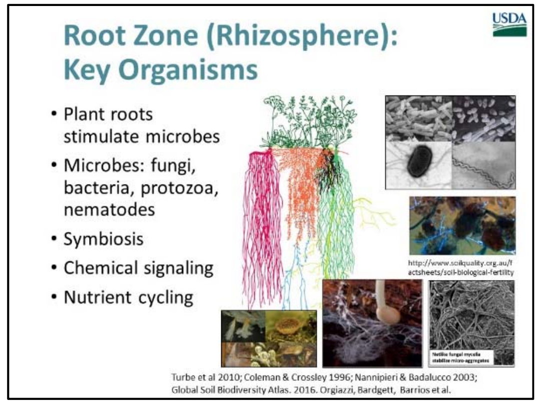
Highest density of roots is in the A horizon but can occur throughout profile.
Roots are important for a number of reasons: Anchor (keeps plant in soil, prevents soil erosion, holds stem upright), Absorption (water and dissolved minerals), Storage (starch and other nutrients), Habitat (provides nutrients to microbes, helps with aggregation)



Slide 28

Slide 29

Different plants attract and support a different microbial community. Additional factors influencing biodiversity composition include composition of plant components, nutrient content in tissues, tissue senescence and temperature, moisture, and inherent soil properties.



Slide 29

Slide 30

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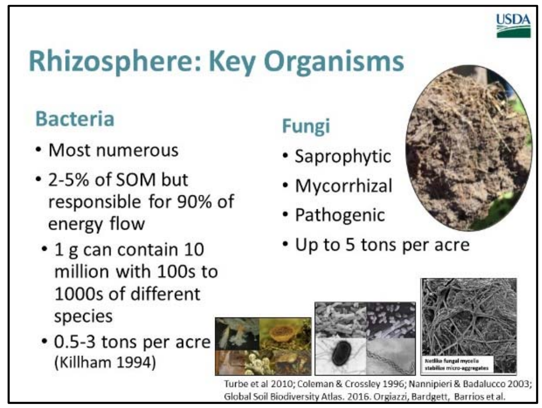


Slide 30

Slide 31

1 gram can contain 10 or more nematodes!

One acre may contain 200 pounds of nematodes!

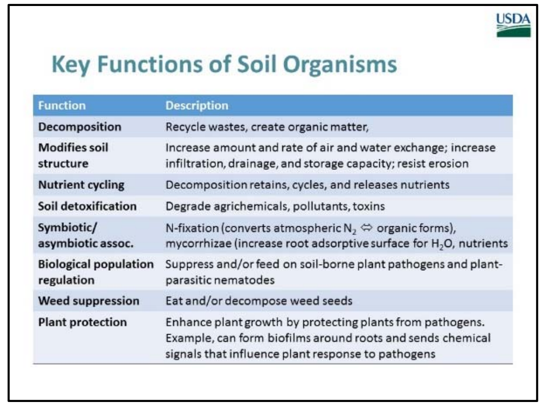
1 gram can contain 10,000+ protists!

One acre may contain the weight equivalent of 2 sheep of protists!

Slide 31

Slide 32

Follow material on presentation slide

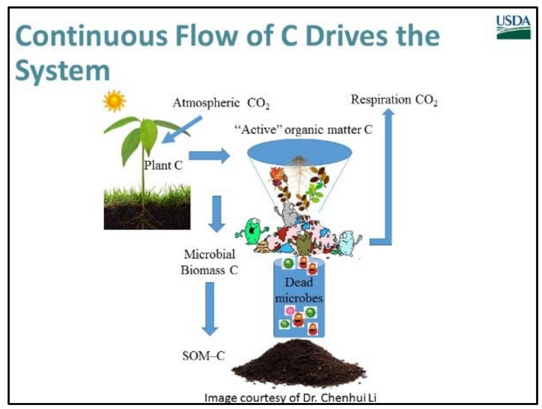


Function	Description
Decomposition	Recycle wastes, create organic matter,
Modifies soil structure	Increase amount and rate of air and water exchange; increase infiltration, drainage, and storage capacity; resist erosion
Nutrient cycling	Decomposition retains, cycles, and releases nutrients
Soil detoxification	Degrade agrichemicals, pollutants, toxins
Symbiotic/ asymbiotic assoc.	N-fixation (converts atmospheric N_2 ⇔ organic forms), mycorrhizae (increase root adsorptive surface for H_2O, nutrients
Biological population regulation	Suppress and/or feed on soil-borne plant pathogens and plant-parasitic nematodes
Weed suppression	Eat and/or decompose weed seeds
Plant protection	Enhance plant growth by protecting plants from pathogens. Example, can form biofilms around roots and sends chemical signals that influence plant response to pathogens

Slide 32

Slide 33

This diagram shows how the flow of active organic matter (organic C) is the driving force of the microbial biomass and their activities.



