Soil Invertebrates: From the Ground Up

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Saint Louis Zoo

Saint Louis Zoo
Animals Always®

Land Acknowledgement

We would like to acknowledge that the Saint Louis Zoo is located on the traditional, ancestral, and unceded territory of the Osage Nation and the Illini Confederacy. We also acknowledge that this area and parts of Missouri had been traditionally used by others including the Pawnee, Sac and Fox, Dakota, Lakota, Otoe, Missouria, Omaha, Ioway, Quapaw, Chickasaw, Kickapoo and the Haudenosaunee. The process of knowing and acknowledging the ground beneath our feet is a way of honoring and expressing gratitude for the people on this land before us. It familiarizes visitors with the cultures and histories of Missouri's indigenous tribes, as well as with their ties in the St. Louis region. We honor our heritage of Native Peoples and what they teach us about stewardship of the earth.

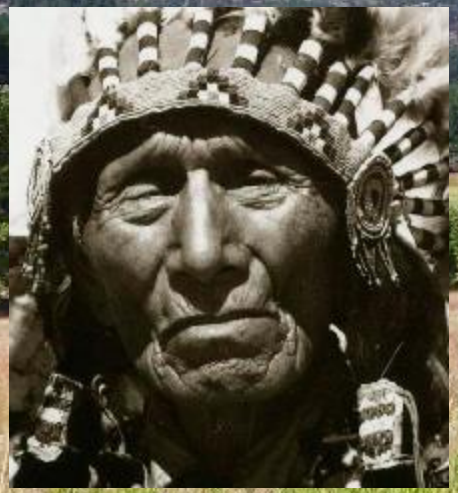
Franklin D. Roosevelt, 32nd President, 1882-1945

"The nation that destroys its soil destroys itself."


"In traditional agriculture,
the soil is the mother.
She's the mother who gives,
to whom you must give back."
Vandana Shiva, PhD
Physicist/Environmental activist
www.TheDirtMovie.org
dirt!
THE MOVIE

The earth is your grandmother and mother, and she is sacred. Every step that is taken upon her should be as a prayer.

Heȟáka Sápa (Black Elk), Oglala Lakota



Soil functions

Soils deliver ecosystem services that enable life on Earth

2015 International Year of Soils

fao.org/soils-2015

Food and Agriculture Organization of the United Nations

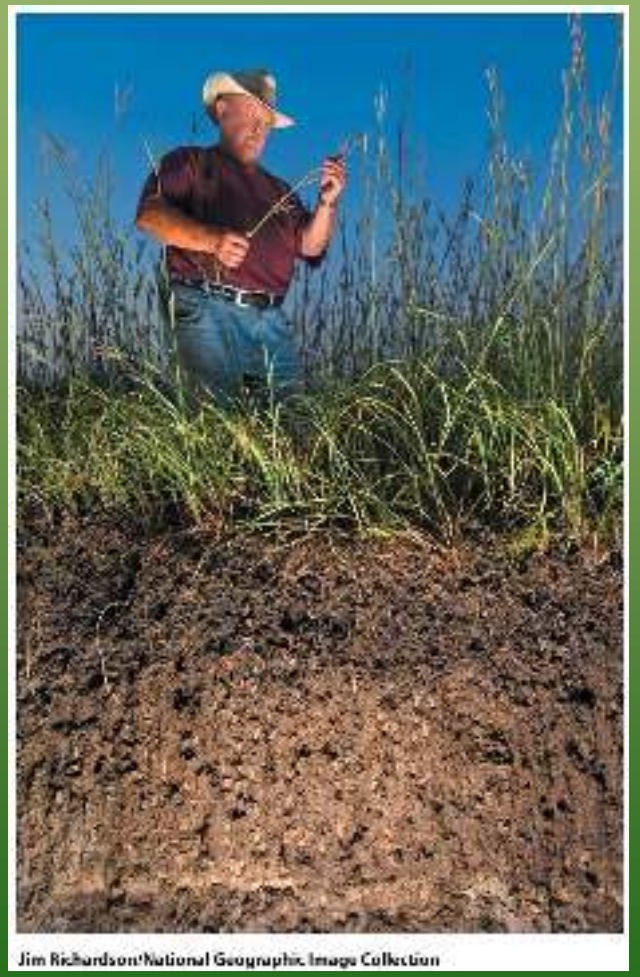
with the support of

Soil

- **Uppermost layer of Earth's crust that supports plants, animals and microbes**
- **Soil Forming Factors**
  - Weathering of parent material
  - Time
    - 1 inch of soil may take 200 to 1000 years
  - Climate
  - Organisms
  - Topography

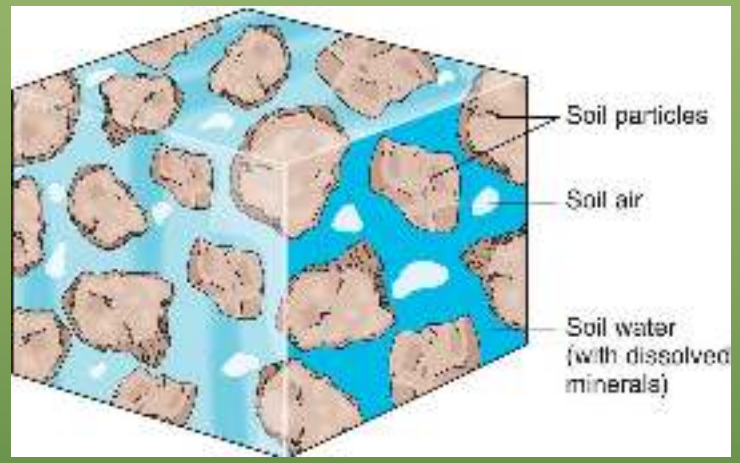
Soil Composition - “typical soil”

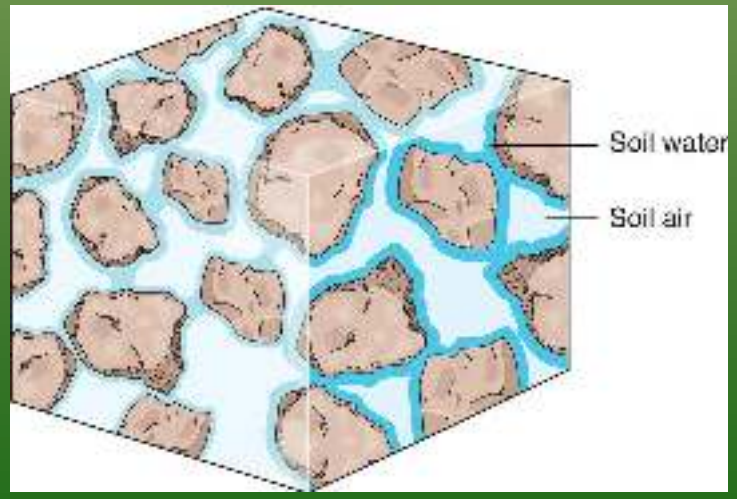
- **Mineral Particles (45%)**
  - Weathered rock
- **Organic Material (5%)**
  - Litter, animal dung, dead remains of plants and animals
  - Humus – black organic matter remaining after most decomposition
    - Collective name for many different organic compounds
- **Water (25%)**
- **Air (25%)**

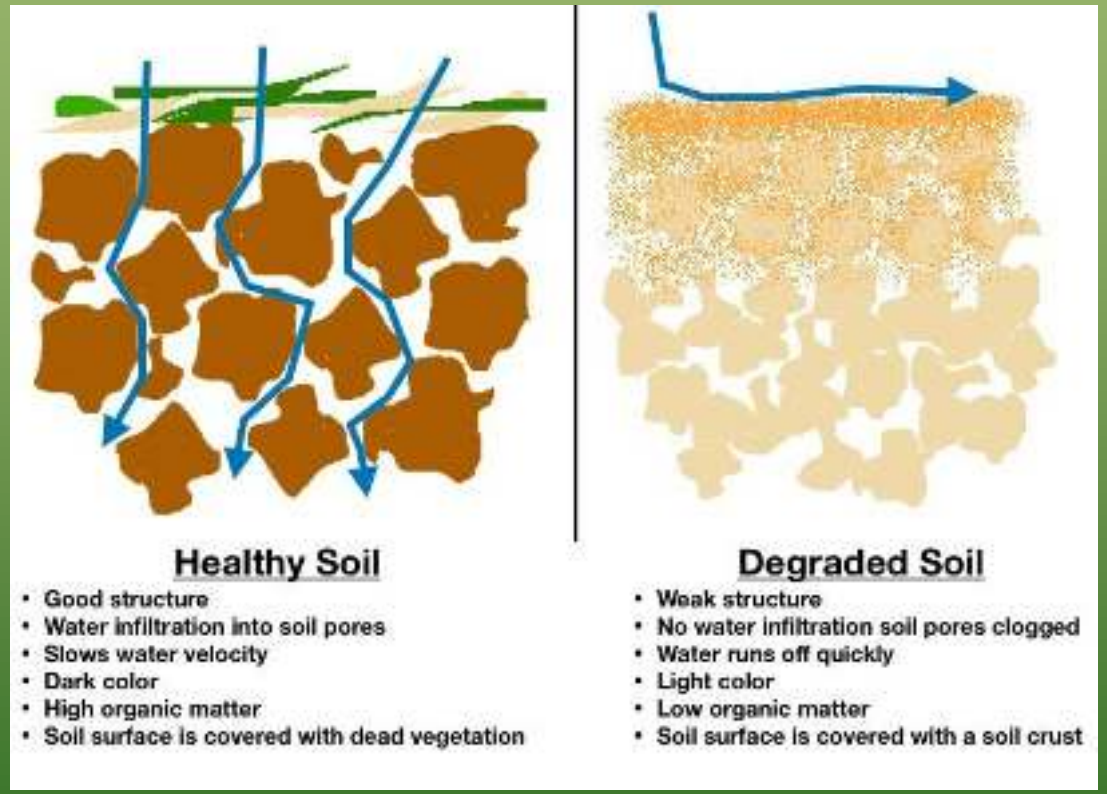


Soil Composition and Structure

- **Pore space**
  - 50% of soil
  - Soil air - good for aeration
  - Soil water - provides water to roots







Soil Layers

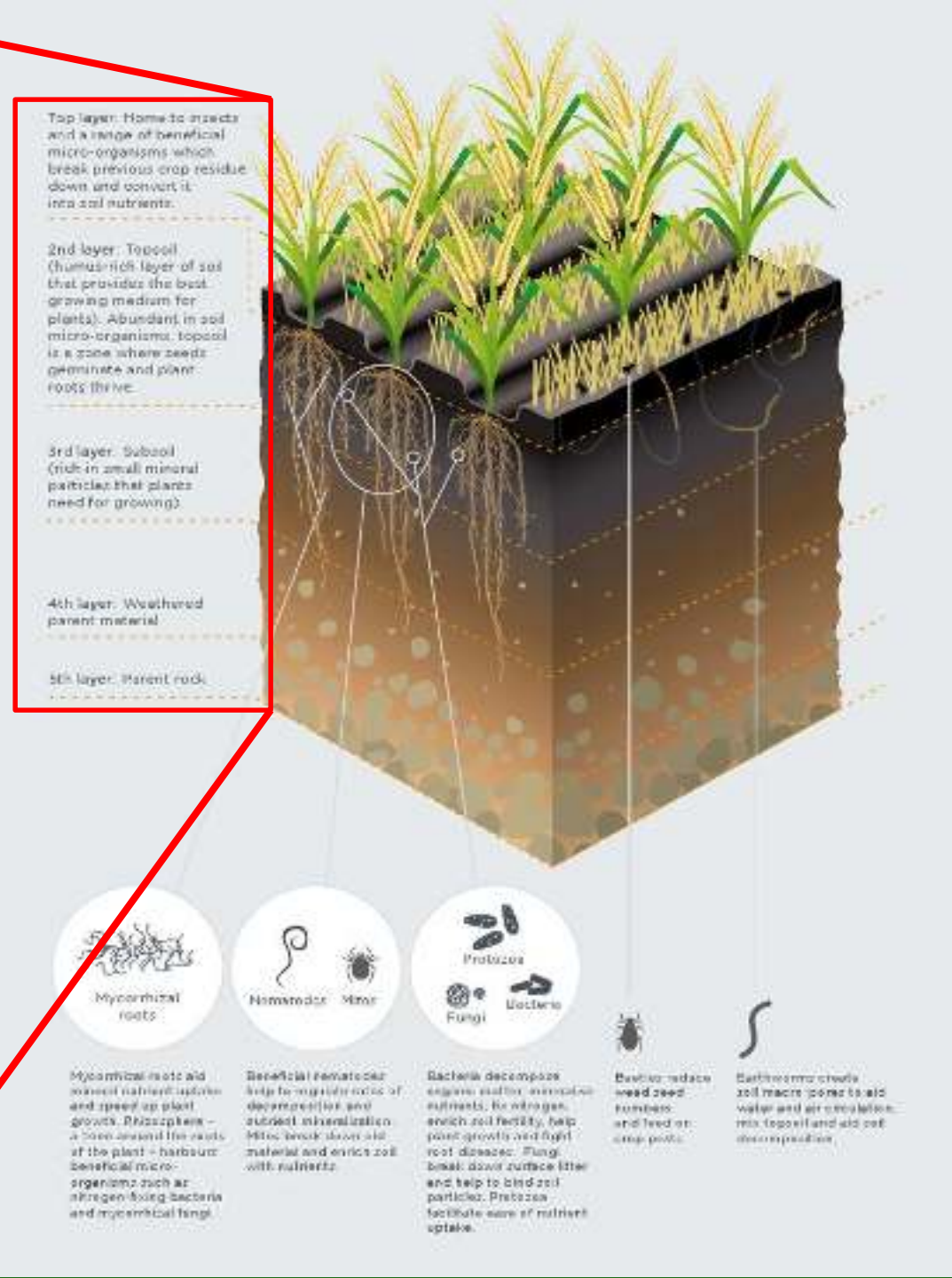
Top layer: Home to insects and a range of beneficial micro-organisms which break previous crop residue down and convert it into soil nutrients.

2nd layer: Topsoil (humus-rich layer of soil that provides the best growing medium for plants). Abundant in soil micro-organisms, topsoil is a zone where seeds germinate and plant roots thrive.

3rd layer: Subsoil (rich in small mineral particles that plants need for growing).

