Soil health: the secret to sustainable agriculture

Presented by: Amrita Mukherjee
Title: Small Farm Advisor- UC Cooperative Extension

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

How Quickly We Forget?

Timothy Egan's The Worst Hard Time

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

Spiral of Soil Degradation

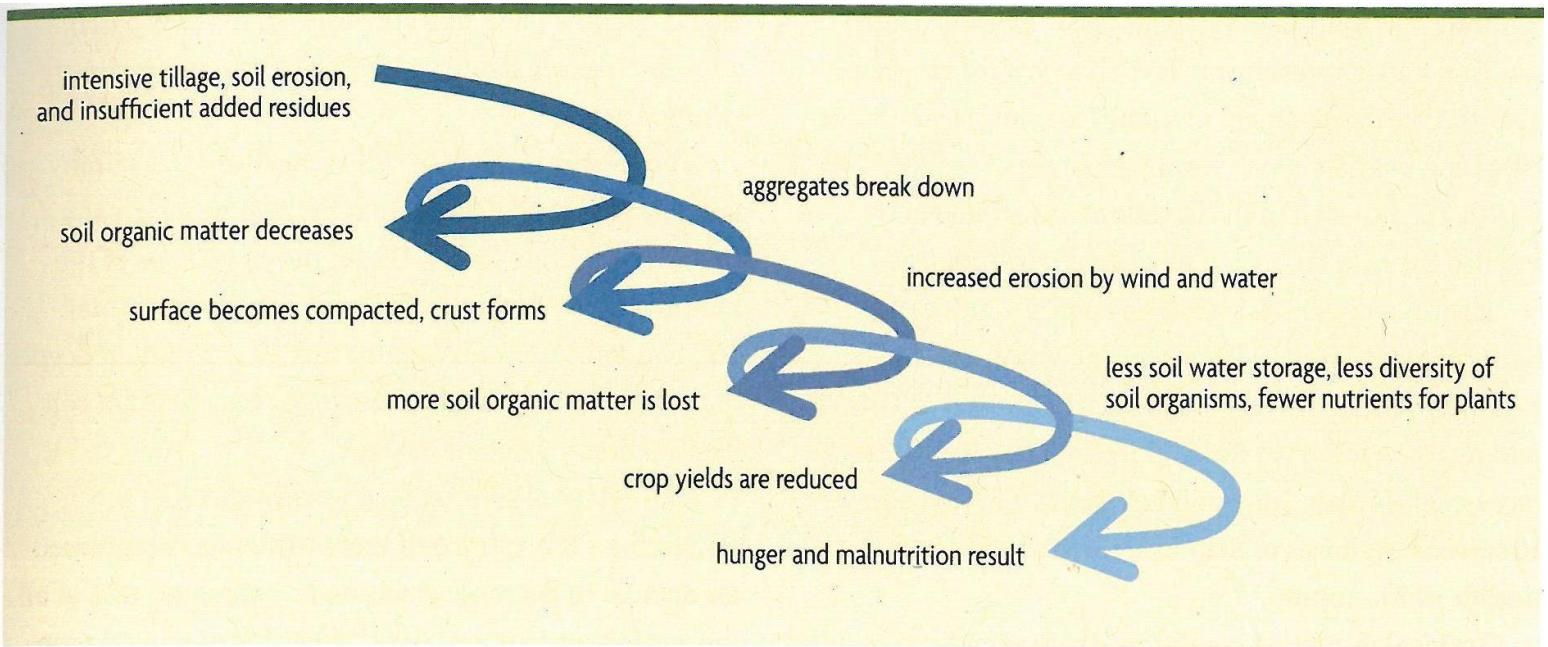


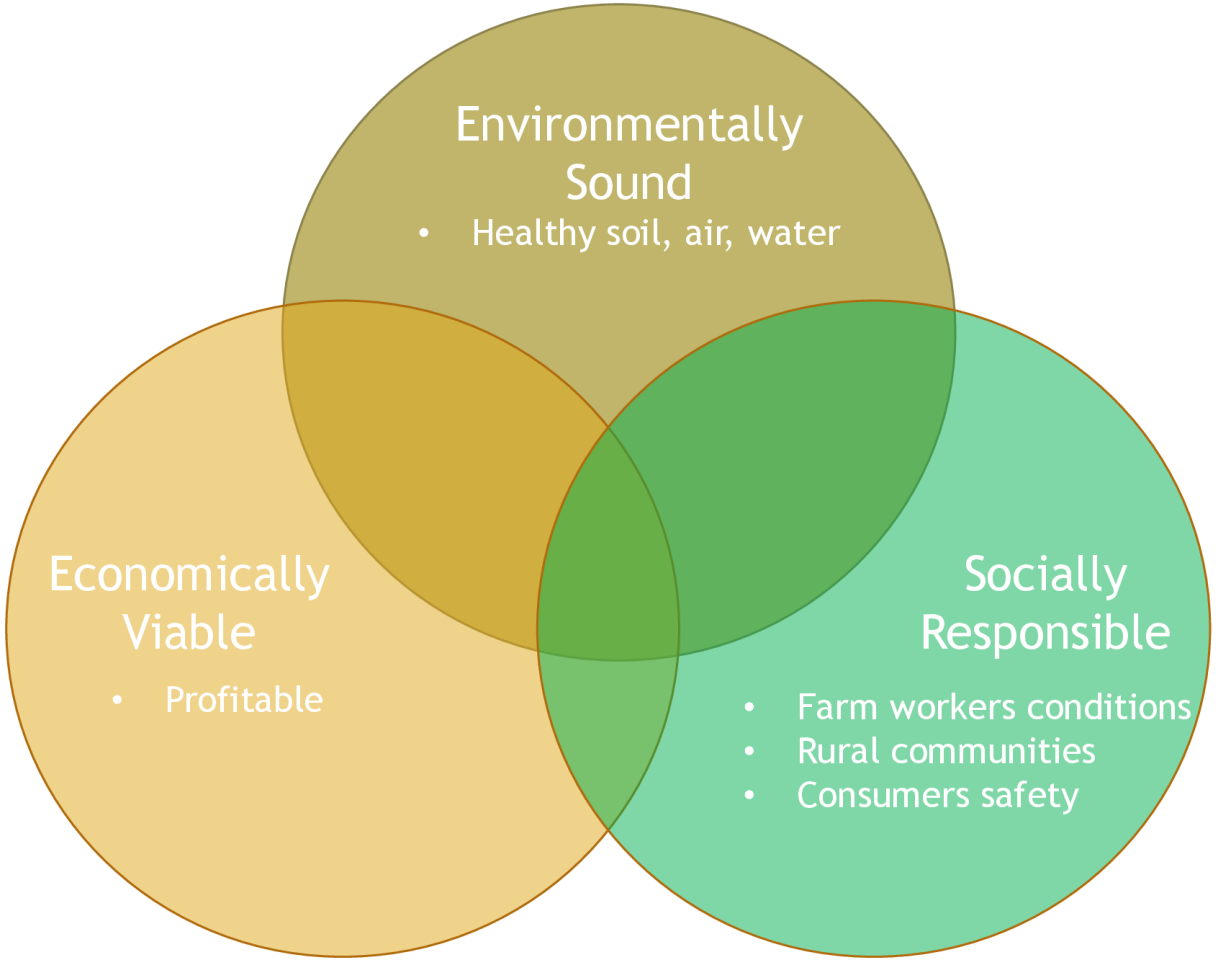
Figure 1.1. The downward spiral of soil degradation. Modified from Topp et al. (1995).

Magdoff and Van Es, 2009. Building Soils for Better Crops. p. 5.

Why is Soil Health Critical?