Slide 33

Slide 34

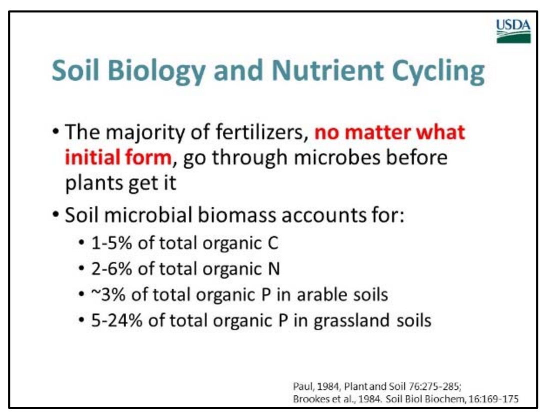
Fertilizer Use Efficiency (Annual Crops)

N: 30-70%

P: 5-40%

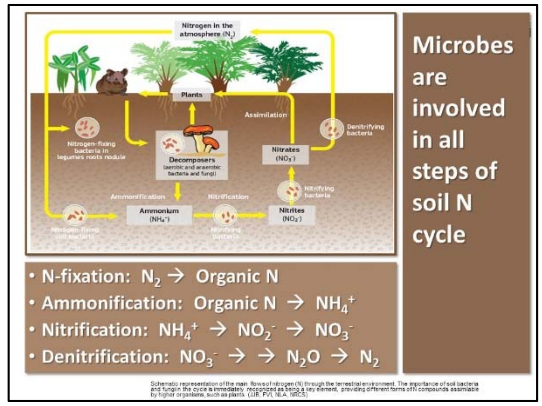
K: 50-80%

NUE cereal: 30-35%



Slide 34

Slide 35
Oftentimes <50% of N added is taken up into plants immediately (referenced source showed 30-70% for N; source is Agron Journal 91:357-363)
Uptake is regulated by relationships between soil microorganisms and plants



Slide 35

Slide 36
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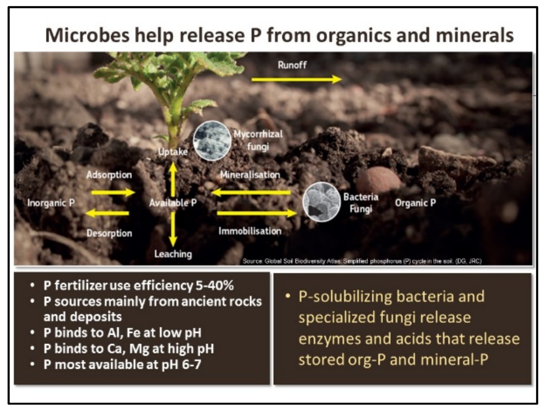
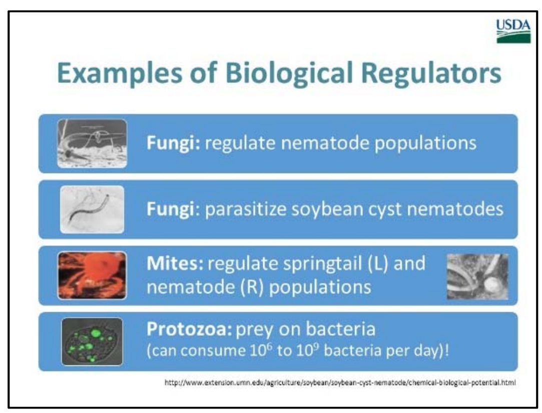


Slide 36

Slide 37
Examples of population control through predation, grazing, and parasitism