4th layer: Weathered parent material

5th layer: Parent rock



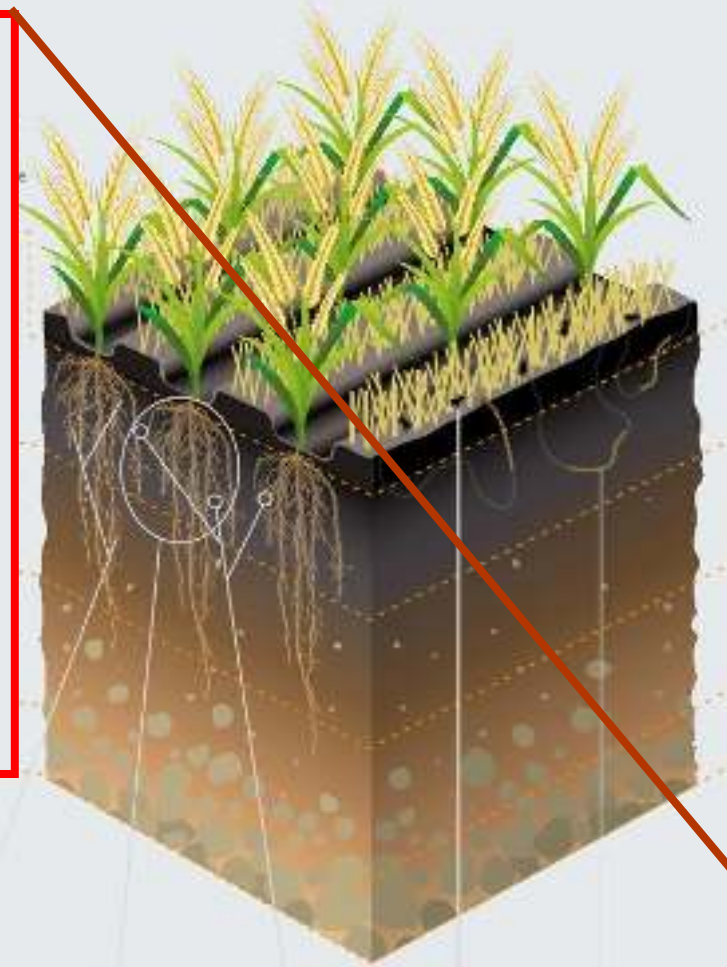
Mycorrhizal roots aid mineral nutrient uptake and speed up plant growth. Rhizosphere – a zone around the roots of the plant – harbours beneficial micro-organisms such as nitrogen-fixing bacteria and mycorrhizal fungi.

Beneficial nematodes help to regulate rates of decomposition and nutrient mineralisation. Mites break down old material and enrich soil with nutrients.

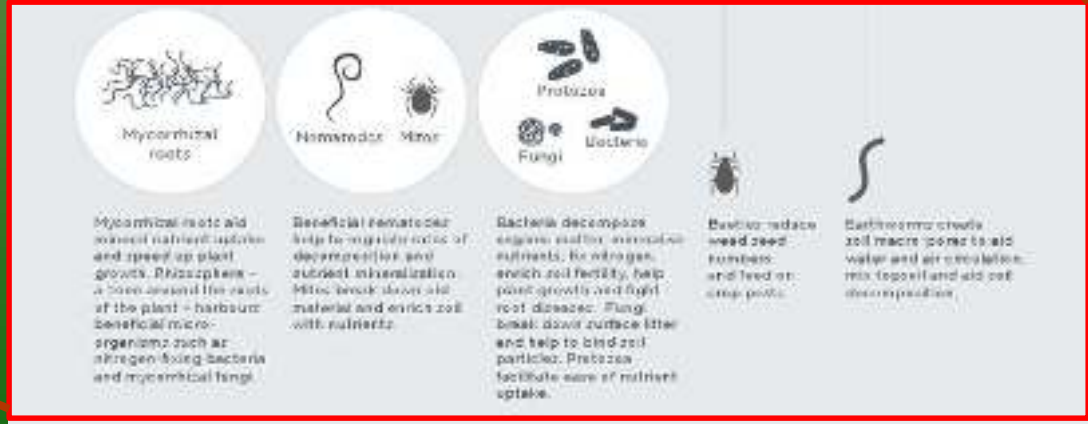
Bacteria decompose organic matter, mineralise nutrients, fix nitrogen, enrich soil fertility, help plant growth and fight root diseases. Fungi break down surface litter and help to bind soil particles. Protozoa facilitate ease of nutrient uptake.

Beetles reduce weed seed numbers and feed on crop pests.

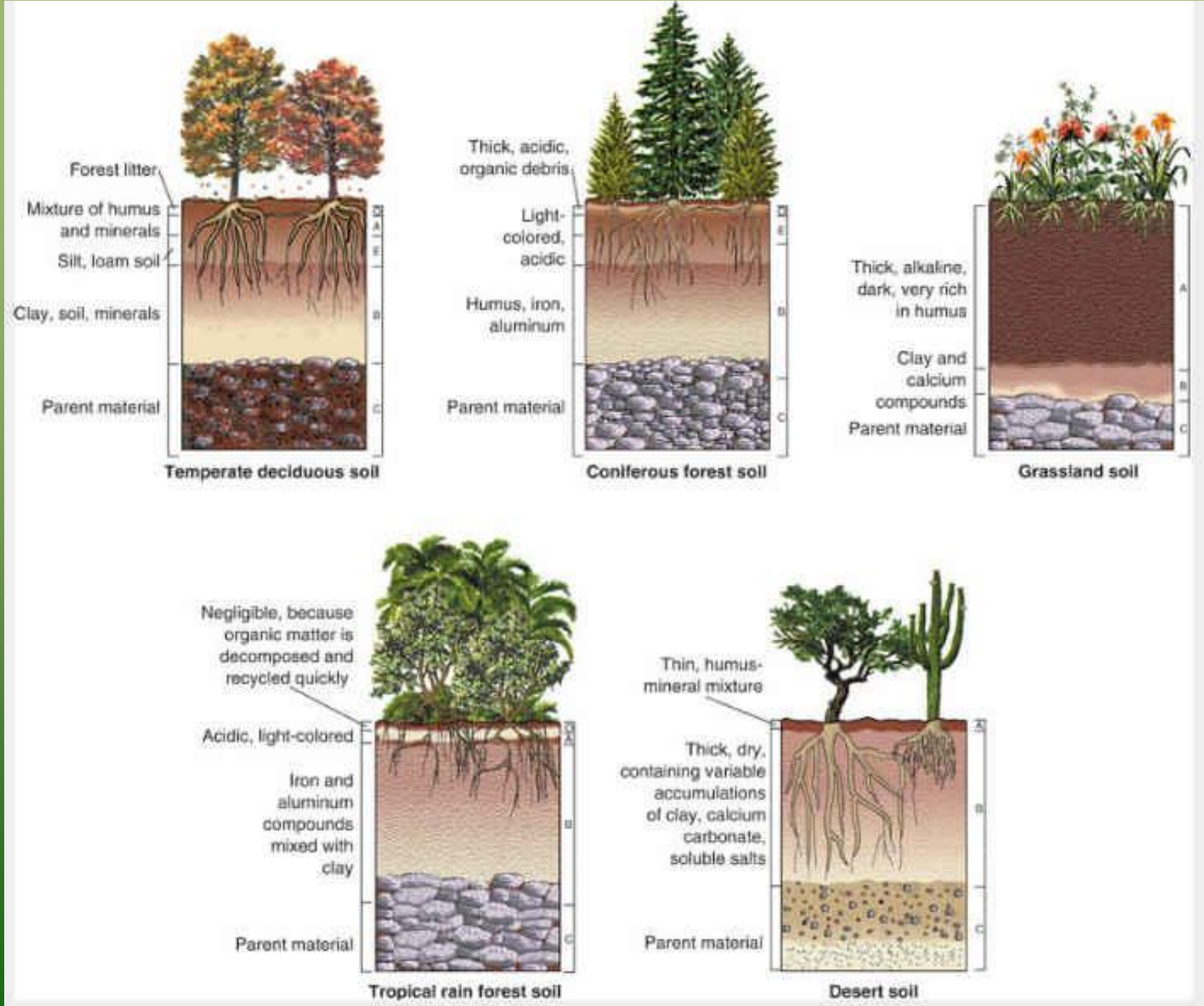
Earthworms create soil macro-pores to aid water and air circulation, mix topsoil and aid soil decomposition.



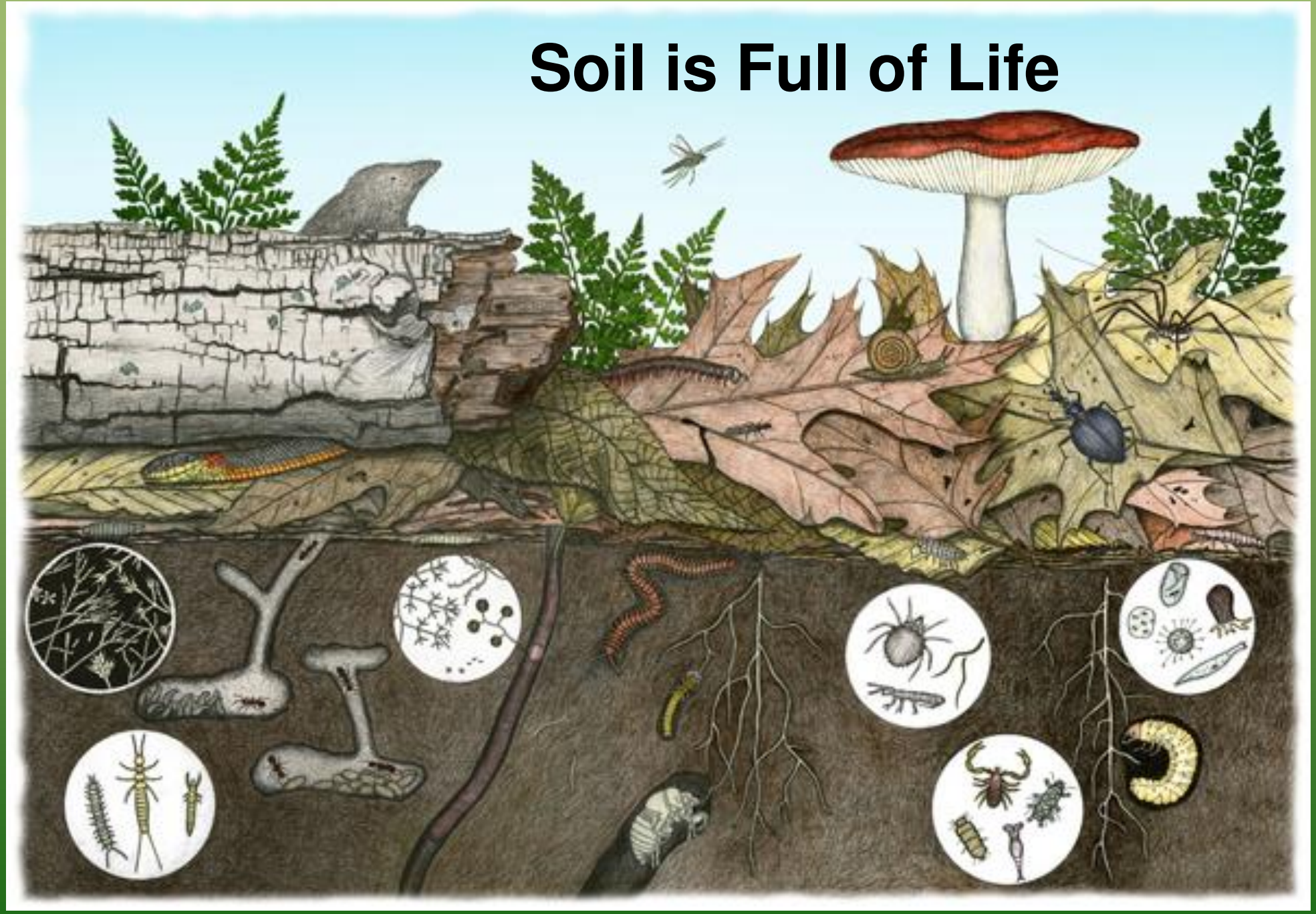
Soil Layers



Soil Layers vary with geology, habitat, ecology, etc.

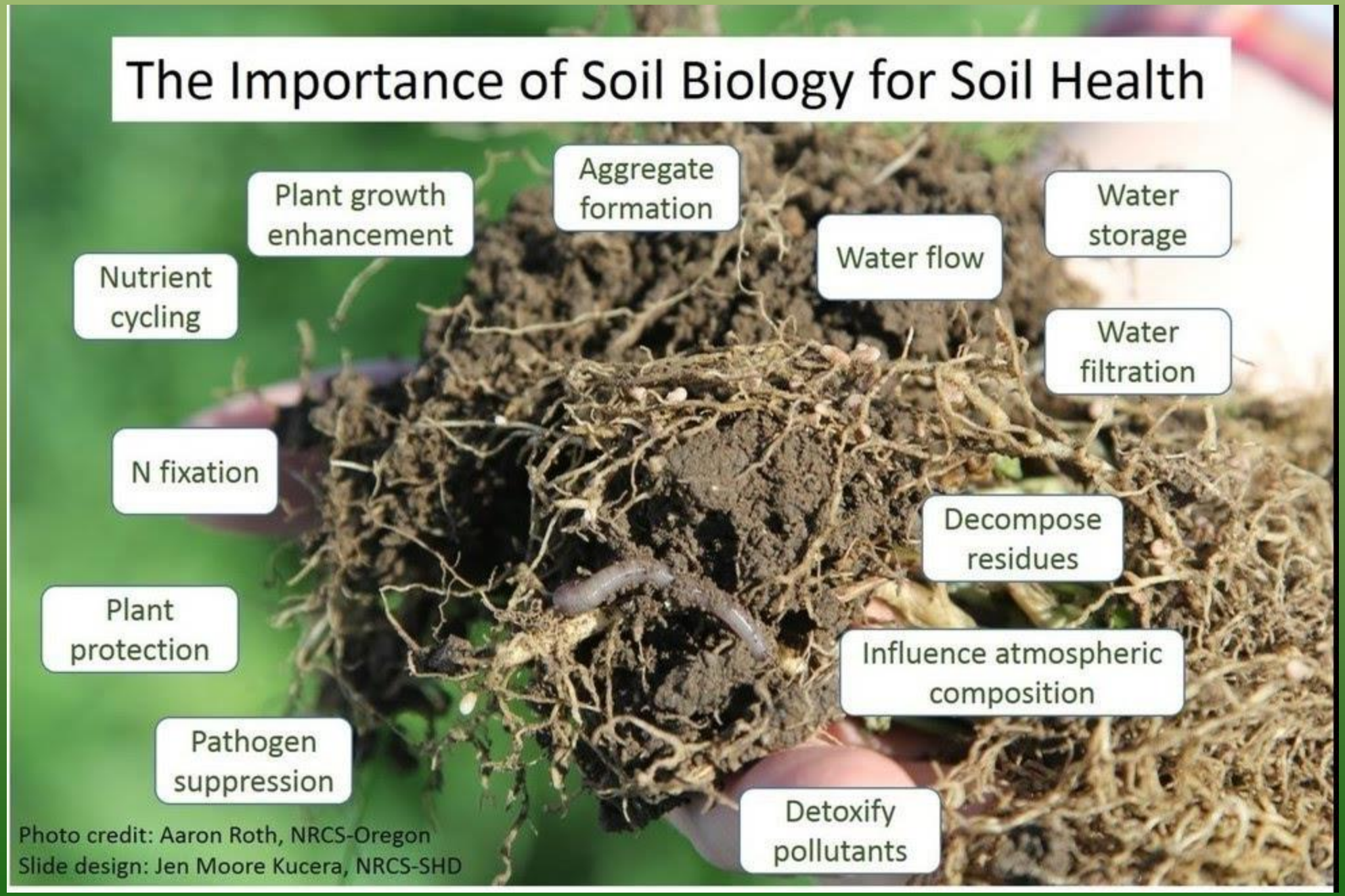


Soil is Full of Life



There are more living organisms in a teaspoon of soil than there are people on earth