- Rapidly increasing world population with increased food and fiber supply requirements
- Continued loss of prime farmland to development
- Improved long-term sustainable agriculture production
- Enhanced economic viability
- Improved environmental resilience

Sustainable Agriculture and Organic Farming



UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

Definition

- Soil health is the capacity of a soil to maintain its function and flow of ecosystem services given a specific set of physical, chemical and environmental boundaries. (USDA-NRCS 2013; Doran et al., 1994)

Core Soil Health Principles

- Simple message; less is more!
  - Keep soil covered
  - Minimize soil disturbance
  - Maximize living roots
  - Energize with diversity

Whole-System Approach

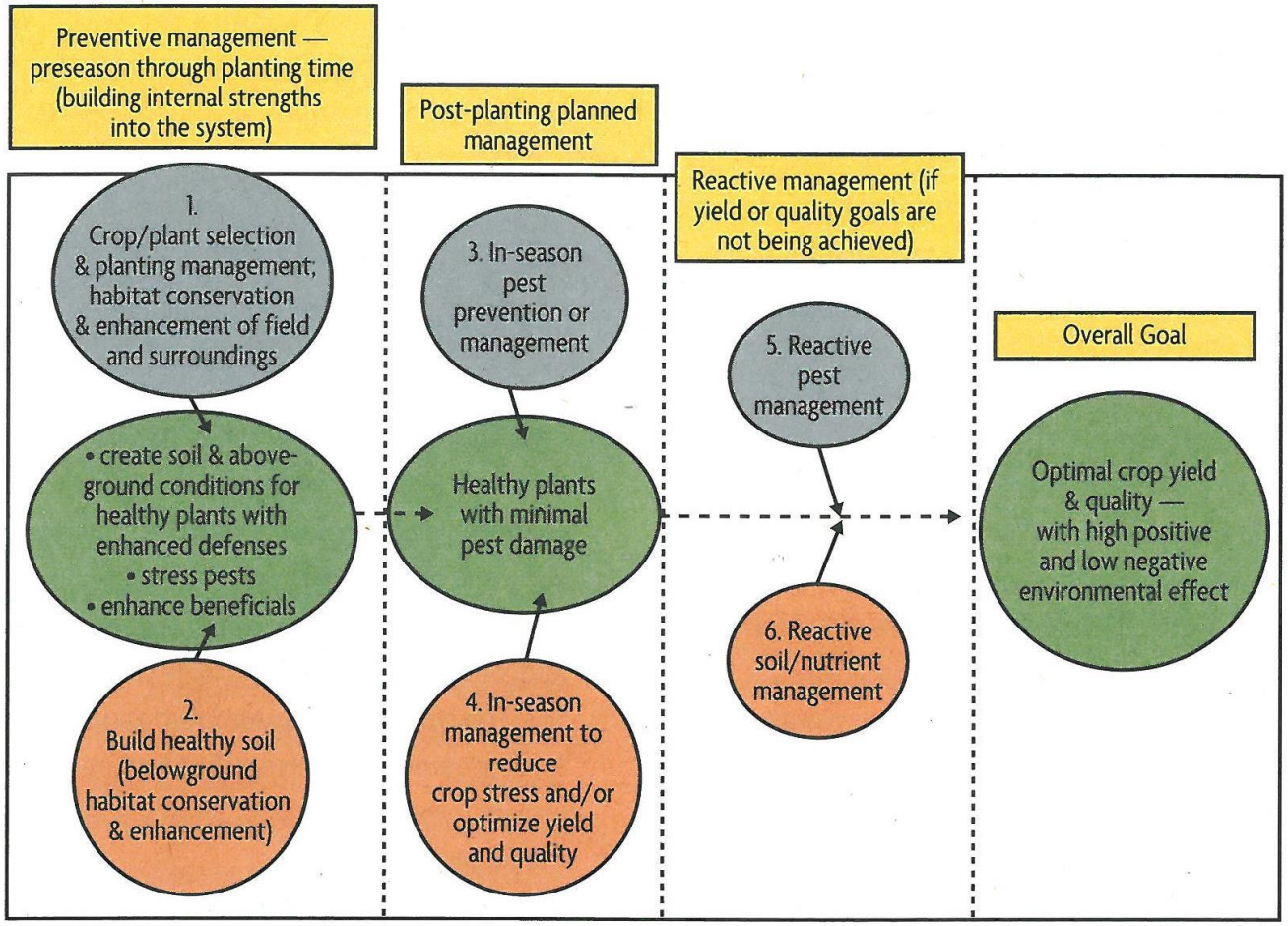


Figure 8.4. A whole-system approach to soil and crop management at the field level. Modified from Magdoff (2007).

Magdoff and Van Es, 2009. Building Soils for Better Crops. p. 83.

Characteristics of a Strong Soil Ecosystem

- Efficiency
- Diversity
- Self-sufficiency
- Self-regulation
- Resiliency

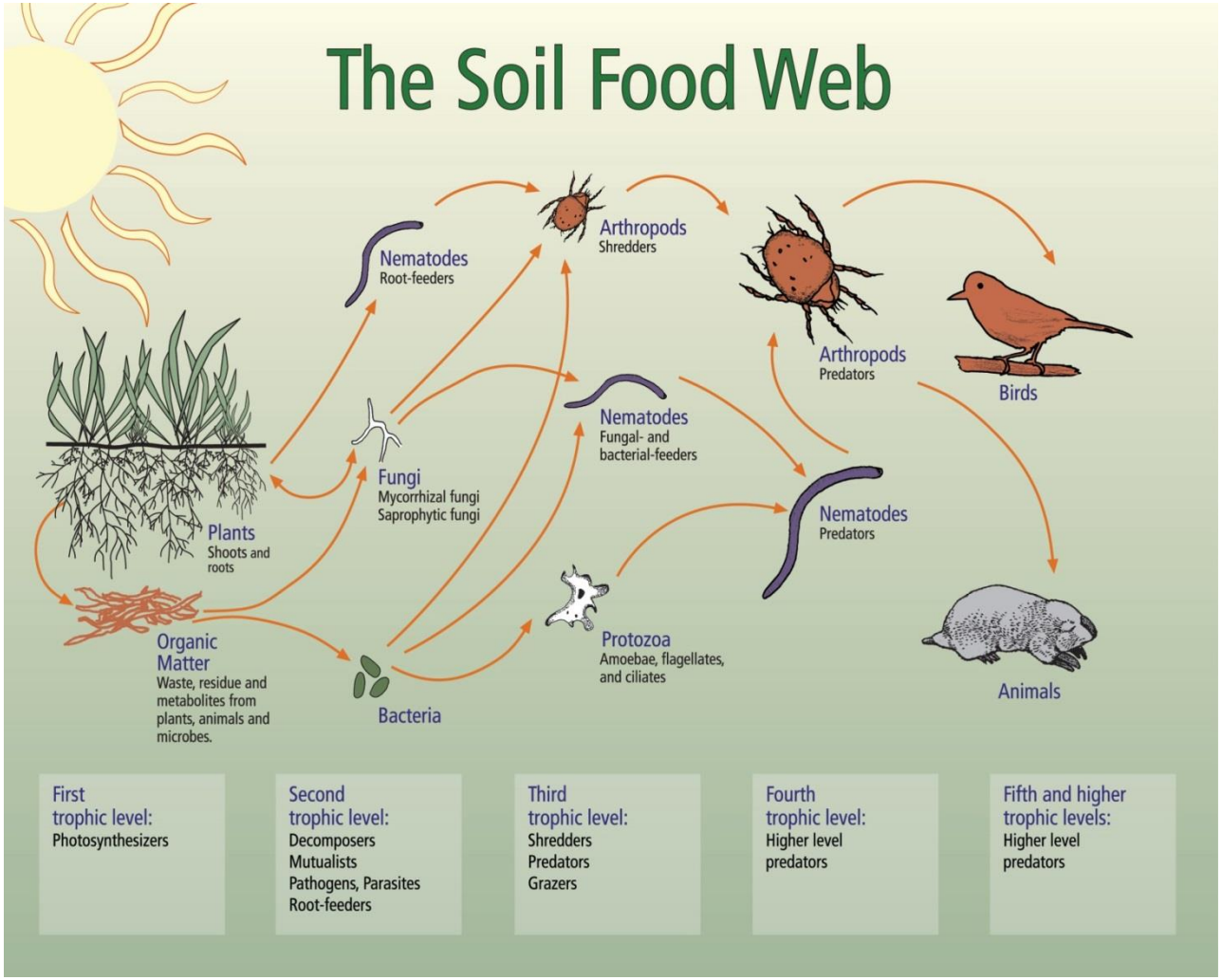
Core Functions and Services of Soil

- Crop productivity
- Nutrient storage and cycling
- Serve as a carbon sink
- Physical stability
- Water holding capacity and flow
- Filtering and buffering capacity
- Degrading or detoxifying pollutants
- Biodiversity