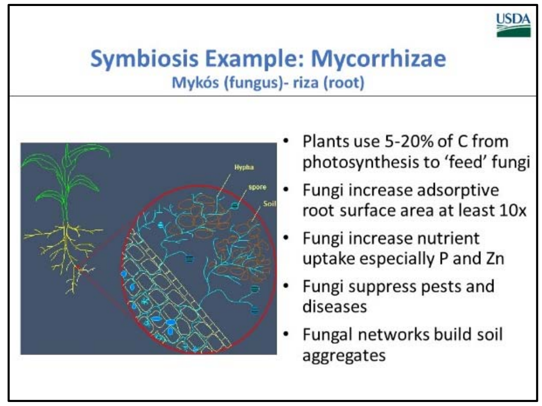
Slide 37

Slide 38

Greek word meaning fungus root

Most crops are mycorrhizal including onions, corn, cotton, wheat, soybeans, potatoes, alfalfa, sugarcane, cassava, rice, most vegetables, beets, apples, grapes, citrus fruit, trees (lumber and fiber), cacao, coffee, rubber.

Some non-mycorrhizal crops have been shown to inhibit mycorrhizae in the next crops according to researchers at Penn State. These include canola, buckwheat, forage radish, camelina, and mustards.



Slide 38

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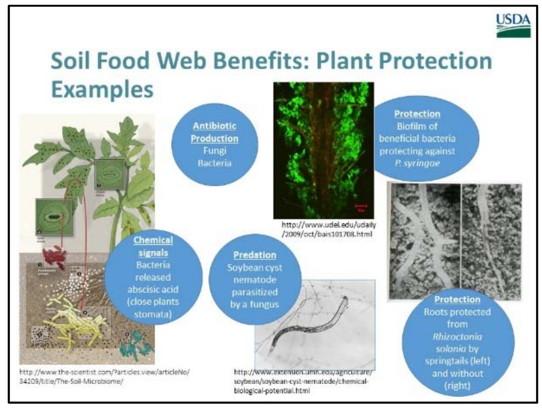
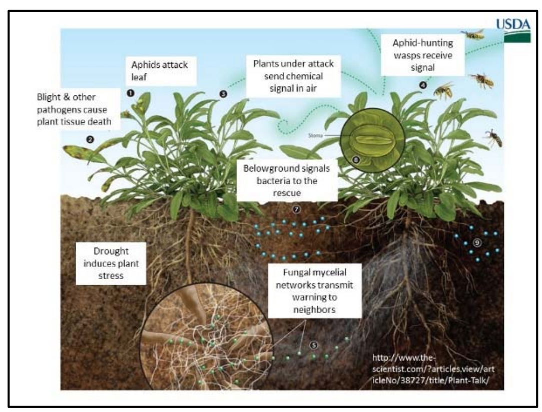


Slide 39

Slide 40

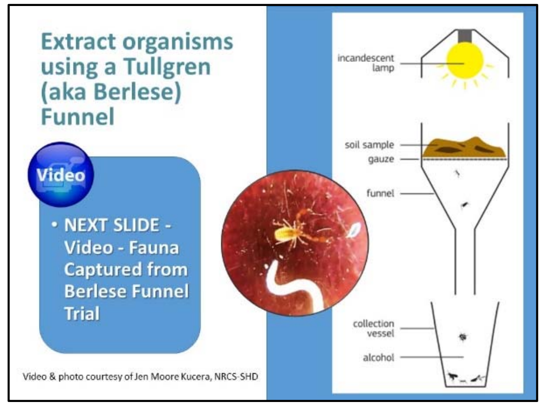
An example of the interconnected nature of the soil/plant system…Aphids and other organisms may attack the plant because it is under stress from drought. The plant can send chemical signals through the air and soil to engage other organisms (i.e. wasps and bacteria) to attack these pests which provides food for these organisms.



Slide 40

Slide 41

This is a method that allows you to capture soil organisms and microorganisms from a sample of soil.



Slide 41

Slide 42

This slide includes a video of some captured soil organisms and microorganisms using the technique.

Slide 42

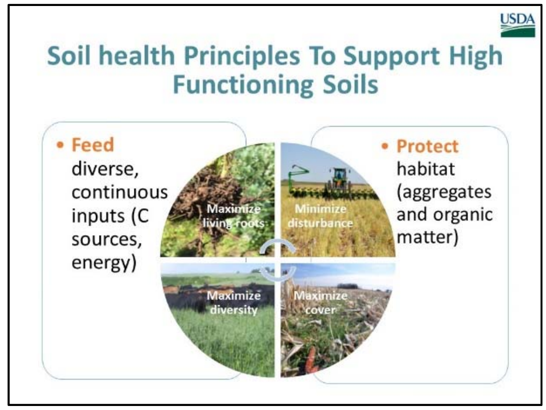
Slide 43

Not surprisingly, many biologically friendly practices are similar or same as those recommended by NRCS.