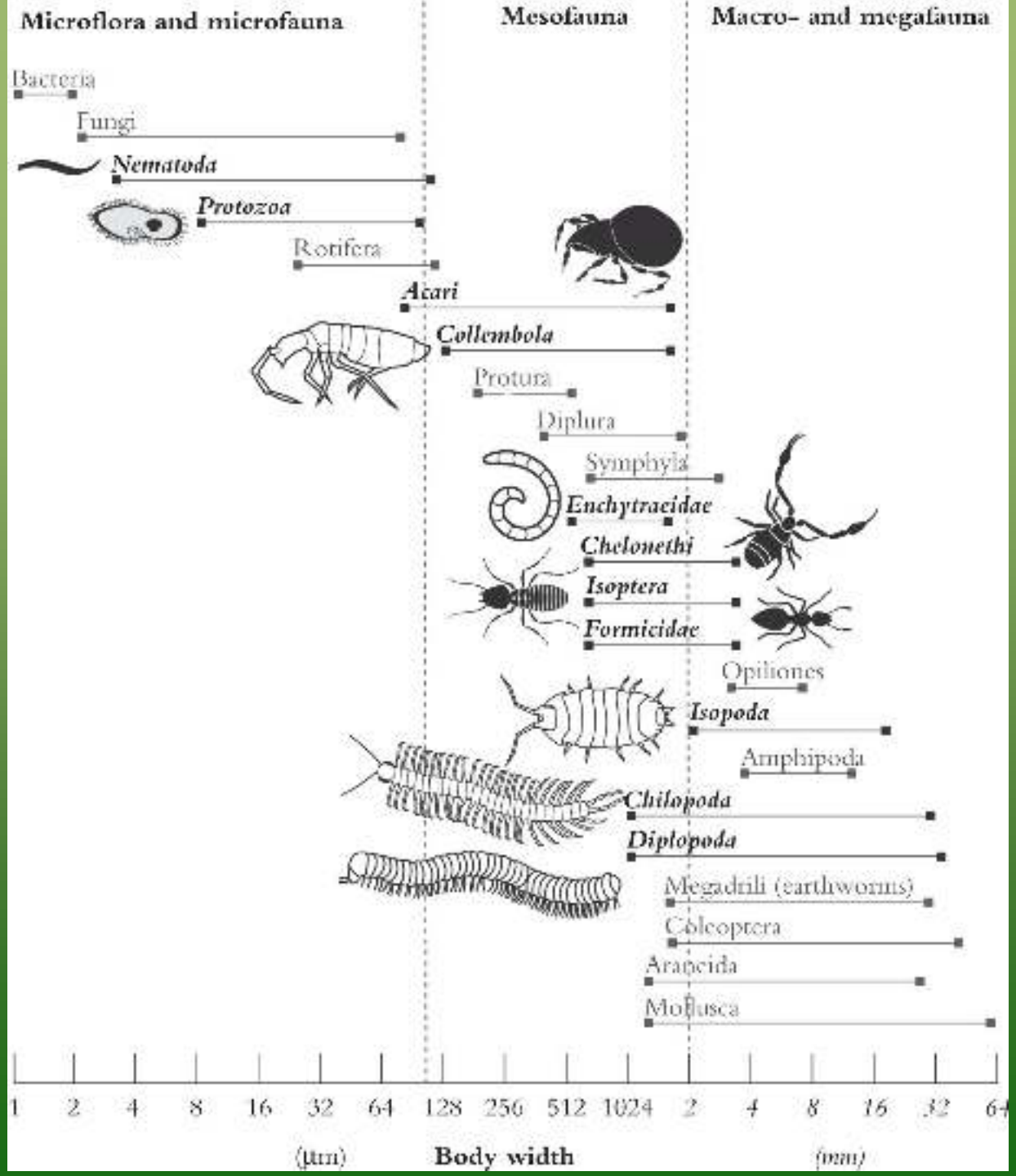
Image from the book The World Beneath Our Feet: A Guide to Life in the Soil by Dr James Nardi


The Importance of Soil Biology for Soil Health
Plant growth enhancement
Aggregate formation
Water storage
Water flow
Nutrient cycling
Water filtration
N fixation
Decompose residues
Plant protection
Influence atmospheric composition
Pathogen suppression
Detoxify pollutants
Photo credit: Aaron Roth, NRCS-Oregon
Slide design: Jen Moore Kucera, NRCS-SHD

Soil Fauna

Soil animals represent nearly 25% of the total diversity of all known living organisms

Nielsen, U. (2019). Soil and Its Fauna. In *Soil Fauna Assemblages: Global to Local Scales* (Ecology, Biodiversity and Conservation, pp. 1-41). Cambridge: Cambridge University Press. doi:10.1017/9781108123518.002



Soil Food Web and Trophic Levels

Producers

1. Little bluestem
2. Partridge pea
3. Nitrogen-fixing bacteria

Primary Consumers

4. Fungi
5. Bacteria
6. Nematodes
7. Earthworm

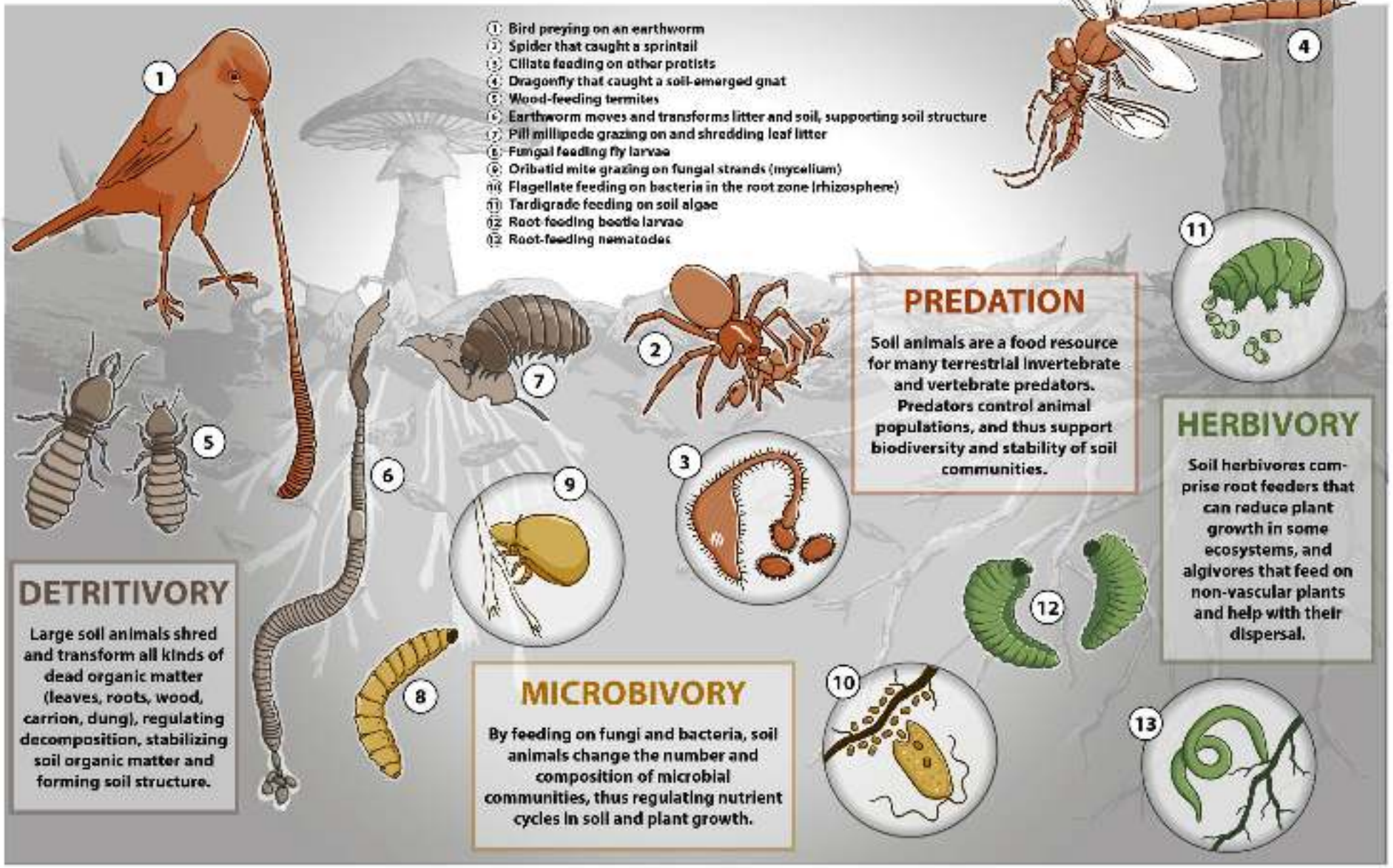
Secondary Consumers

8. Tiger beetle larva
9. Soil centipede
10. Ground beetle

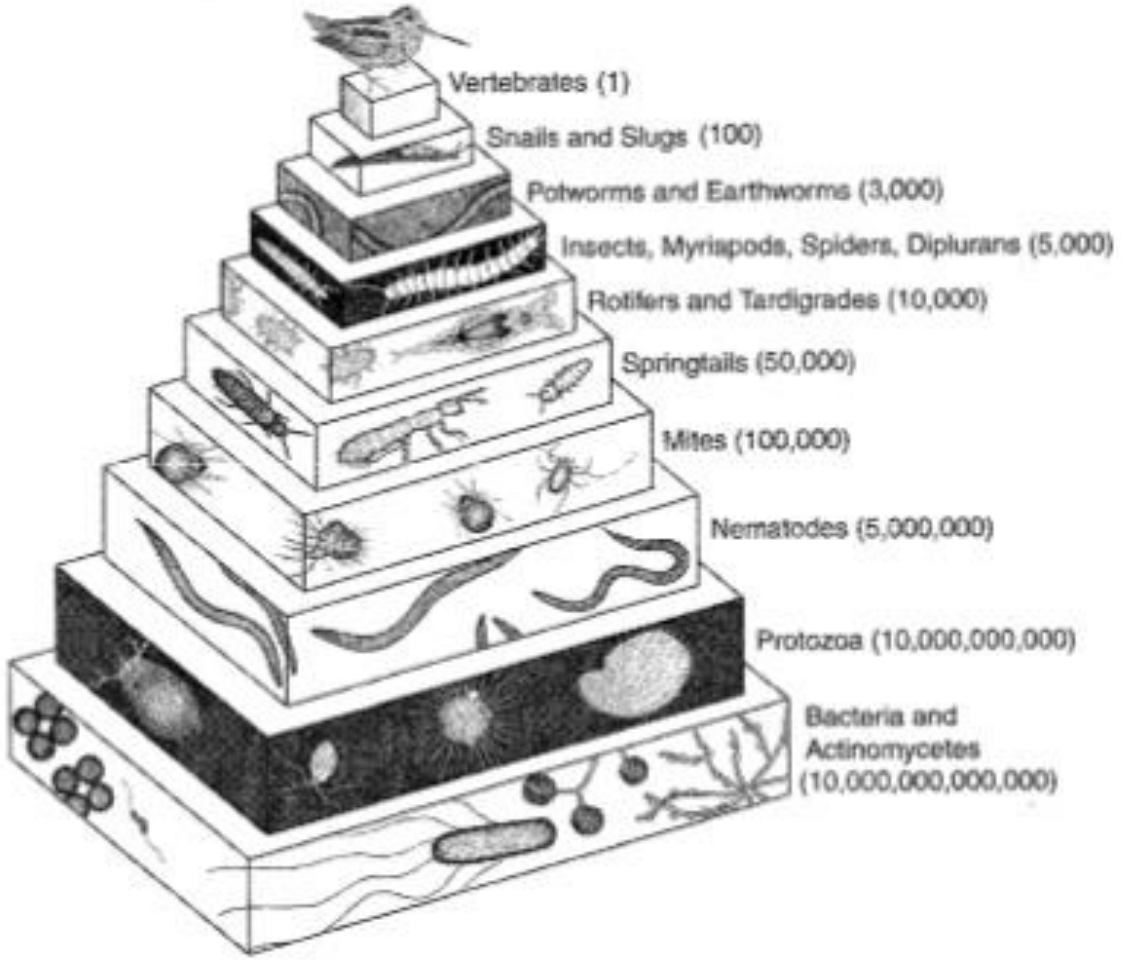
Tertiary Consumers

11. Northern flicker
12. Eastern mole

FEEDING INTERACTIONS AND FUNCTIONING OF SOILS



Foodweb pyramid in one square meter of soil



James B. Nardi, *Life in the Soil*, 2007

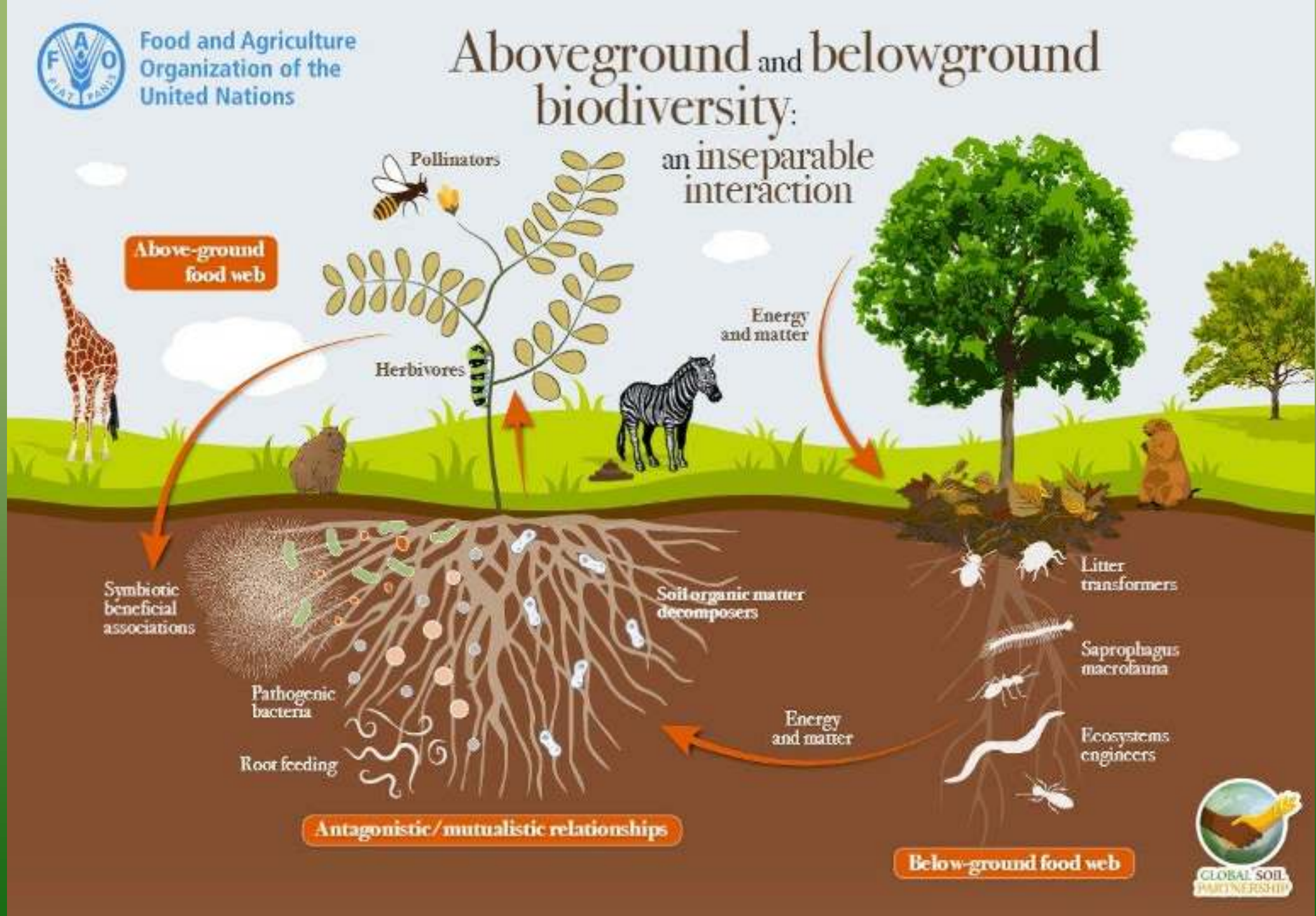
Ecological Roles of Soil Animals

Decomposers
- Break down plant and animal matter into pieces that bacteria and fungi can use