Core Soil Health Principles

- Simple message; less is more
  - Keep soil covered
  - Minimize soil disturbance
  - Maximize living roots
  - Energize with diversity

Are You Managing and Feeding Your Underground Livestock?



Source: Soil Biology Primer

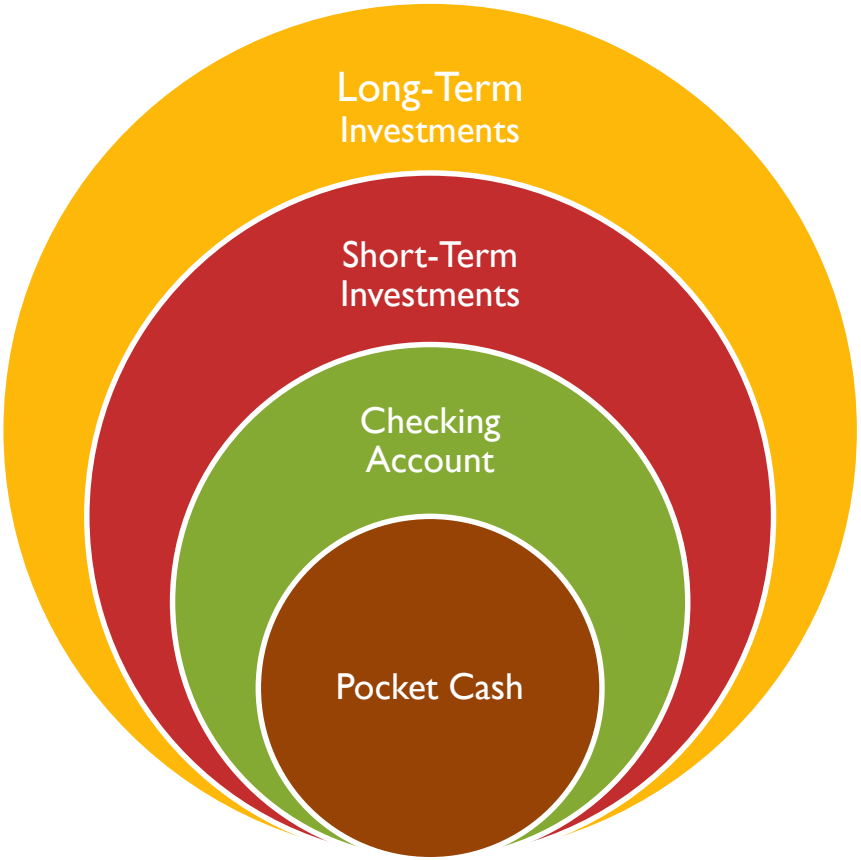
A Healthy Functioning Soil and its Inhabitants

- Need a high quality diet
- Performance-based like that of an athlete
- Sufficient protein
- Balanced carbon
- Diverse sources for energy and nutrients

Tend to Reduce Soil Health	Tend to Promote Soil Health
Aggressive tillage	No-till or conservation tillage
Annual/seasonal fallow	Cover crops/ green manures
Mono-cropping	Diverse crop rotations
Annual crops	Perennial crops
Excessive inorganic fertilizer use	Organic fertilizers, amendments, manures
Excessive crop residue removal	Crop residue retention
Broad spectrum fumigants/pesticides	Integrated pest management (IPM)
Broad spectrum herbicides	Weed control by mulching, cultivation or plant vigor

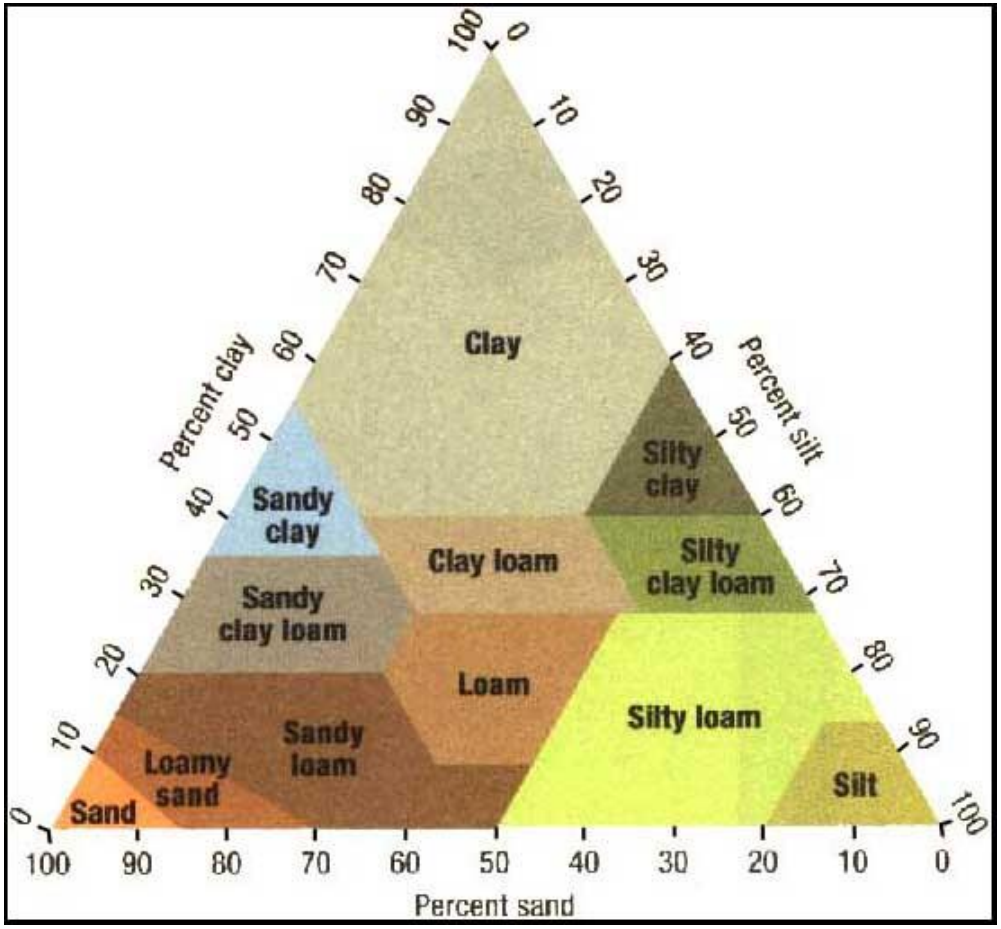
Lehman, M.R. et al., 2015. Soil biology for resilient, healthy soil. Doi:10.2489/jswc.70.1.12A

What are Your Investment Strategies for a Resilient, Healthy Soil?