Slide 43

Slide 44

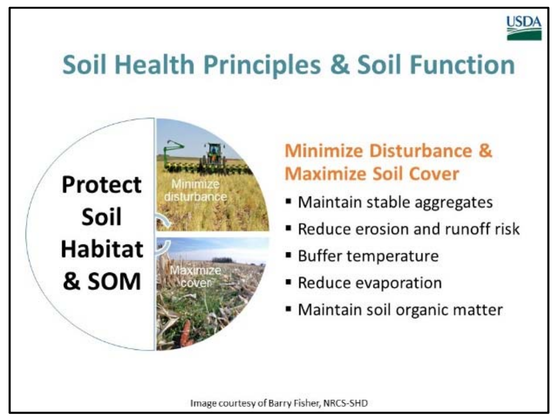
This is the answer to the question on the previous slide.



Slide 44

Slide 45

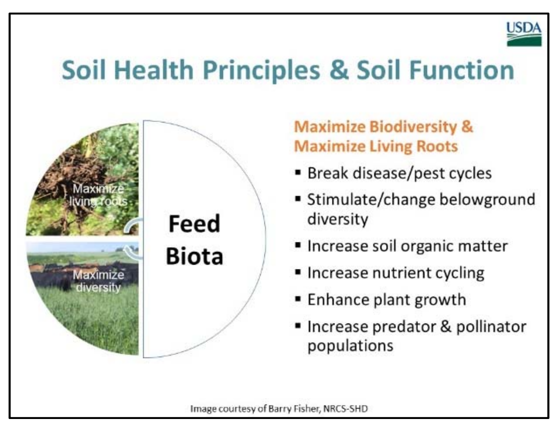
The first two principles focus on protection of the soil habitat: minimizing disturbance and maximizing soil cover maintains or increases stable soil aggregates and soil organic matter (SOM), and protects the fragile surface of the soil that is most susceptible to the degrading forces of wind and water. Covering the soil also buffers against extreme swings in temperature that stress plants and soil organisms, reduces evaporation rates, and increases water-use efficiency. SOM is highest at the soil surface and is critical for stabilizing soil aggregates. Maintaining SOM helps support additional soil functions including water infiltration and storage, nutrient-holding capacity and release, and habitat for soil biota.



Slide 45

Slide 46

The second two principles focus on feeding the organisms inhabiting soil. Maximizing the diversity of food (energy and carbon inputs) and aboveground biodiversity through increased plant, animal, or soil amendments increases the diversity of soil organisms, microorganisms, and activities. Diversity not only refers to food sources, but also aboveground diversification of plants and animals, and microbial diversification underground. Diversification stimulates a host of additional benefits including breaking disease cycles, providing habitat for pollinators, wildlife, and beneficial predators, and stimulating plant growth.



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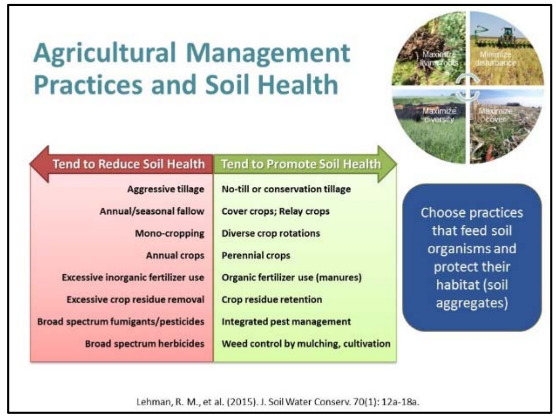

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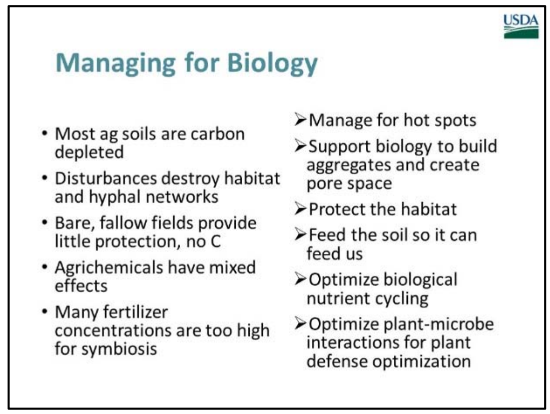