Enrich Soil
- Integrate Nutrients

Soil Engineers
- Tunnel into soil, bring subsoil to surface, help hydrate and aerate soil

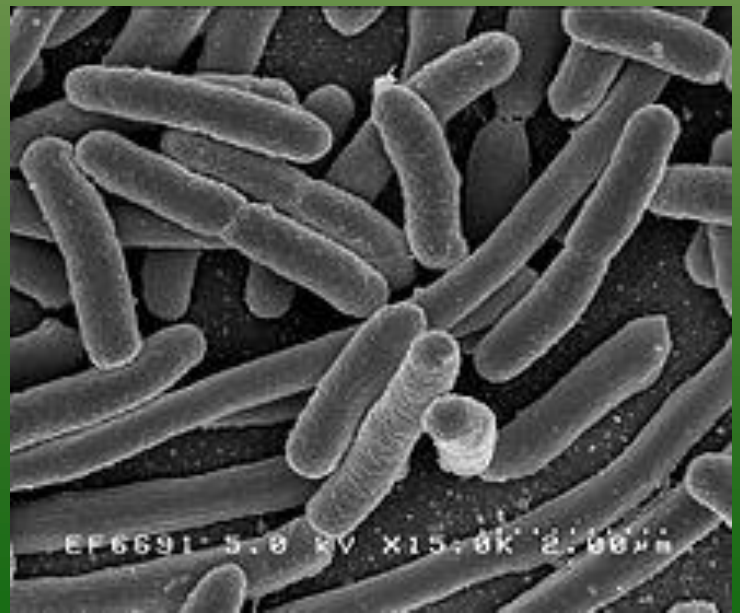
Roles in Food Webs
- Herbivores, fungivores, bacterivores, predators, parasitoids, pollinators


Food and Agriculture Organization of the United Nations
Aboveground and belowground biodiversity:
an inseparable interaction
Pollinators
Above-ground food web
Herbivores
Energy and matter
Symbiotic beneficial associations
Soil organic matter decomposers
Litter transformers
Saprophagus macrofauna
Pathogenic bacteria
Root feeding
Energy and matter
Ecosystems engineers
Antagonistic/mutualistic relationships
Below-ground food web
GLOBAL SOIL PARTNERSHIP

Soil Organisms

Bacteria

- Most abundant soil organism (biomass)
- Feed on carbon, contribute to decomposition, are eaten by micro- and mesofauna
- Transform atmospheric N2 (Nitrogen) to forms that are available to plants



Fungi

- Very abundant
- Decompose plant residue
- Regulate pathogens
- Multiply the capacity of roots to absorb water, nutrients and tolerate drought

Protozoans

What to look for:
- **Amoebae: cytoplasmic extensions**
- **Testate Amoebae: shell-like test**
- **Ciliates: use cilia to sense or move**
- **Flagellates: use whip-like organs to propel**

Where they live:
- **In water film, shallow and deep soil**

Agricultural/Ecological Roles:
- **Important in nutrient cycling, predators, decomposers**

What they eat:
- **Bacteria, algae, fungi**

Rotifers and Tardigrades

(Phylum Rotifera and Tardigrada)

What to look for:

- **Rotifers: crowns of cilia for vortex feeding**
- **Tardigrades (water bears): eight stubby legs with claws, piercing mouthparts**

Where they live:

- **In water films within the soil and leaf litter**

Agricultural/Ecological Roles:

- **Predators and scavengers**

What they eat:

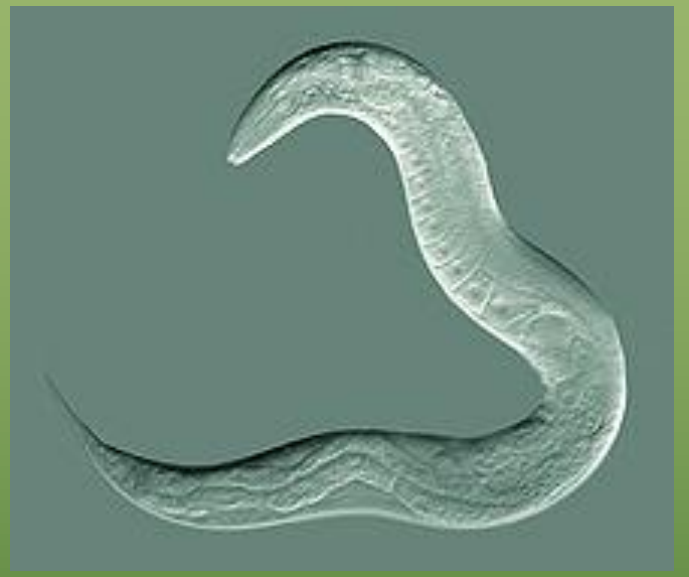
- **Bacteria, protozoa, nematodes, fungi, plants, algae**

Nematodes/Round Worms

Phylum Nematoda

What to look for:

- **Unsegmented transparent worms with tapered ends**
- **Specialized mouthparts for food resources**



Where they live:

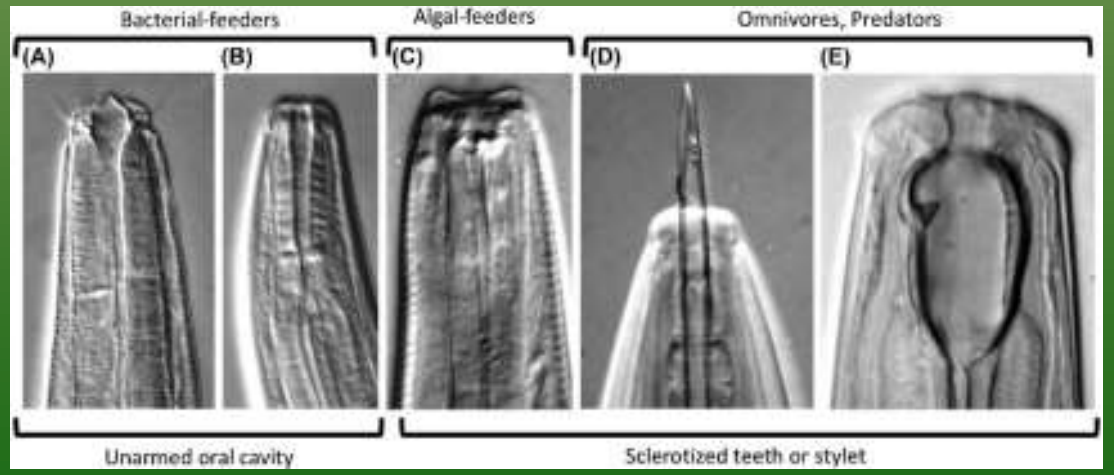
- **In water films or pores within soils**

Agricultural/Ecological Roles:

- **Predators, omnivores, plant parasites**
- **Move bacteria through soil layers**

What they eat:

- **Protozoa, tardigrades, rotifers, other nematodes; bacteria, fungi, plants**



Potworms

(Phylum Annelida, Class Clitellata, Order Tubificida, Family Enchytraeidae)

What to look for:

- **White segmented worms, smaller than earthworms**

Where they live:

- **In upper soil layer**

Agricultural/Ecological Roles:

- **Ecosystem engineers, integrating organic matter and minerals, decomposers, consumers**

What they eat:

- **Fungi, bacteria, decaying organic matter; also ingest soil particles**

Earthworms

(Phylum Annelida, Class Clitellata, Order Opithopora)

What to look for:

- **Tube-like, segmented bodies**
- **Clitellum present, closer to head**

Where they live:

- **Soil surface and leaf litter; with in soil layers, and in deep soil**

Agricultural/Ecological Roles:

- **Impact soil structure through burrowing and mixing; make some nutrients accessible to plants**
- **Some introduced species deplete leaf litter and do not mix nutrients with soil layers**

What they eat:

- **Leaf litter and soil (organic matter)**

Snails and Slugs

(Phylum Mollusca, Class Gastropoda, Order Pulmonata)

What to look for:

- **Slime/mucus covered body with one or two pairs of tentacles on head**
- **Shell in snails**

Where they live:

- **Soil surface and leaf litter; on plants, under logs, bark and rocks**

Agricultural/Ecological Roles:

- **Decomposers, herbivores (Can be agricultural pests), some are predators**

What they eat:

- **Fungi, decaying plant material, plants, dung, carrion**
- **Earthworms, potworms, other snails or slugs.**

Arthropods: Springtails

(Phylum Arthropoda, Class Collembola)

What to look for:

- **Some are elongate, others are globular**
- ***Furcula* that propels like a spring**

Where they live:

- **Leaf litter, decaying logs, fungi, soil surface; within soil layers**

Agricultural/Ecological Roles:

- **Decomposers, some are predators**

What they eat:

- **Decaying plants, fungi, bacteria, pollen, rotifers, nematodes, other springtails**

Arthropods: Millipedes

(Phylum Arthropoda, Class Diplopoda)

What to look for:

- **Elongated, segmented body with two pairs of legs per segment**
- **One pair of antennae, chewing mouth parts**

Where they live:

- **Leaf litter, upper soil layer, under logs, stones, a few in deep soils**

Agricultural/Ecological Roles:

- **Decomposers, scavengers, particularly important in plant decomposition**

What they eat:

- **Decaying vegetation and fungi**

Arthropods: Centipedes

(Phylum Arthropoda, Class Chilopoda)

What to look for:

- Segmented body, often flattened, with one pair of legs per segment
- First pair of legs modified to inject venom

Where they live:

- Soil layers-shallow and deep; under logs, bark and stones

Agricultural/Ecological Roles:

- Predators; some are detritivores

What they eat:

- Earthworms, other arthropods; may also eat small reptiles or mammals

Arthropods: Mites

(Phylum Arthropoda, Class Arachnida)

What to look for:

- Pear shaped, dark bodies
- Adults with eight legs

Where they live:

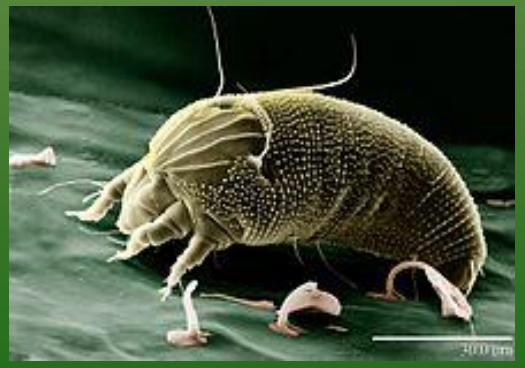
- Soil surface, within soil layers, and in deep soil

Agricultural/Ecological Roles:

- Critical decomposers; some are predatory
- Help disperse bacteria and fungi

What they eat:

- Bacteria, decaying organic material, fungi, springtails, nematodes, insect eggs and larvae



Arthropods: Spiders

(Phylum Arthropoda, Class Arachnida)

What to look for:

- **Two body regions, eight legs, multiple eyes**
- **Fang-like Chelicerae for capturing, injecting or digging**

Where they live:

- **Soil surface, leaf litter, in webs**

Agricultural/Ecological Roles:

- **Predators; move and work the soils**

What they eat:

- **Other arthropods**

Arthropods: Insects

(Phylum Arthropoda, Class Insecta)

Insects: Flower Flies

(Class Insecta, Order Diptera, Family Syrphidae)

What to look for:

- Adults have coloration that mimics bees or wasps
- Larvae are gray-green, legless

Where they live:

- Larvae live within leaf litter or rotting wood or on plants
- Adults on flowers

Agricultural/Ecological Roles:

- Decomposers, predators, pollinators

What they eat:

- Larvae eat decaying vegetation or other insects
- Adults eat nectar, sometimes pollen

Insects: Soldier Beetles

(Class Insecta, Order Coleoptera, Family Cantharidae)

What to look for:

- **Adults with leathery wing covers**
- **Larvae are dark with sickle shaped jaws**

Where they live:

- **Larvae soil, leaf litter, under stones**
- **Adults on flowers**

Agricultural/Ecological Roles:

- **Predators important in biocontrol; pollinators**

What they eat:

- **Insect eggs, larvae; aphids, snails, slugs**

Insects: Fireflies

(Class Insecta, Order Coleoptera, Family Lampyridae)

What to look for:

- **Adults with leathery wing covers**
- **Larvae, heavily segmented**
- **Luminous segments in adults and larvae**

Where they live:

- **Leaf litter, under bark; adults in tall grass**

Agricultural/Ecological Roles:

- **Predators**

What they eat:

- **Snails, slugs, earthworms, caterpillars**

Insects: Ground Beetles

(Class Insecta, Order Coleoptera, Family Carabidae)

What to look for:

- **Adults usually with brown, black color and ridges wing covers**
- **Larvae with sickle like jaws**

Where they live:

- **Soil, leaf litter**

Agricultural/Ecological Roles:

- **Predators important in biocontrol; some also decomposers or eat weed seeds**

What they eat:

- **Snails, slugs, caterpillars, grasshoppers, beetles, flies, more**

R and LR: Jim Kalisch, UNL Entomology

Lynette Schimming, BugGuide.net

Insects: Carrion and Burying Beetles

(Class Insecta, Order Coleoptera, Family Silphidae)

What to look for:

Burying beetles, red, orange and black Carrion beetles: oval bodies, black with yellow or orange

Where they live:

Within or below carrion

Agricultural/Ecological Roles:

Decomposition of animal carcasses

What they eat:

Carrion

Insects: Dung Beetles

(Class Insecta, Order Coleoptera, Family Geotrupidae and Scarabaeidae)

What to look for:

- **Adults with oval bodies, clubbed antennae and scalloped legs**
- **Larvae are c-shaped**

Where they live:

- **Larvae are within dung or within nests with dung**
- **Adults in many habitats**

Agricultural/Ecological Roles:

- **Decomposers; reduce parasitic flies and reduce food pathogen spread; critical to grazing operations, worth more than $380 million/yr; diggers , seed dispersers**

What they eat:

- **Dung, particularly herbivorous mammals**

Insects: Ants

(Class Insecta, Order Hymenoptera, Family Formicidae)

What to look for:

- **Red, brown, black**
- **Constricted “waist” with lobes**
- **Elbowed antennae**

Where they live:

- **Underground in nests, leaf litter**

Agricultural/Ecological Roles:

- **Ecosystem engineers, predators, decomposers, seed dispersers**

What they eat:

- **Small arthropods, dead animals, plants, fungi, sap, seeds**

Insects: Ground Nesting Bees

Class Insecta, Order Hymenoptera, Superfamily Apoidea, Family several)

What to look for:

- **Constricted waist, often hairy, pollen carrying structures**

Where they live:

- **Larvae (young) in nests in the soil, adults are found on flowers**

Agricultural/Ecological Roles:

- **Pollinators of crops and wild plants; diggers**

What they eat:

- **Pollen, nectar**

Insects: Ground Nesting Predatory Wasps

(Class Insecta, Order Hymenoptera, Superfamily Apoidea, Family various)

What to look for:

- **Adults with constricted waist**
- **No pollen carrying structures, not hairy**

Where they live:

- **Larvae (young) in nests in the soil, adults are found on flowers**

Agricultural/Ecological Roles:

- **Predators important in biocontrol; pollinators; diggers**

What they eat:

- **Arthropods, nectar**

Vertebrates

What to look for:
- **Various species**

Where they live:
- **Soil surface and below**

Agricultural/Ecological Roles:
- **Herbivores, predators; ecological engineers**

What they eat:
- **Plants, seeds, other vertebrates, worms, arthropods**

Soil Life: Pests

What to look for:

- **Various species**

Where they live:

- **Soil among plant roots**

Agricultural/Ecological Roles:

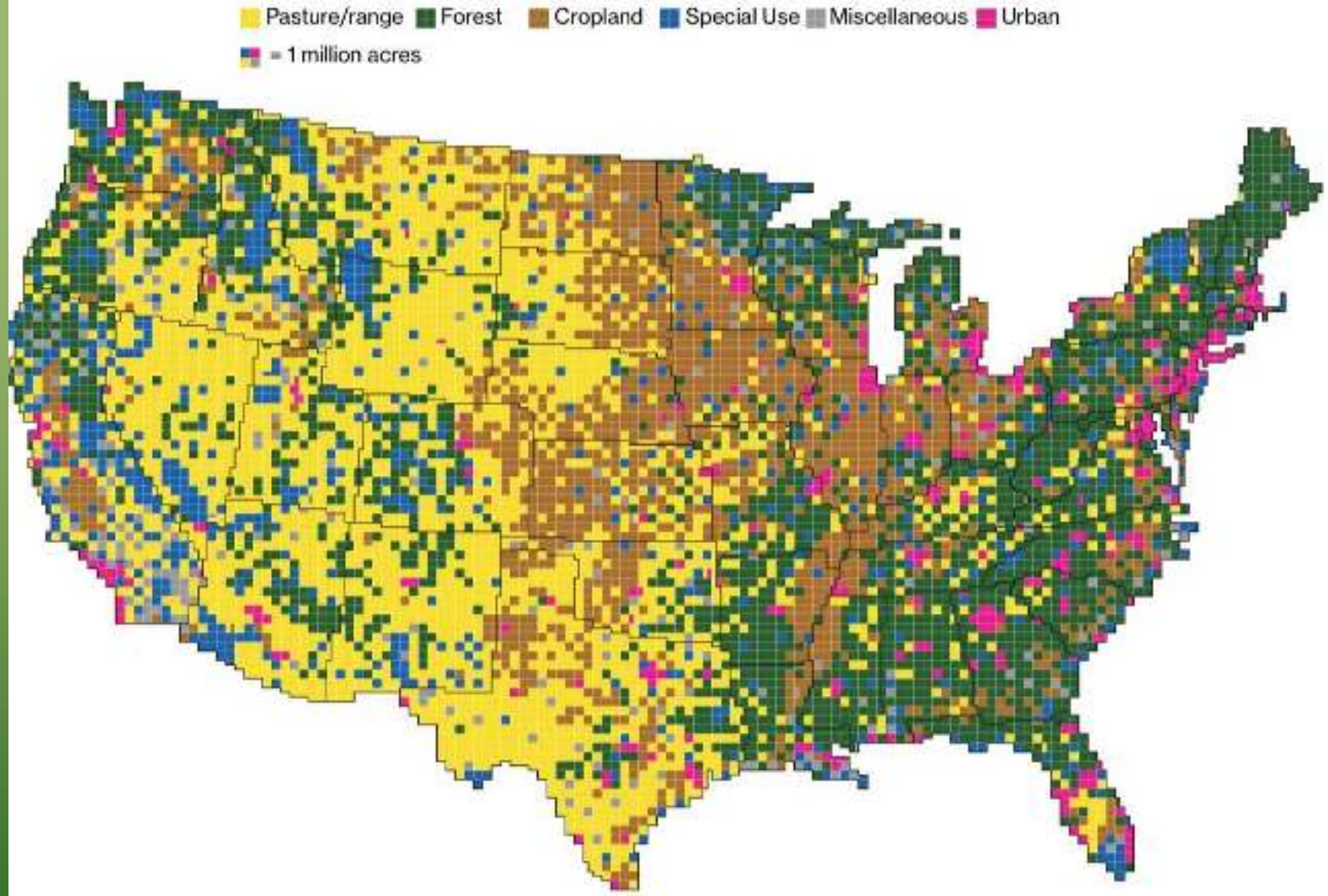
- **Herbivores, decomposers; some are crop pests or ornamental plant pests**
-

What they eat:

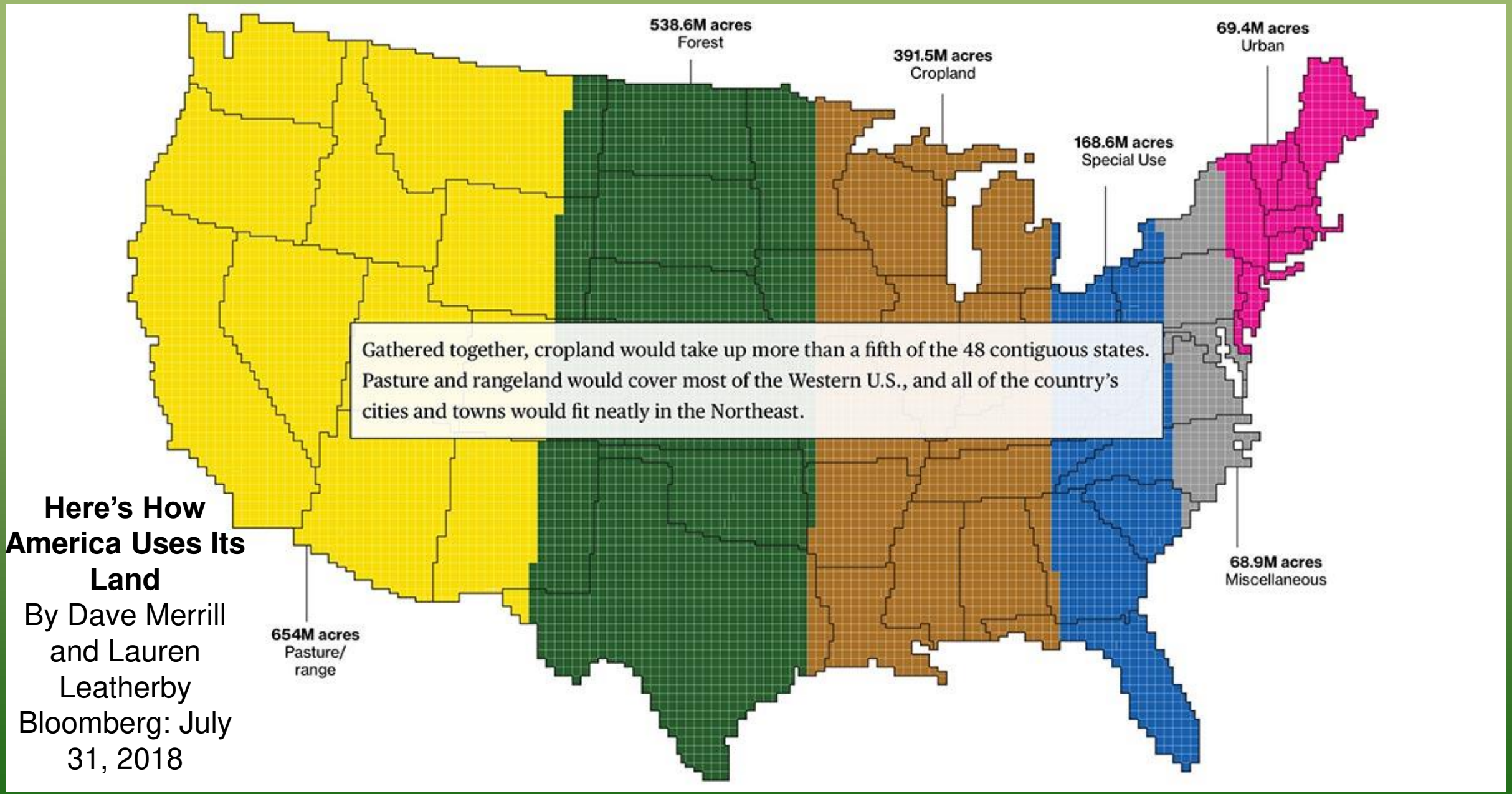
- **Roots, decaying plants and wood**

How do we use soil?

Here's How America Uses Its Land
By Dave Merrill and Lauren Leatherby
Bloomberg: July 31, 2018



Using surveys, satellite images and categorizations from various government agencies, the U.S. Department of Agriculture divides the U.S. into six major types of land. The data can't be pinpointed to a city block–each square on the map represents 250,000 acres of land. But piecing the data together state-by-state can give a general sense of how U.S. land is used.



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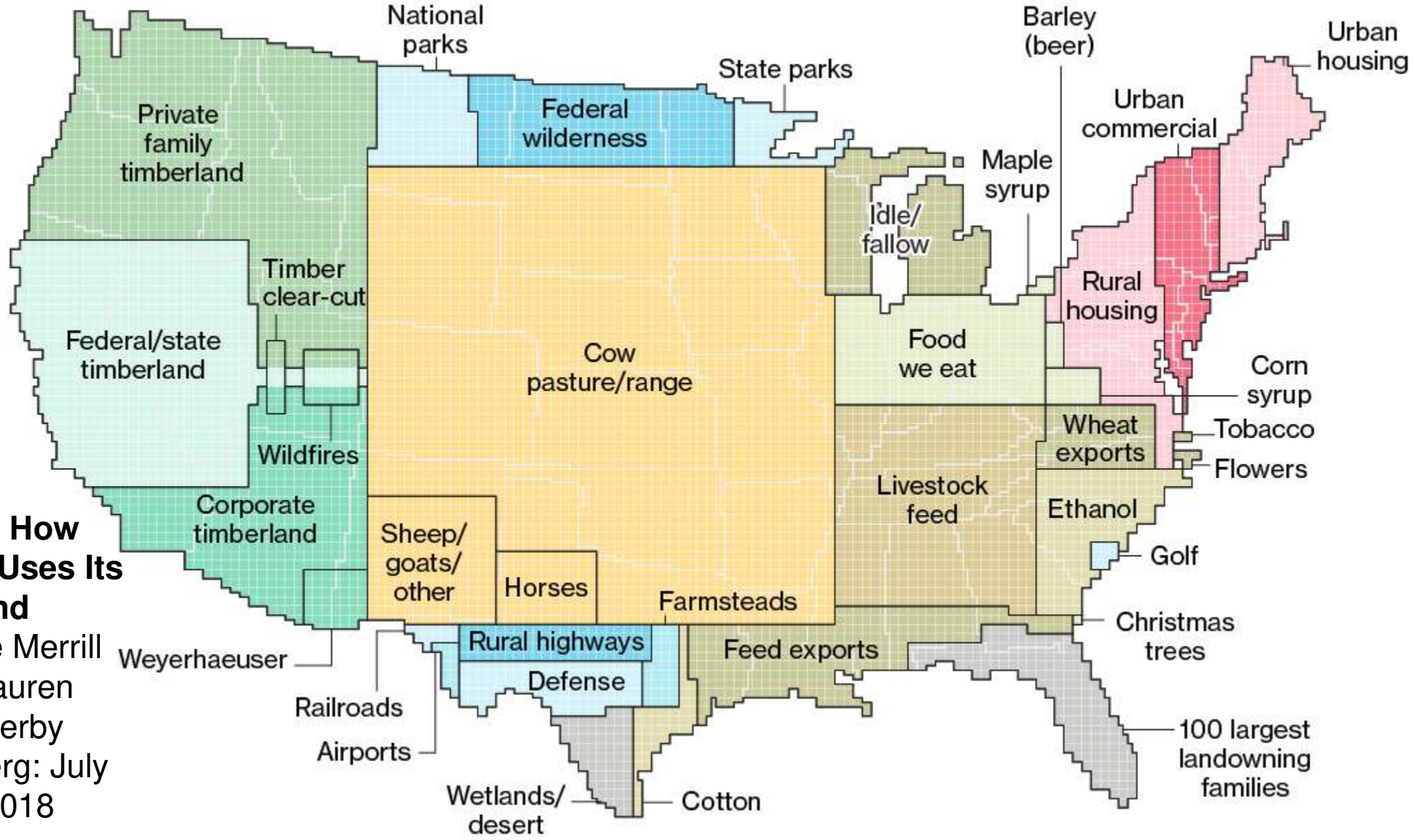
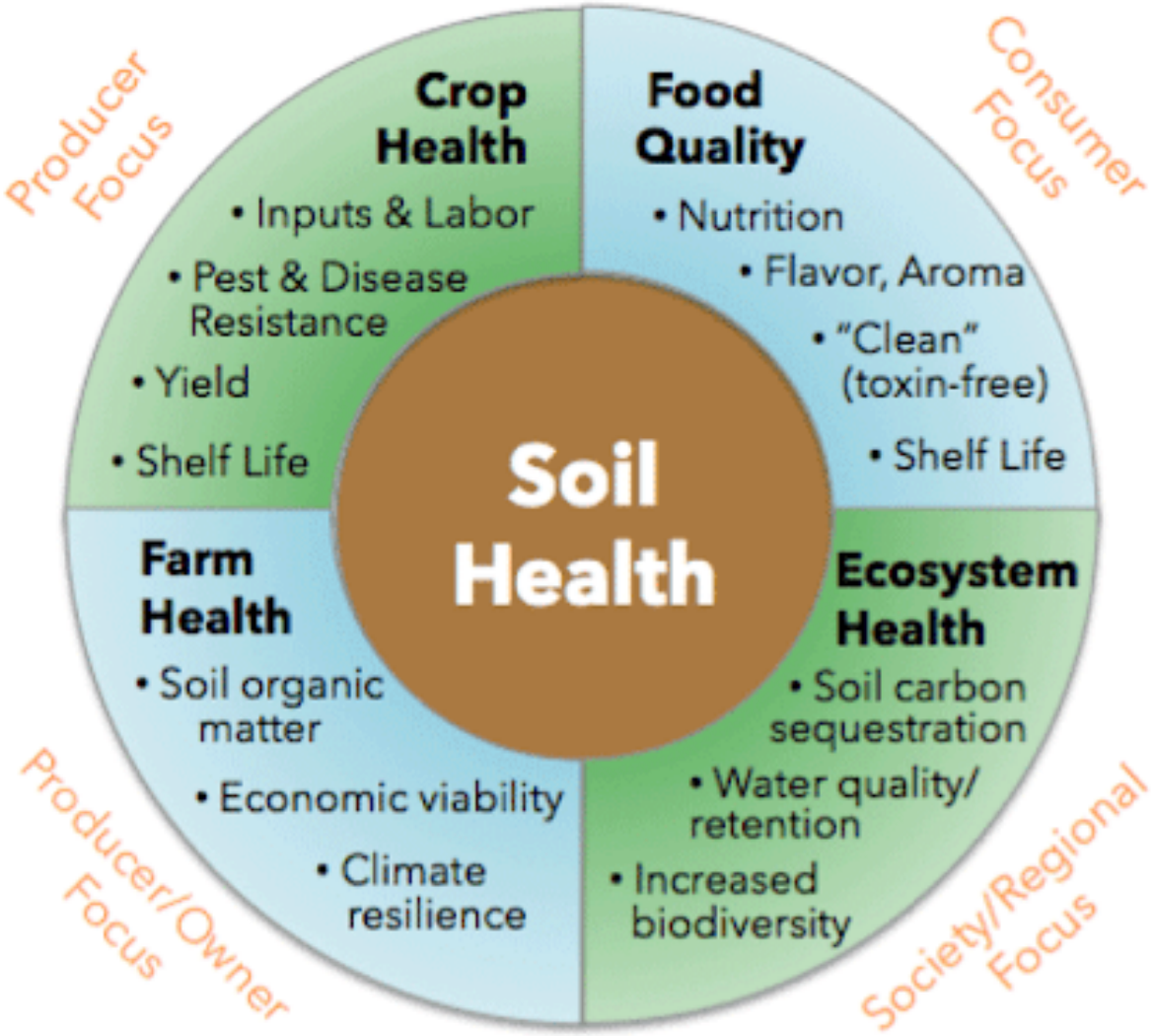