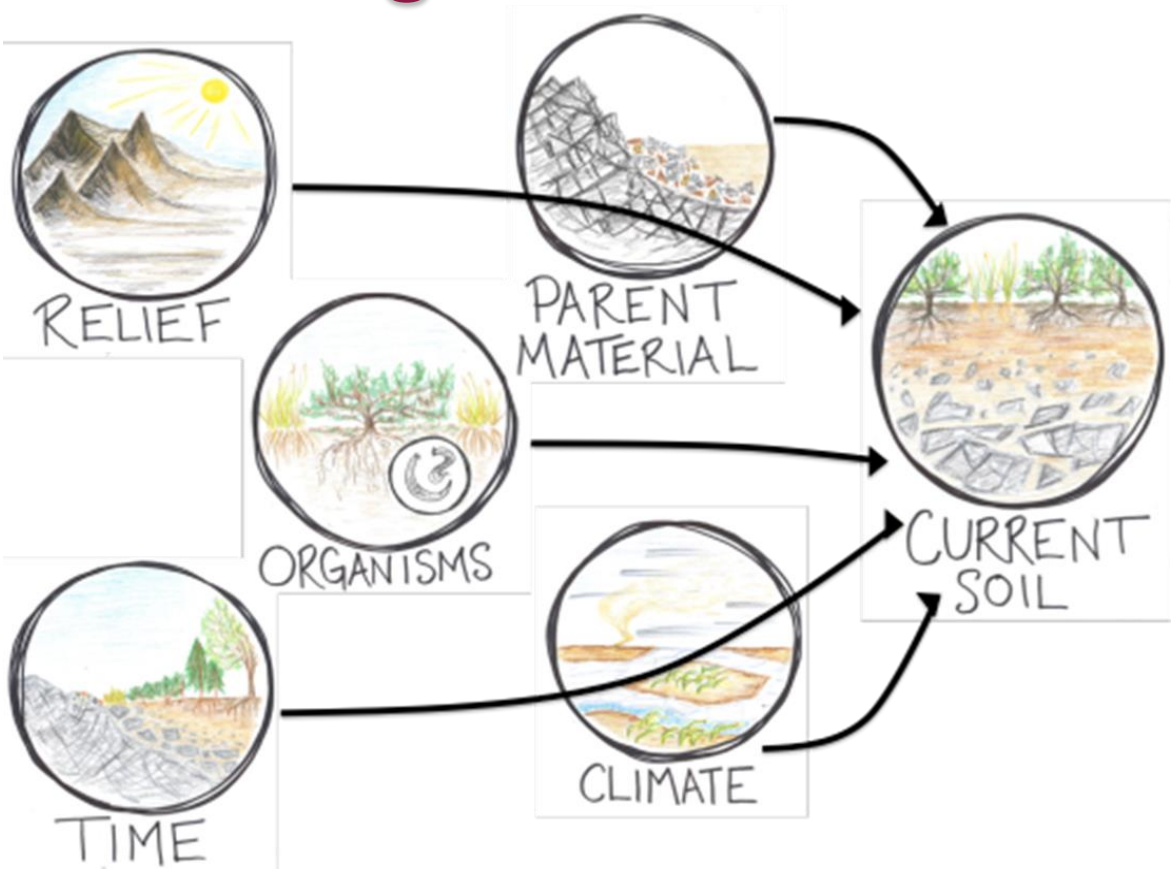
UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

Knowing what you have?



UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

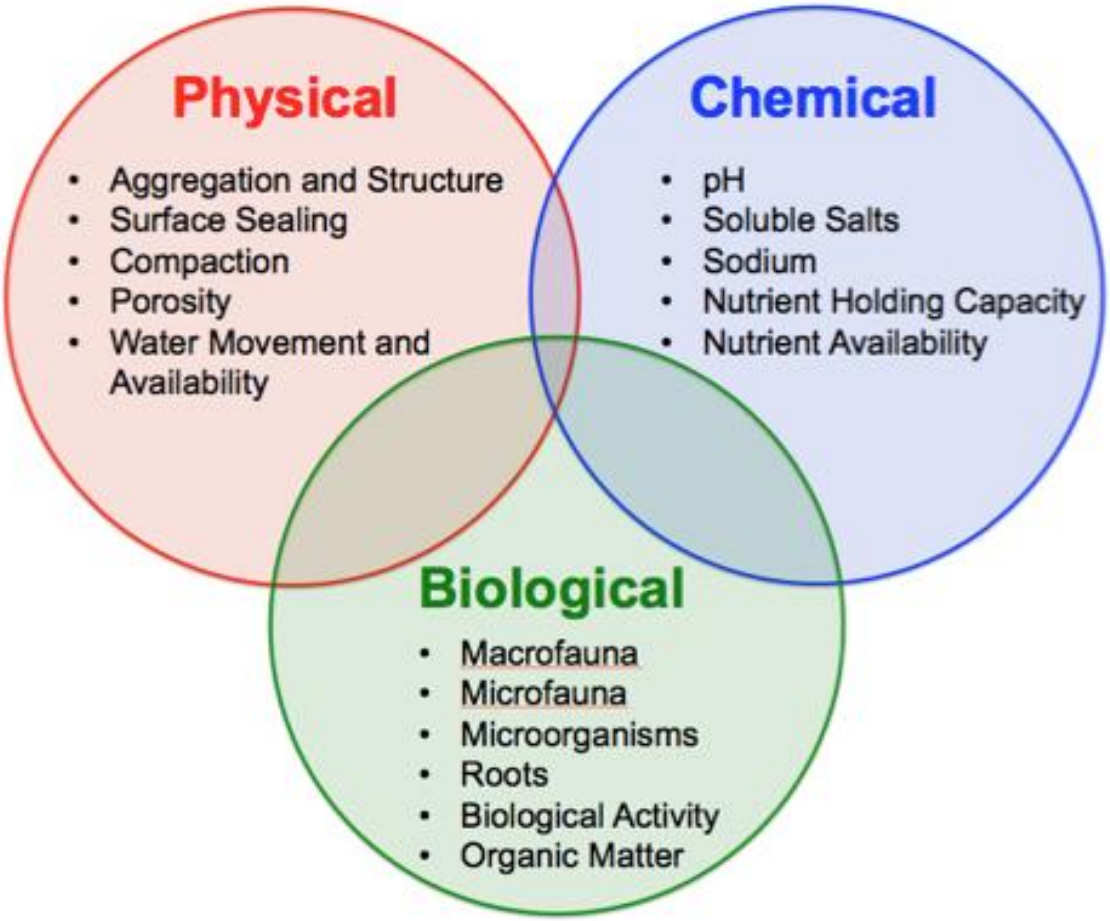
What can you change? What you cannot change?