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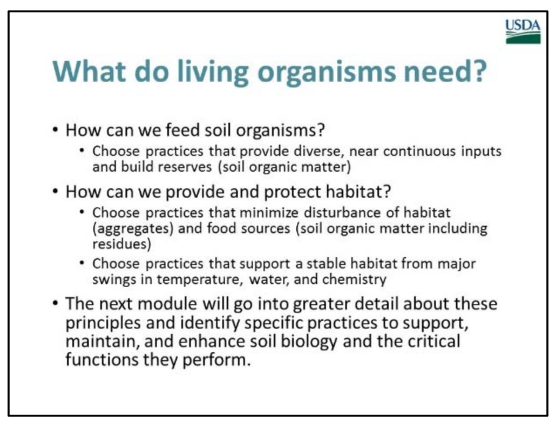

Slide 49

Test their Knowledge - Questions for the audience

Q: What are the three broad functional groups of soil organisms?

1. Soil ecosystem engineers (i.e. earthworms)
2. Biological regulators (i.e. nematodes)
3. Chemical engineers/microbial decomposers (i.e. bacteria and fungi)

List 5 biological hotspots in the soil.

1. Litter layer (Detritusphere)
2. Earthworm and root channels (Drilosphere)
3. Pore space (Porosphere)
4. Aggregate surfaces (Aggregatusphere)
5. Root zone (Rhizosphere)

What are optimal conditions for soil organisms?

1. Near neutral pH (6-7.5)
2. Warm soil temperatures (60 - 90°F)
3. Soil water at field capacity
4. Good aeration (low bulk density)
5. Abundant and diverse food sources
6. Diverse soil pore sizes
7. Minimal contaminants, salts

Soil microbial biomass accounts for __2-6%__ of total soil organic nitrogen.

Q: What does denitrification create?
A: It creates nitrogen gas from nitrate.

Q: What microbe helps to regulate nematode populations?
A: Fungi

Q: What are some benefits of fungi?
A: They increase the adsorptive root area by at least 10x, they increase nutrient uptake (especially P and Zn), they suppress pests and diseases, they help build soil aggregates.

Soil Health Evaluation

Name of Activity: Soil biology	Date of Activity:

A. Instruction	Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree
1. The agent/specialist was well prepared.	①	②	③	④	⑤	⑥
2. The agent/specialist presented the subject matter clearly.	①	②	③	④	⑤	⑥

B. General Learning and Change	Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree
1. I have a deeper understanding of the subject matter as a result of this session.	①	②	③	④	⑤	⑥
2. I have situations in which I can use what I have learned in this session.	①	②	③	④	⑤	⑥
3. I will change my practices based on what I learned from this session.	①	②	③	④	⑤	⑥

C. Specific Learning How much *did you / do you* know about these subjects?	*Before this program I knew...*					*Now I know....*				
	Very little	Little	Some	Much	Very Much	Very little	Little	Some	Much	Very Much
1. *The broad functional groups of soil organisms*	①	②	③	④	⑤	①	②	③	④	⑤
2. The important role soil biology plays in soil health	①	②	③	④	⑤	①	②	③	④	⑤
3. The five biological hotspots of soil function	①	②	③	④	⑤	①	②	③	④	⑤
4. Soil health principles	①	②	③	④	⑤	①	②	③	④	⑤

D. Specific Practices To what degree *did you / will you* do the following?	*Before this program I did...*					*In the future I will realistically do....*				
	Very little	Little	Some	Much	Very Much	Very little	Little	Some	Much	Very Much
1. *Measure different field indicators of soil health*	①	②	③	④	⑤	①	②	③	④	⑤
2. *Incorporate sustainable agricultural methods for soil health*	①	②	③	④	⑤	①	②	③	④	⑤
3. Seek additional NRCS information on financial and/or technical assistance for improving soil health	①	②	③	④	⑤	①	②	③	④	⑤

E. Satisfaction with Activity	Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree
1. I would recommend this program to others.	①	②	③	④	⑤	⑥
2. As a result of this program, I am more likely to seek additional information from UT/TSU Extension.	①	②	③	④	⑤	⑥

F. Any suggested changes, additions, etc. to the curriculum?

Thank you for participating in this survey!