Soil Health

Soil Health, also referred to as ***Soil Quality***, is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans. This definition speaks to the importance of managing soils so they are sustainable for future generations.

Soil Health is Central:

Food, Crop, Farm and Ecosystem Health Dependence Upon Soil Health



Practices that can put Soil Health at Risk

Tillage

- Breaks up soil structure, destroys aggregates and soil pores
- Existing channels for water infiltration from dead roots and earthworm and animal tunnels are lost
- Loss of soil cover increases soil temperatures
- Increases soil loss and water runoff
- Effects food webs
- Destroys nests of ground nesting invertebrates
- Increases Nitrogen loss/runoff

Synthetic Fertilizers

- Creates spikes in the abundance of available nitrogen, phosphorous and potassium can disrupt the process of decomposition and nutrient cycling
- Long-term use of nitrogen fertilizers – especially ammonium based N fertilizers – can accelerate soil acidification, which can affect soil microbial communities

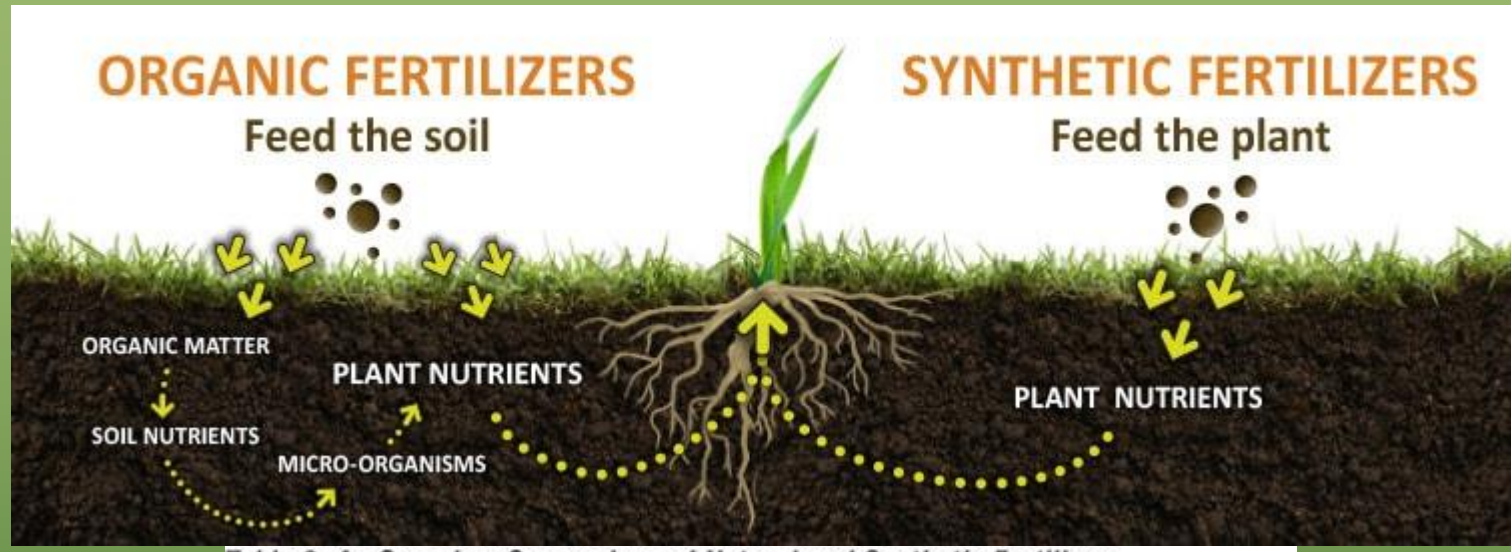


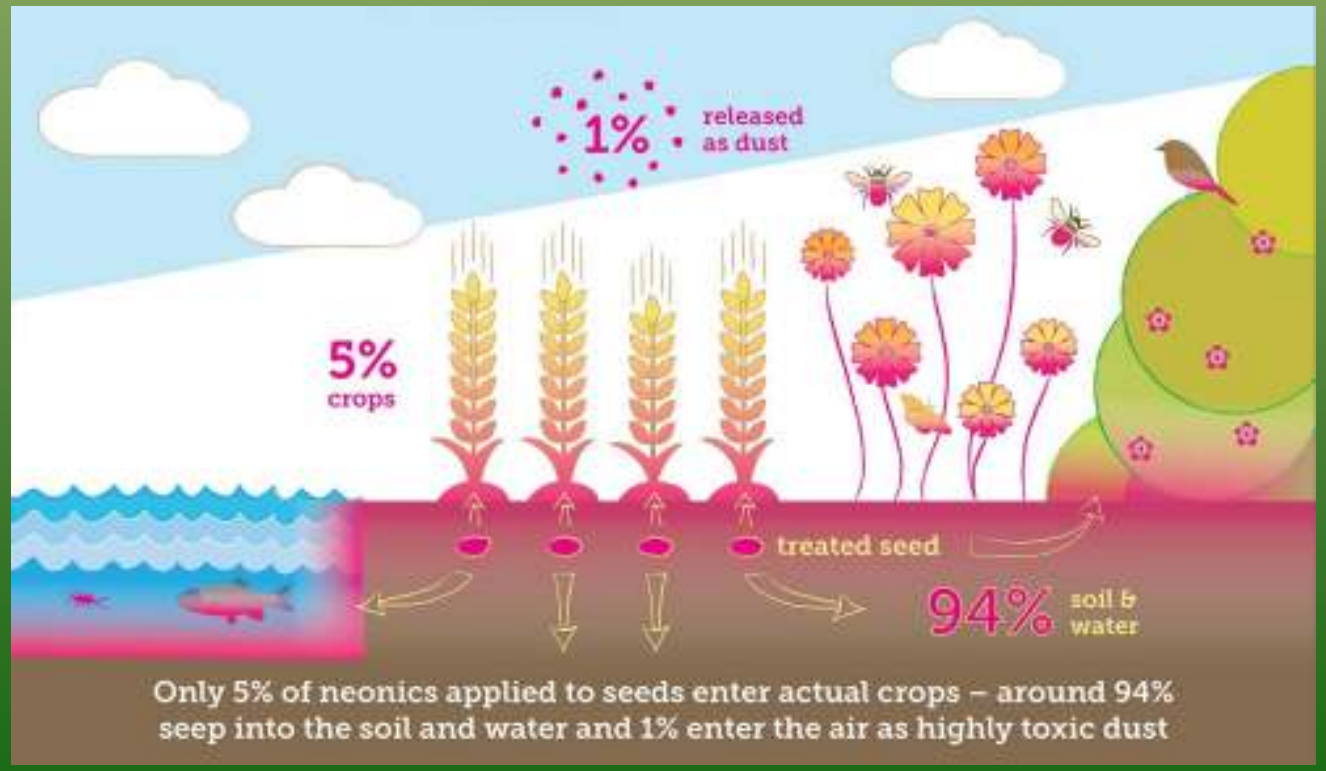
Table 2: An Overview Comparison of Natural and Synthetic Fertilizers

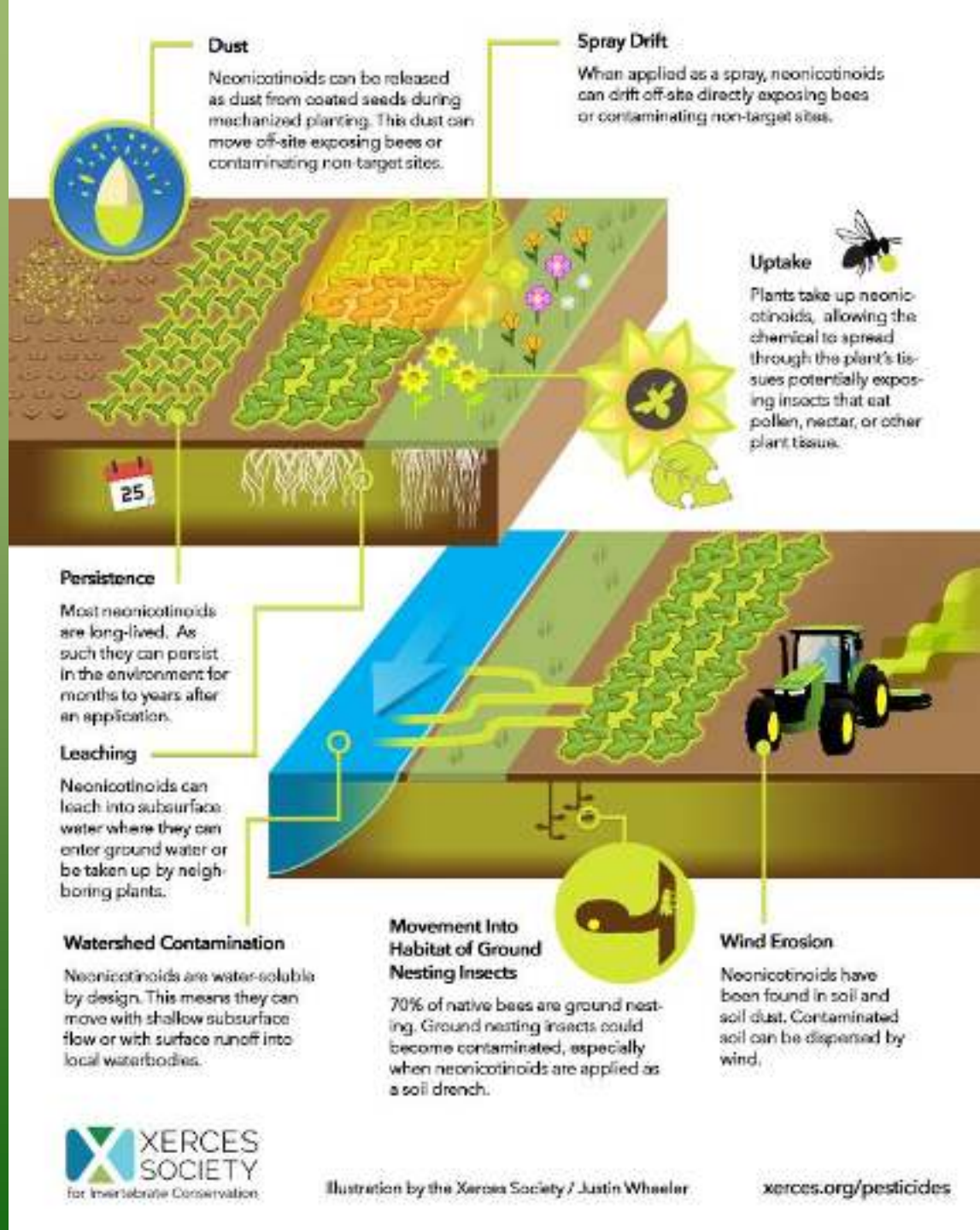
Natural Organic Fertilizer	Synthetic Fertilizer
Less efficient—less N for the money.	More efficient—more N for the money.
Application difficulty due to large amount of applied product and lack of appropriate application equipment.	Application difficulty due to greater potential for physiological burn if overlap is too great.
Slow-release. Dependent on soil temperature (microbial activity) for release.	Tailored to meet needs of turf and season. Readily available to turf in both quick and slow-release forms.
Low input from nonrenewable resources.*	High input from nonrenewable resources.
More sustainable.	Less sustainable.