Dynamic soil properties

- Organic matter content
- Soil structure
- Infiltration rate
- Bulk density
- Water holding capacity
- Nutrient holding capacity

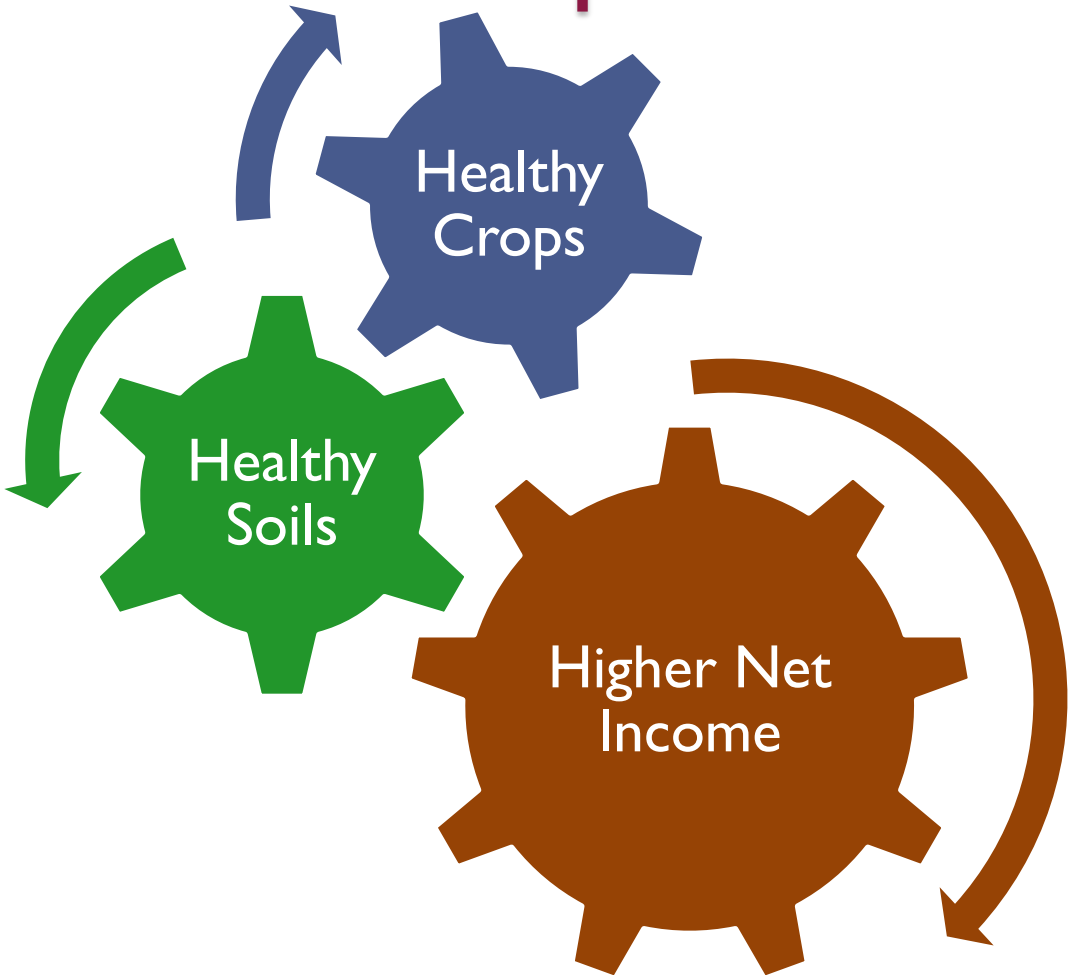
Managing for Healthy Soil Processes



Intersection of Optimum Function and Sustainability

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

Ideal Relationship



UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

Core Soil Health Principles

- Simple message; less is more
  - Keep soil covered
  - Minimize soil disturbance
  - Maximize living roots
  - Energize with diversity

Why keep the soil covered?

- Armor for the soil
  - Adding new organic matter (crop and forage residues) every year is the most important way to improve and maintain soil health
  - Bare soil is susceptible to wind and water erosion, evapo-transpiration, extreme surface temperatures, and crusting
  - 110+ degrees soil microorganisms begin to shut down activity

Benefits of Cover Crops

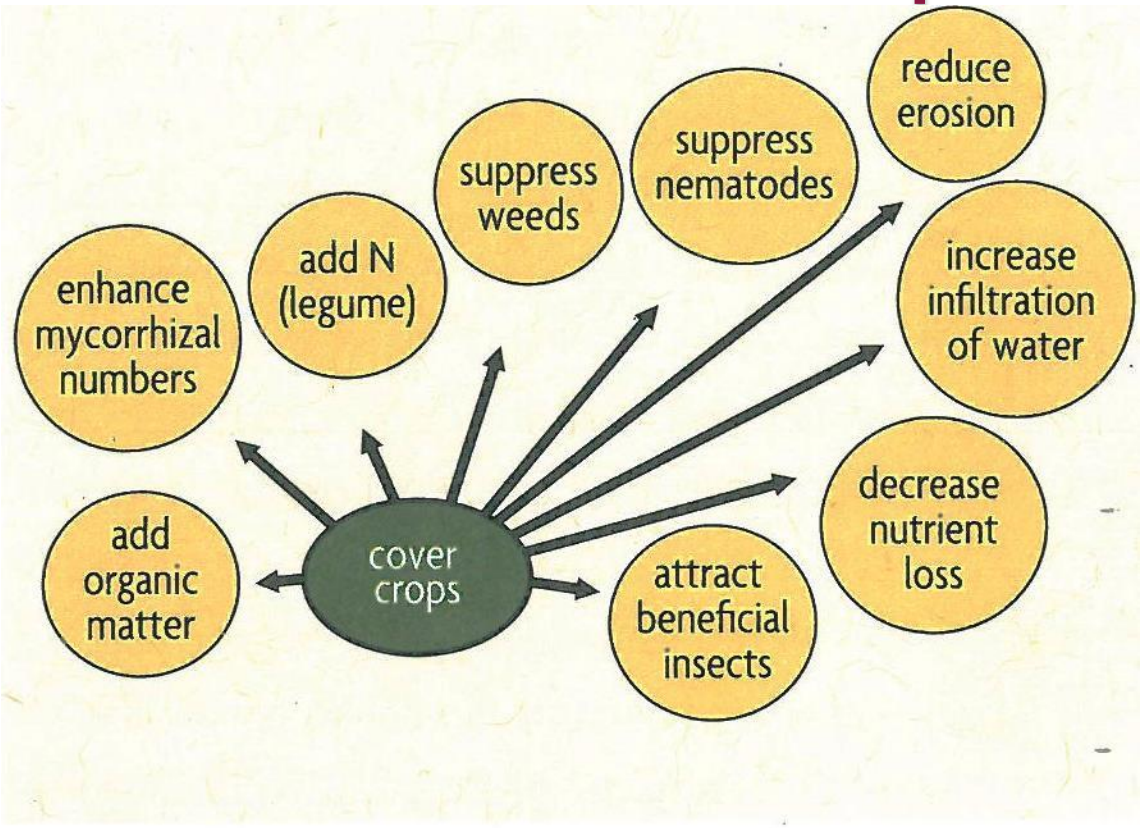


Figure 10.1. Cover crops have multiple benefits.

Magdoff and Van Es, 2009. Building Soils for Better Crops. p. 102.

Types of Cover Crops (Legumes)

- Winter Annuals
  - Crimson clover
  - Field peas
  - Hairy vetch
  - Subterranean clover
- Summer Annuals
  - Berseem clover
  - Cowpeas
  - Soybeans
  - Velvet bean
- Biennial and Perennials
  - Alfalfa
  - Crown vetch
  - Red clover
  - Sweet clover
  - White clover

Types of Cover Crops

- Grasses
  - Winter rye
  - Oats
  - Annual ryegrass
  - Sudangrass
- Brassicas
  - Mustard
  - Rapeseed
  - Forage radish
  - Turnips
- Other crops
  - Buckwheat
  - Phacelia

Cover Crop Mixes

- Cool Season Grasses
- Cool Season Broadleaves
- Warm Season Grasses
- Warm Season Broadleaves
- Brassicas