**Nonrenewable resources include extracted phosphorus and fossil fuels (coal, gas, oil) required to produce the fertilizer, transport it and apply it.*

Fate of Pesticides in Soil

- Direct Effects
- Indirect Effects





MAXIMIZE CONTINUOUS LIVING ROOTS

- Crop Rotation
- Relay Crops
- Forage and Biomass
- Planting
- Perennial Crops
- Cover Crops

MINIMIZE DISTURBANCE

- No-till
- Reduced Tillage
- Controlled Traffic
- Avoid Tillage When Wet
- IPM

MAXIMIZE BIODIVERSITY

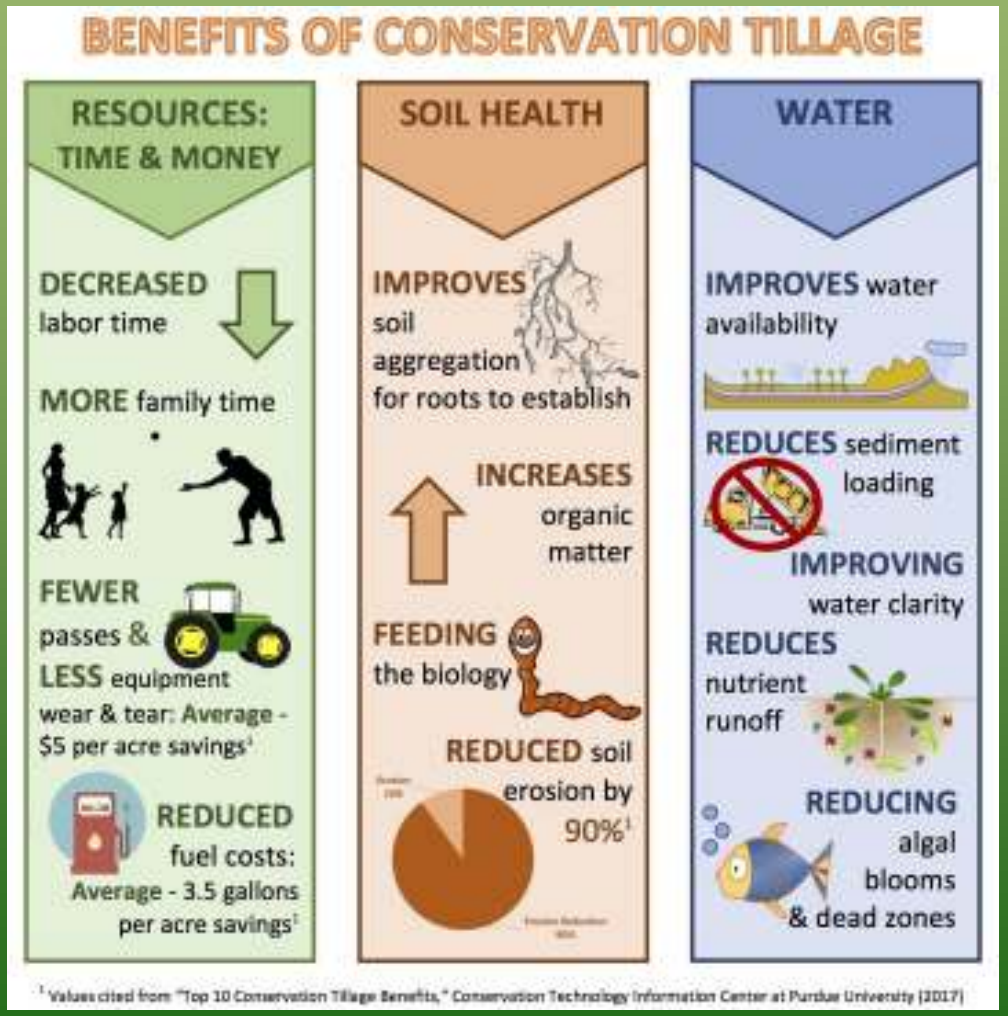
- Crop Rotation
- Rotational Grazing
- IPM
- Pollinator Plantings
- Organic Fertilizers
- Legumes in Mix
- Agroforestry
- Cover Crops
- Crop/Livestock Integration

MAXIMIZE SOIL COVER

- Mulching
- Reduced Tillage
- Forage and Biomass Planting
- Residue Retention
- Cover Crops
- Green Manures

Practices that can improve Soil Health

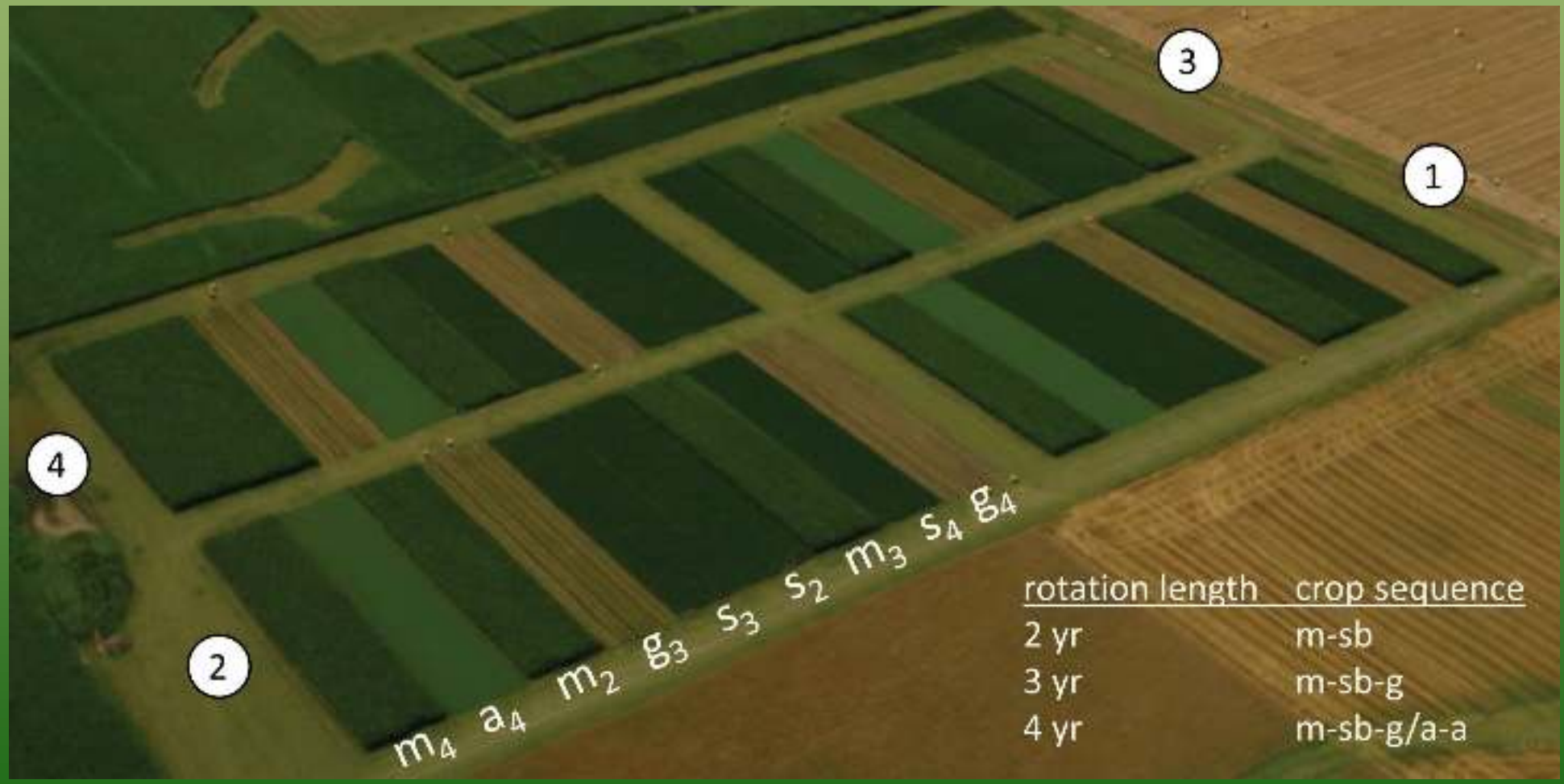
No-Till and Conservation Tillage



Crop Rotation

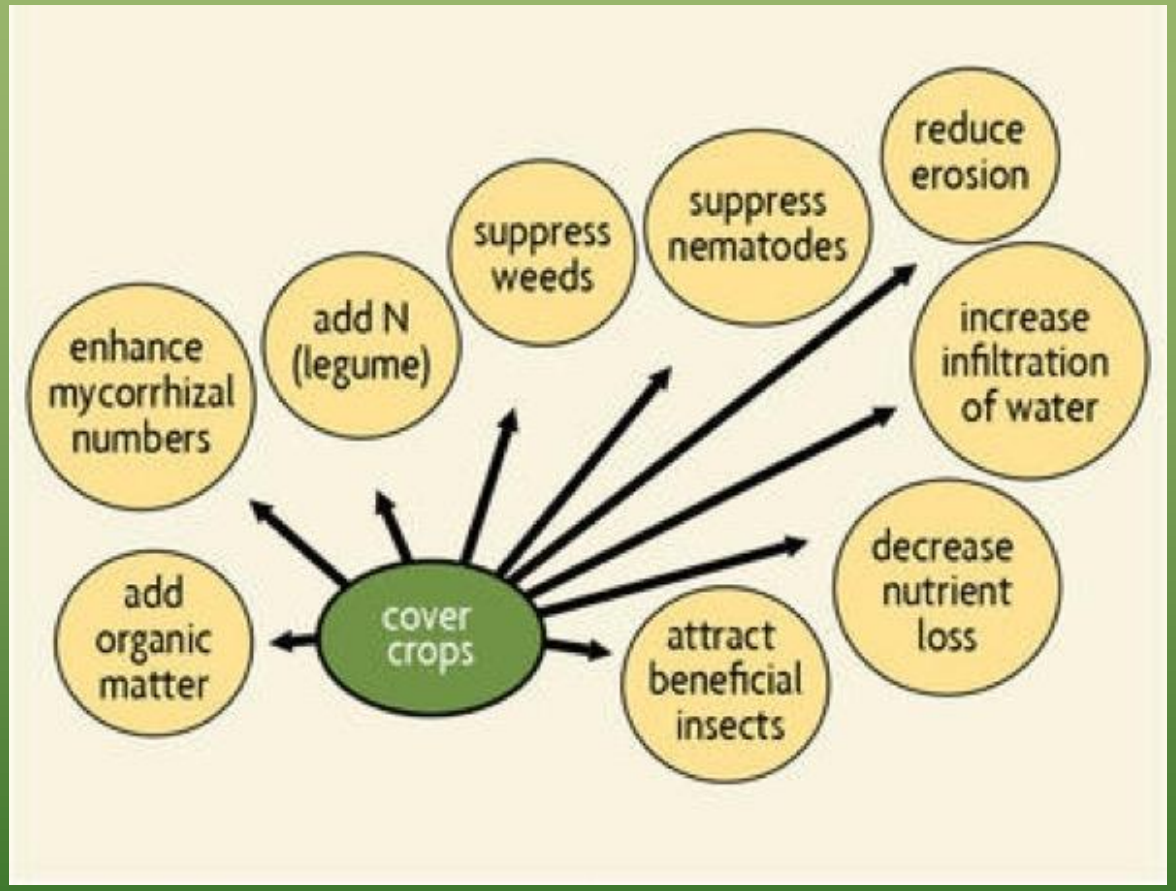
Planting a series of different crops in the same field over a period of years

- Reduces insect damage and disease, maintains soil fertility and reduces soil erosion



Aerial view of the Marsden Farm (Iowa State) plots. (m=corn/maize, s=soybeans, g=small grain, a=alfalfa)

Cover Crops



Summer Flowering Cover Crops Support Wild Bees in Vineyards. Houston Wilson, Jessica S. Wong, Robbin W. Thorp, Albie F. Miles, Kent M. Daane, and Miguel A. Altieri. 2017. Environmental Entomology, 47(1), 2018, 63–69

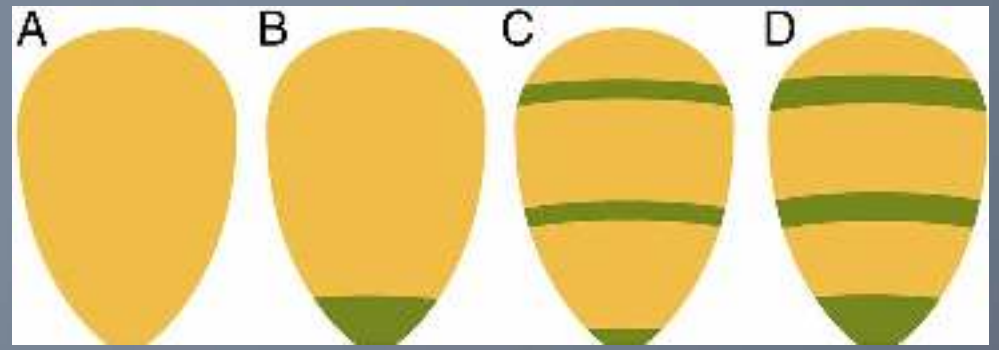
Soil Conservation

- **Contour Plowing**
  - Plowing around hill instead of up-down
- **Strip Cropping**
  - Alternating strips of different crops along natural contours
- **Terracing**
  - Creating terraces on steep slopes to prevent erosion