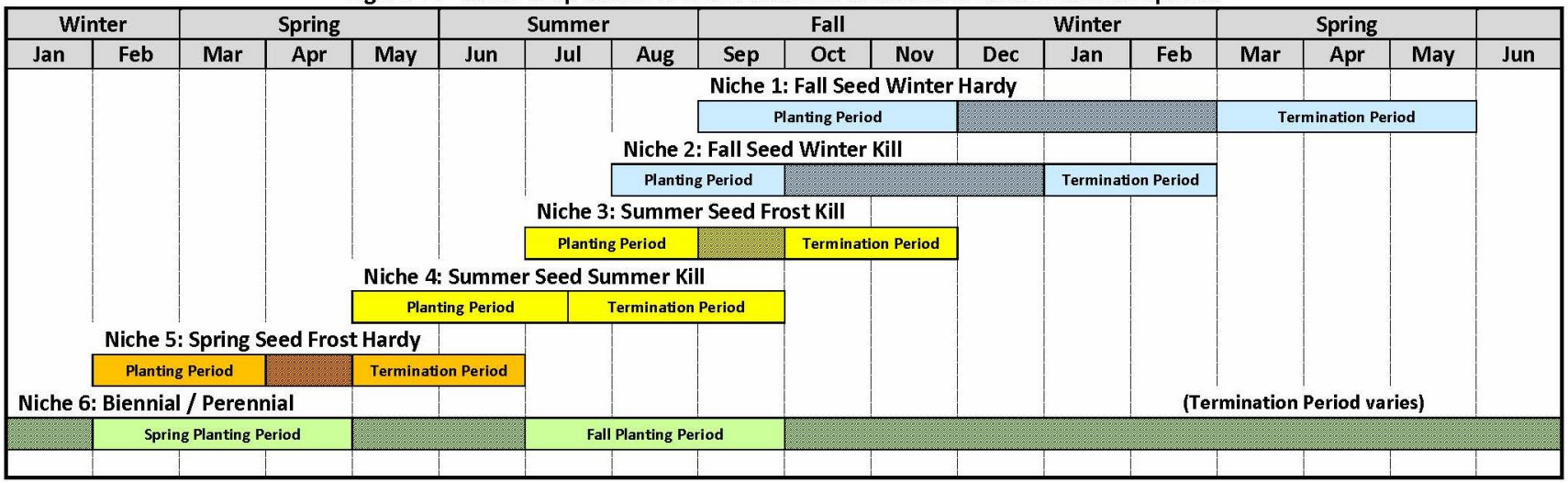
UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

Different Uses of Cover Crops

Biomass (lb/A)	Nitrogen (lb N/A)	Beneficials	Weed Control	Nematode Contol
Sorghum-sudangrass (8–10,000)	Crimson Clover (100-150)	Hairy Vetch	Iron Clay Cowpea	Lupin
Rye (3-7,000)	Hairy Vetch (90-200)	Lupin	Rye	Sunn Hemp
Black oat (4-7,000)	Sunn Hemp (80-120)	Buckwheat	Buckwheat	Black Oat
Wheat (3-5,000)	Iron Clay Cowpea (100-150)	Winter Pea	Radish	Sorghum-sudangrass
Sunn Hemp (5,000 or more)	Winter Pea (100-150)	Iron Clay Cowpea	Sunn Hemp	Canola/ Rapeseed
Velvet Bean (5-10,000)	Velvet Bean (150-270)	Crimson Clover	Black Oat	Mustards
Canola/ Rapeseed (2-5,000)	Lupin (100-300)	Red Clover	Pearl Millet	Velvet Bean

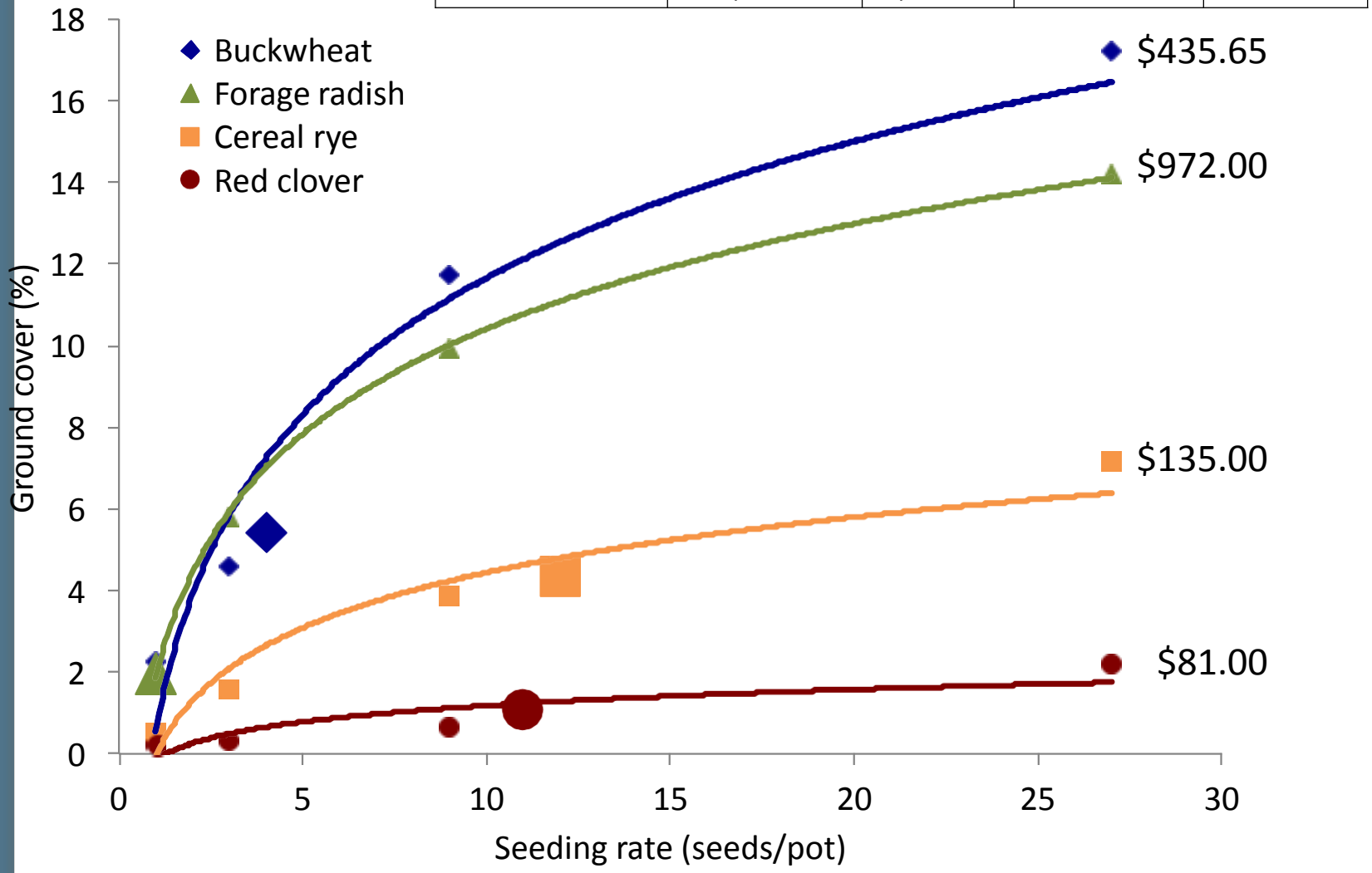
Source: USDA-ARS National Soil Dynamics Laboratory Conservation Systems Research

Figure 1. Cover Crop Seasonal Niche Calendar & Matrix of Recommended Species

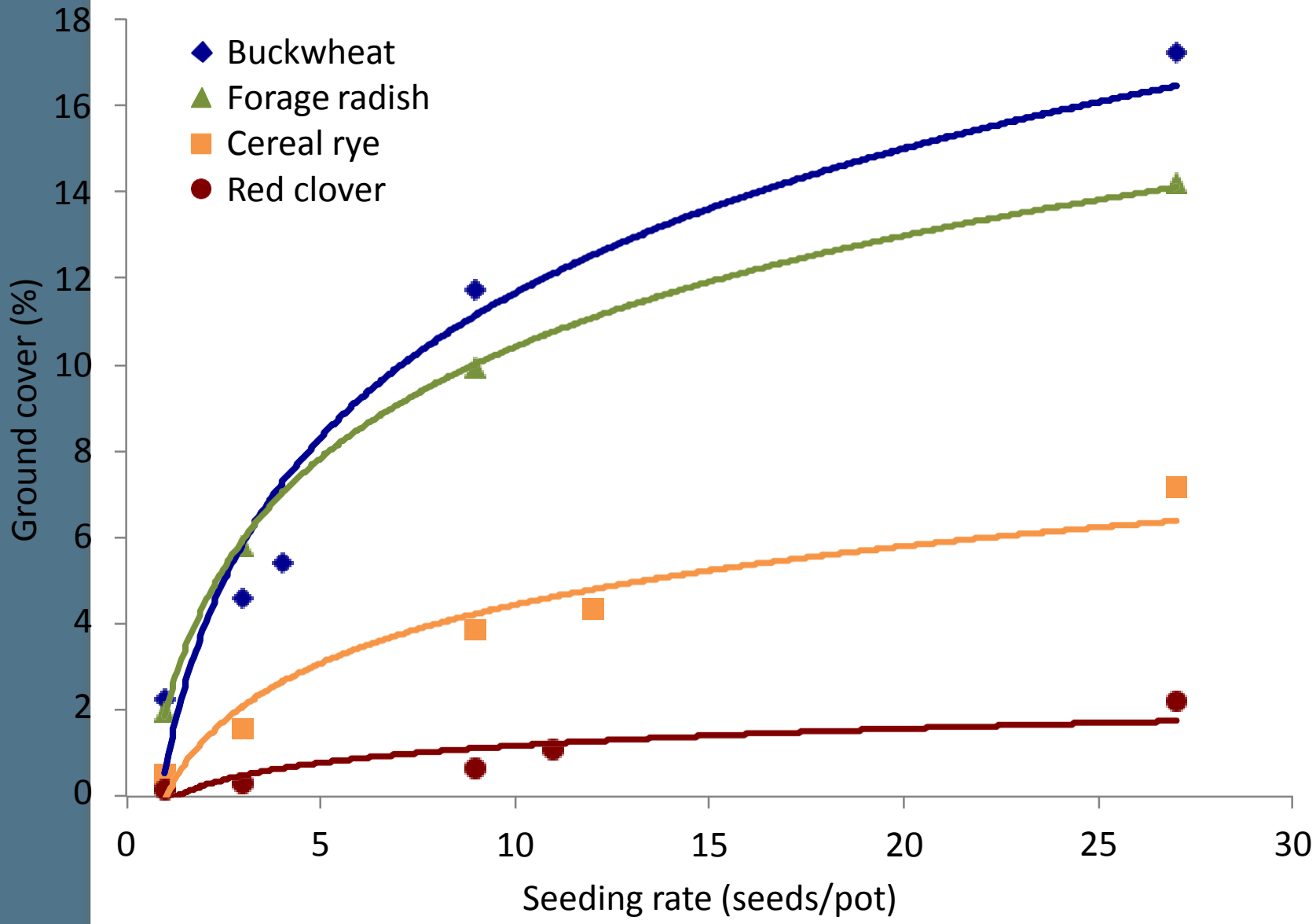


Niche Name	Description	Functional Groups & Recommended Species		
		Grass	Broadleaf / Forb	Legume
1. Fall Seed Winter Hardy	Winterhardy cool-season annual planted in fall and terminated in spring.	annual ryegrass; small grains (barley, oat, wheat, triticale, rye)	rapeseed; forage turnip	red clover; crimson clover; Austrian winter pea; woollypod vetch; hairy vetch
2. Fall Seed Winter Kill	Fast-growing, frost-hardy annual seeded in early fall. Expected to freeze-kill mid-winter (at 15 to 20° F.)	spring oat	forage radish; mustard, phacelia	Canadian spring pea
3. Summer Seed Frost Kill	Frost-tender, warm-season annual planted in mid to late summer. Expected to winterkill at first frost.	sorghum-sudangrass; pearl millet; foxtail millet	buckwheat; black oil sunflower	forage soybean; cowpea; sunnhemp
4. Summer Seed Summer Kill	Frost-tender, warm-season annual seeded early summer. Terminated in time to plant back another crop in summer or fall.	sorghum-sudangrass; pearl millet; foxtail millet	buckwheat; black oil sunflower	forage soybean; cowpea; sunnhemp
5. Spring Seed Frost Hardy	Fast-growing, frost-hardy cool-season annual planted in late winter/early spring.	spring oat; winter (or spring) small grains (barley, wheat, triticale, rye)	forage radish; mustard; phacelia; rapeseed; forage turnip;	Canadian spring pea; Austrian winter pea; woolypod vetch; hairy vetch
6. Biennial / Perennial	Biennial or perennial, grown at least one summer, typically 18 months	tall fescue; orchardgrass		alfalfa; red clover; white clover; yellow blossom sweetclover

Name	$/lb	$/acre	Target (lb/a)	Seeds/pot
Buckwheat	$1.10	$64.54	60	4
Forage Radish	$3.00	$36.00	12	1
Cereal Rye	$0.50	$60.00	120	12
Red Clover	$3.30	$33.00	10	11



Relative cover at 3 weeks after seeding



Cover crops for N

- Hairy vetch
- Clovers
- Winter peas
- Alfalfa

Cover Crops Add Nitrogen (Legume):

- Legumes are Symbiotic with Ryzobium & AMF, important in pastures to drive the carbon and nutrient cycles.
- AMF bring in Zn, P, Moly, and Fe needed for nodulation (Much more efficient system).
- Legumes add the most plant-available N if terminated when about 30% of the crop is in bloom.

Promote Biological N-fixation

- Legumes can fix atmospheric N through symbiotic relationship between the pla and Rhizobium.
- Growing legume cover crops can supply additional N for the subsequent crop providing that a majority of the above ground biomass is returned to the soil.
- Considerations:
  - Works best when N is limiting
  - Legumes need to be properly inoculated

Legumes- Biological N fixation

Legume	N fixed lb/acre
Alfalfa	195
Red clover	115
Cowpea	90
Pea	63
Common bean	41

Cover Crops Attract Beneficial Insects:

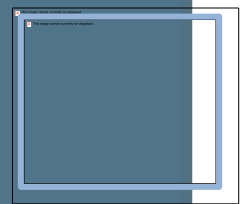
Build it… they will come!

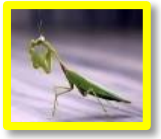
162,000 weed seeds/ 1 sq. meter of a farm field. 137,000 to 161,000 predators per acre of corn canopy.

Approximately 10 percent of weed seeds are eaten per day by Millipedes, Small crickets, Isopods, Field Crickets an Carabid Beetles.

Jan 9, 2015. Dr. Jonathan Lundgren SD ARS/USDA.

















Bottom Photos: Soil Biology Primer

Illustration design by Carlyn Iverson; concept from Michael Lehman.