Prairie Strips

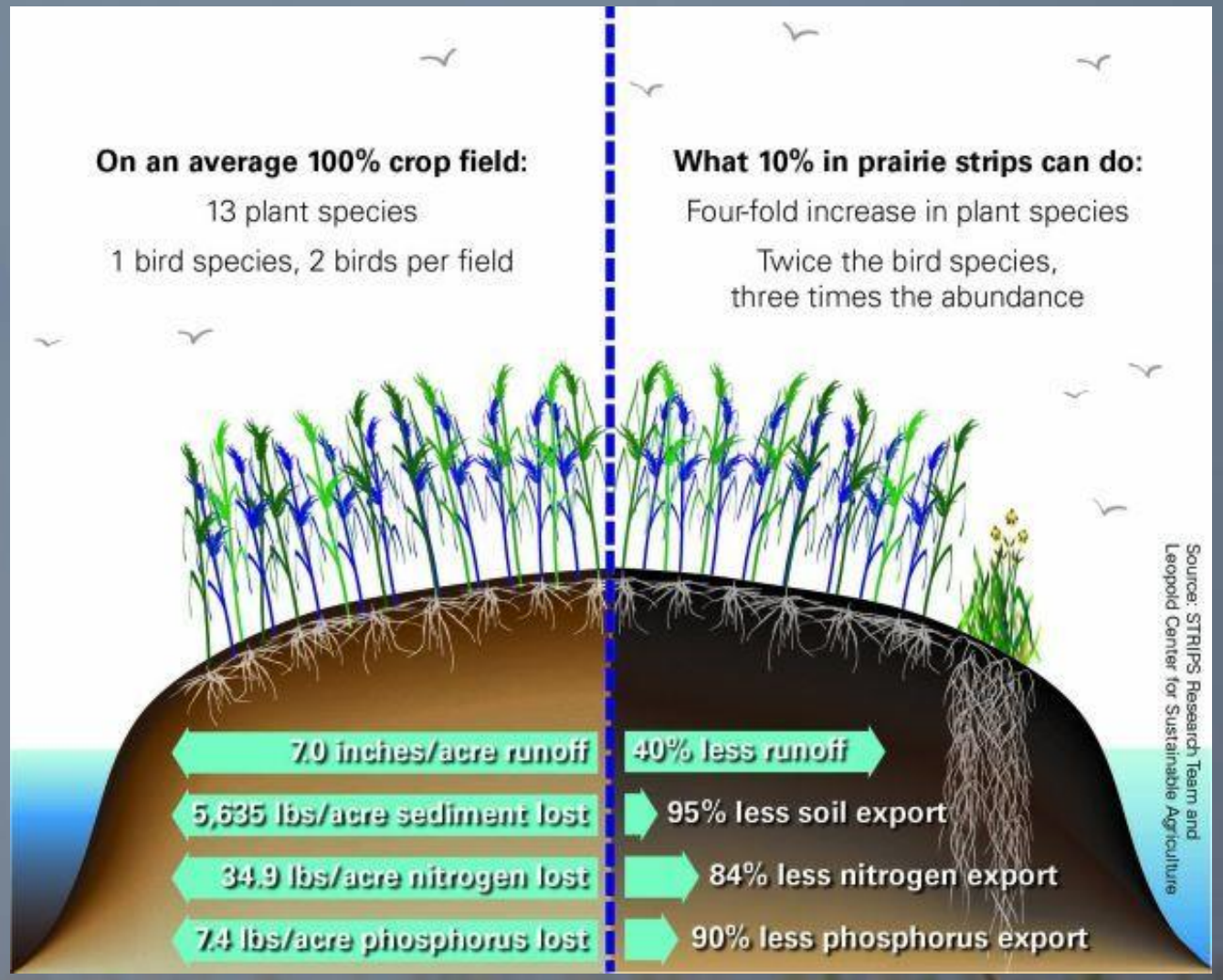
Prairie strips improve biodiversity and the delivery of multiple ecosystem services from corn–soybean croplands

Lisa A. Schulte, Jarad Niemi, Matthew J. Helmers, Matt Liebman, J. Gordon Arbuckle, David E. James, Randall K. Kolka, Matthew E. O'Neal, Mark D. Tomer, John C. Tyndall, Heidi Asbjornsen, Pauline Drobney, Jeri Neal, Gary Van Ryswyk, and Chris Witte. PNAS October 17, 2017 114 (42) 11247-11252



Schematic representation of the STRIPS experiment. Treatments from left to right are 100% row crop control (*A*), 90% row crop and 10% footslope prairie strip (*B*), 90% row crop and 10% contour prairie strips (*C*), and 80% row crop and 20% contour prairie strips (*D*).

Prairie Strips



Insect pollinator abundance was also 3.5 times higher

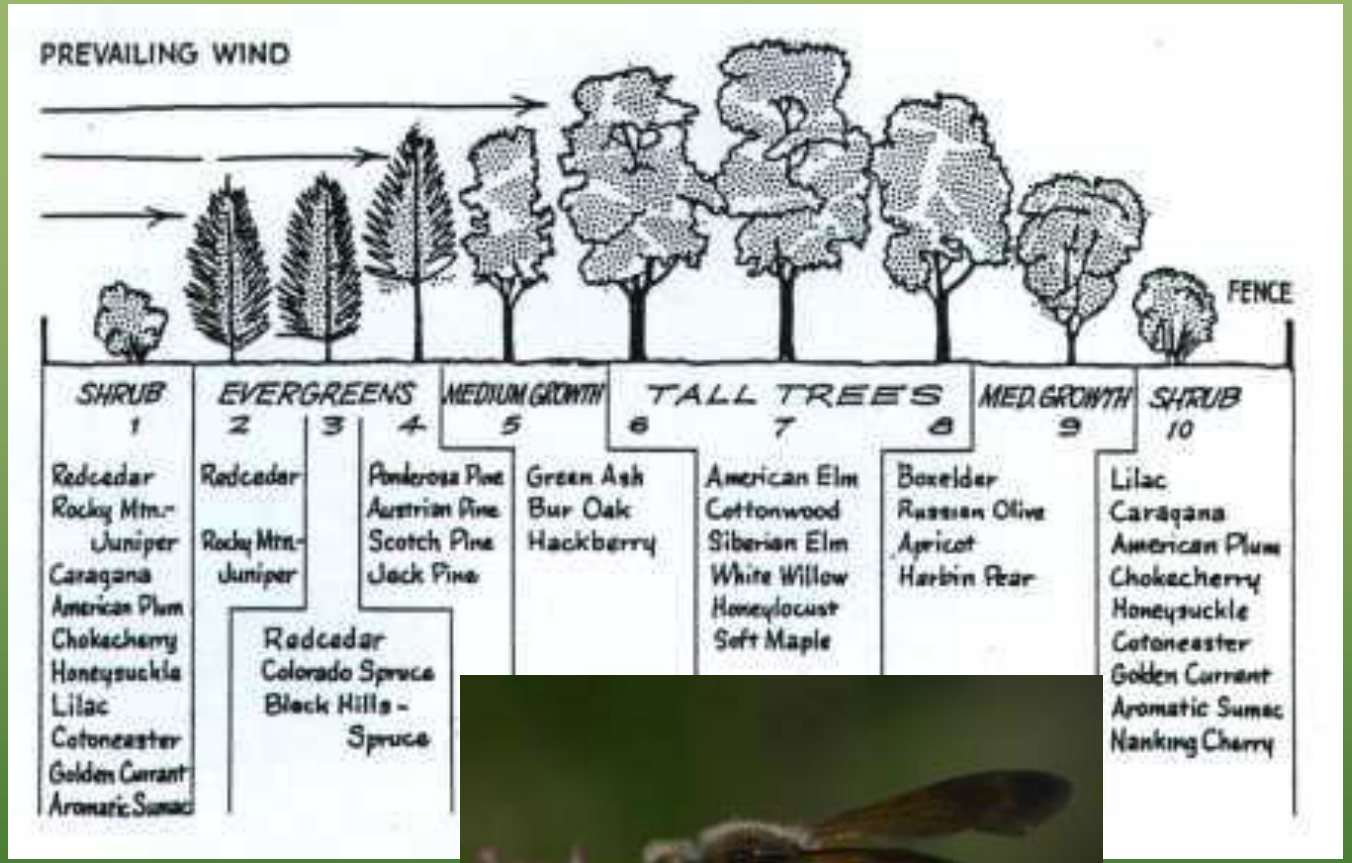
Preserving Soil Fertility

- **Organic fertilizers**
  - Animal manure, crop residue, bone meal and compost
  - Nutrient available to plants only as material decomposes
- **Inorganic fertilizers**
  - Manufactured from chemical compounds
  - Soluble
    - Fast acting, short lasting
    - Mobile- easily leach and pollute groundwater

Windbreaks and Shelterbelts

Some Benefits

- Soil Protection
- Increased Crop Production
- Livestock Protection and Increased Productivity
- Pollinator and Wildlife Habitat
- Pesticide Drift
- Climate Amelioration
- Farm and Home Protection
- Possible Wildlife Corridors



Mulch

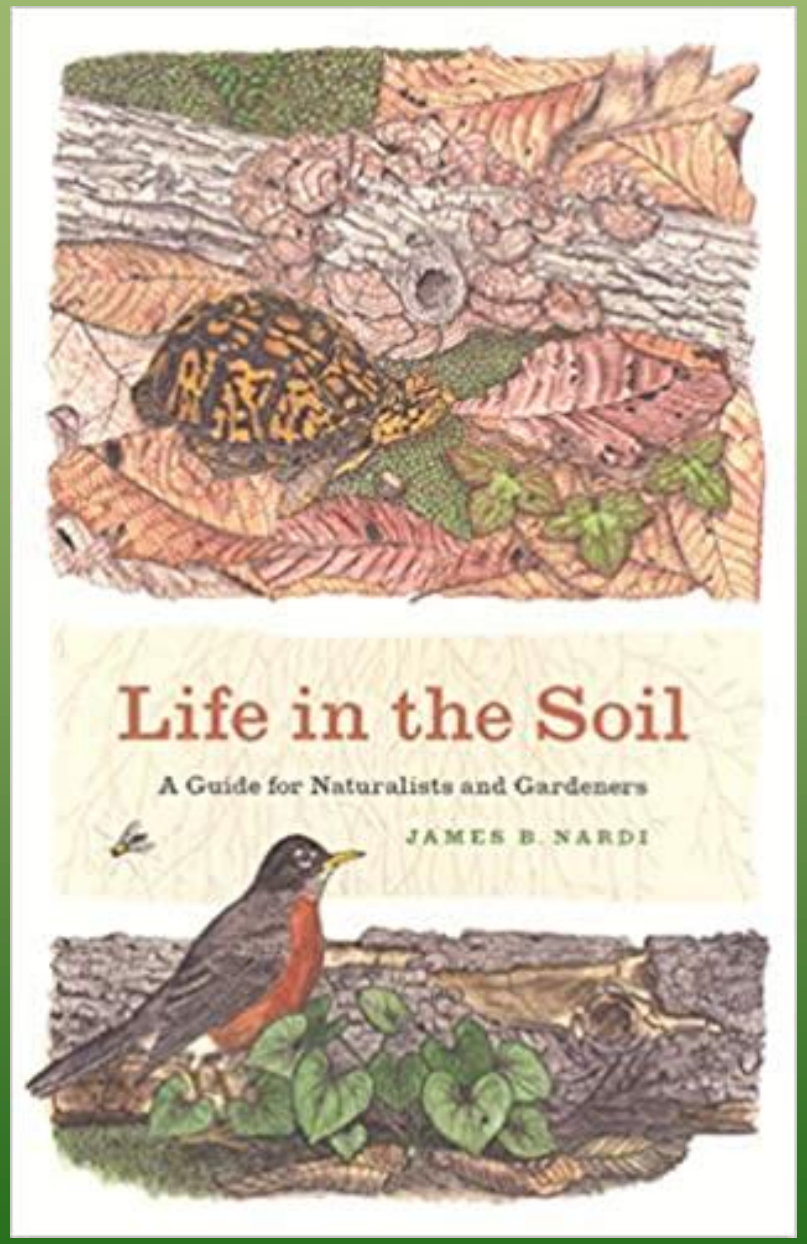
Mulch is simply a protective layer of a material that is spread on top of the soil

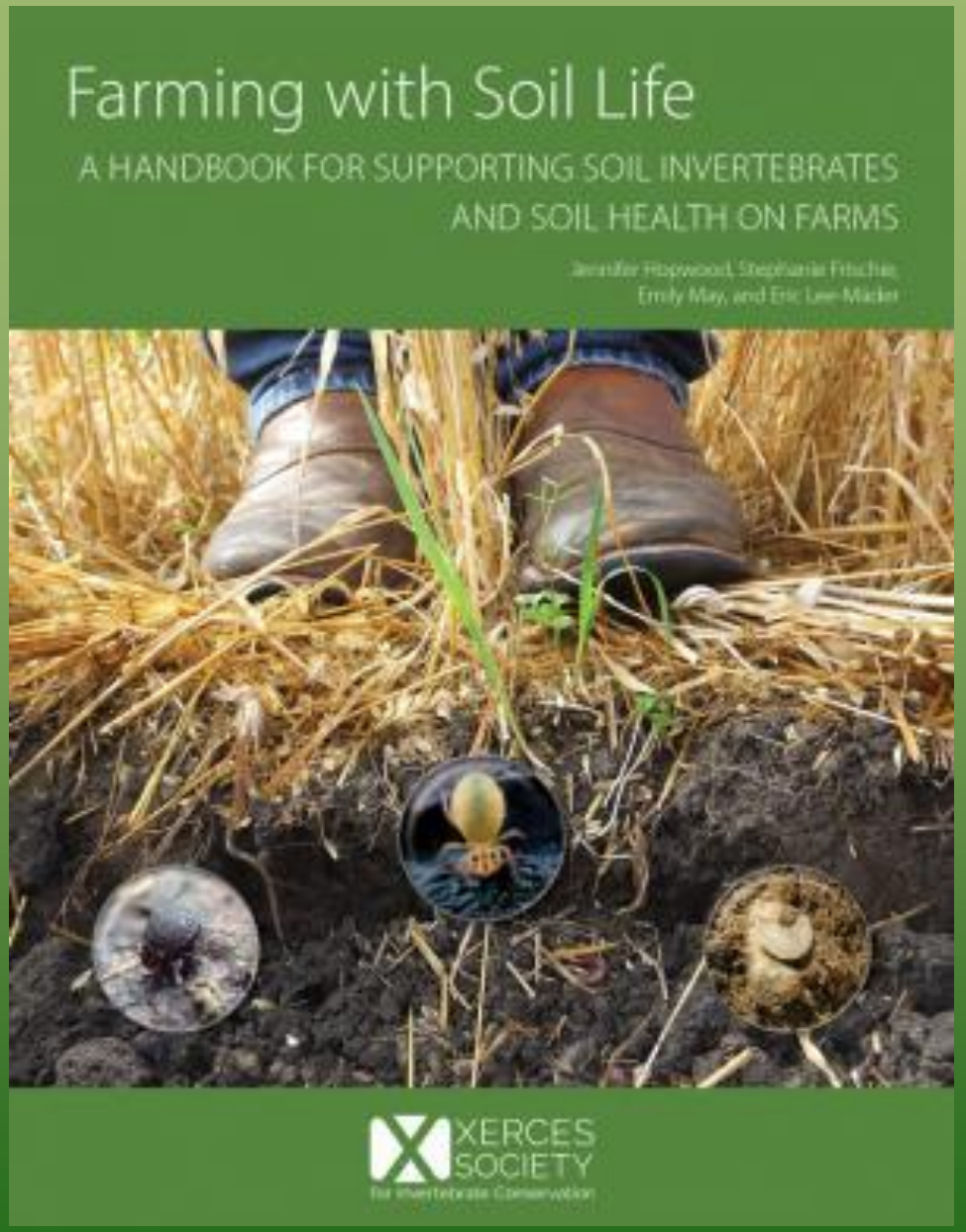
Mulch

- Protects the soil from erosion
- Reduces compaction from the impact of heavy rains
- Conserves moisture, reducing the need for frequent watering
- Maintains a more even soil temperature
- Prevents weed growth
- Keeps fruits and vegetables clean
- Keeps feet clean, allowing access to garden even when damp
- Provides a "finished" look to the garden
- Organic mulches also improve the condition of the soil.

Farming Practices and Soil Life

	More Soil Life		Less Soil Life
Tillage	No-Till	Minimal	Conventional
Fertilizers	Organic		Inorganic
Pesticides	Lower		Higher
Above-ground Diversity	Higher		Lower


Life in the Soil
A Guide for Naturalists and Gardeners
JAMES B. NARDI


Farming with Soil Life
A HANDBOOK FOR SUPPORTING SOIL INVERTEBRATES AND SOIL HEALTH ON FARMS
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