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

Carbon as a Key Driver

- Decomposition
- Mineralization
  - Function in N, P and S nutrient cycles
- Respiration
- Sequestration

NH4, NO3, P, S, K, Ca, Al

Cation Exchange Capacity (CEC)

Microbial Biomass C and N

Total Organic Carbon (TOC) and Nitrogen (N)

Aggregate Stability

Particle Size Distribution

Bulk Density

Soil strength

Soil Carbon (C)

N mineralization

Soil respiration

Biomass C to Total Organic Carbon (TOC) ratio

Water and nutrient holding capacity

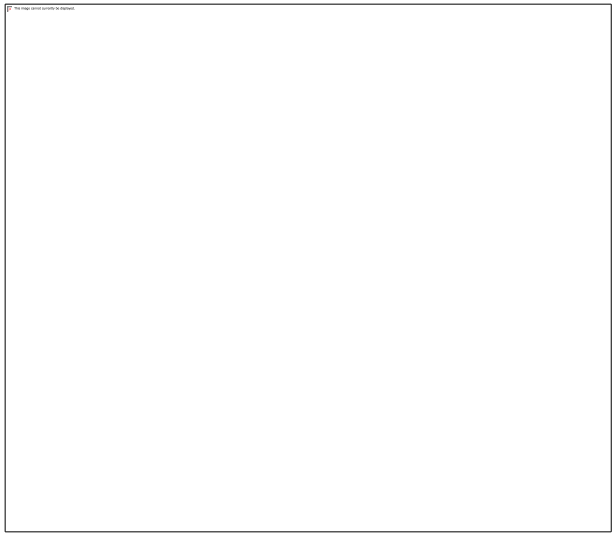
Water retention and availability

Water infiltration

Adapted from USDA-ARS National Soil Dynamics Laboratory

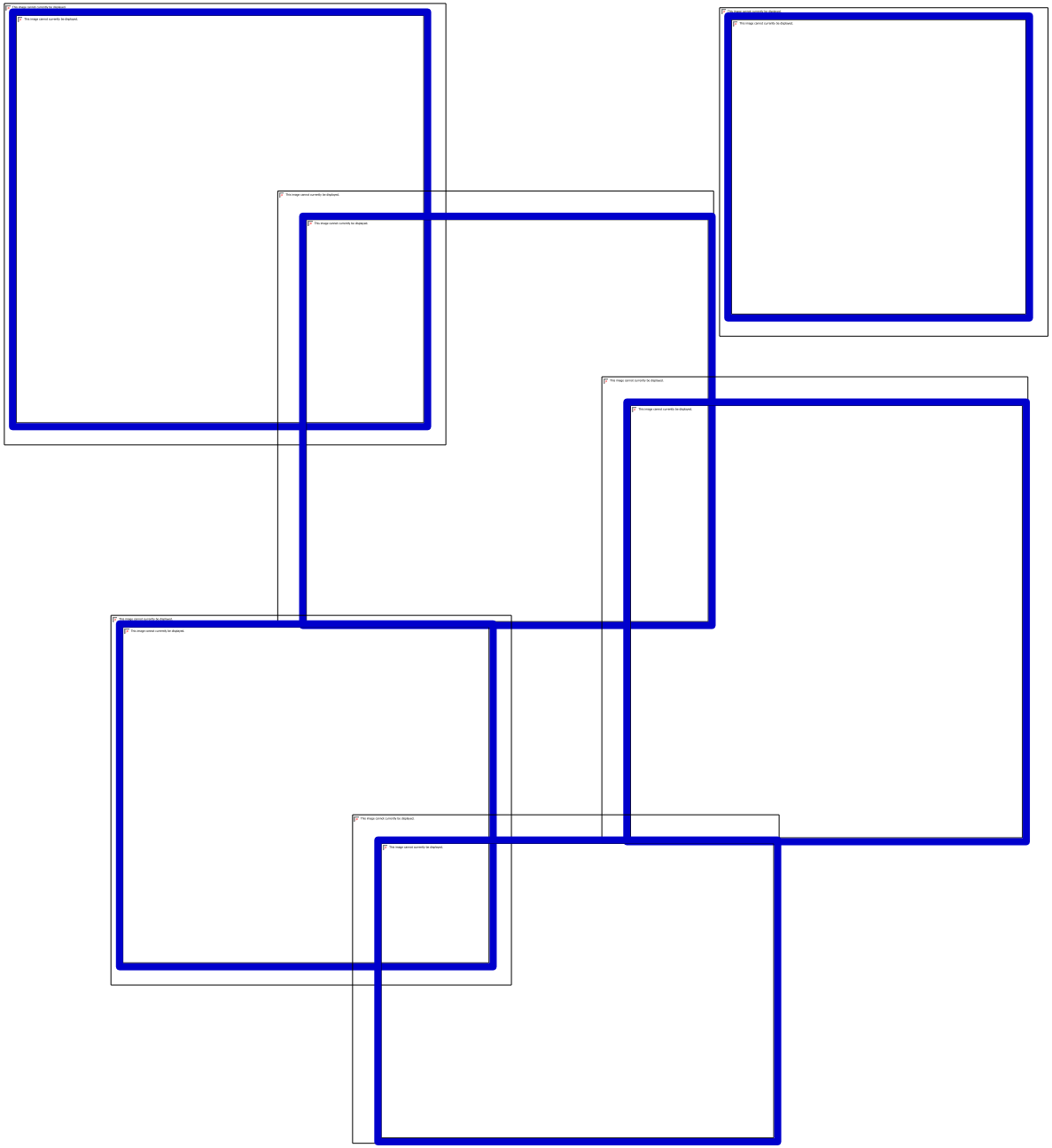
Photo courtesy of P. Ackerman-Leist

Brassicas



- Low in fiber and carbon (C)
- Scavenge existing nitrogen
- Serve as a biofumigant
- Leaf structure and size can help capture and retain moisture into late fall
- Grow into late fall and early winter
- Stimulate growth and activity of soil microorganisms

Cover Crops Add Plant Diversity:



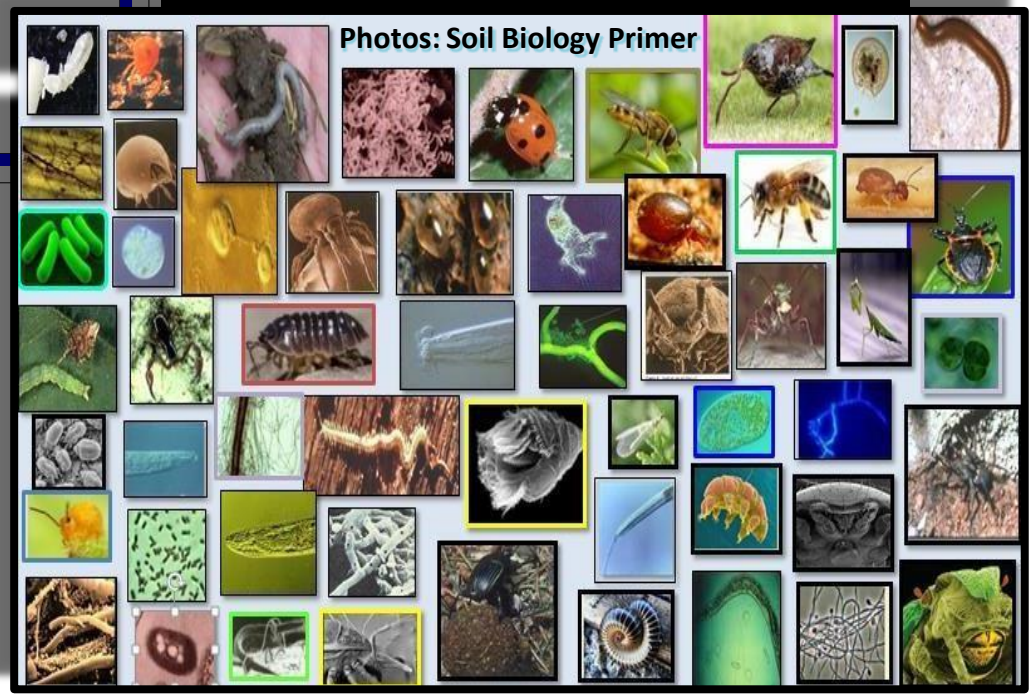
Crops Add Plant Diversity:

Diversity in root systems = diversity in soil biota

Approximately 2/3 Of Your OM Increase Will Come From Roots!

Diverse Plants = Diverse Soil Food Web = Healthy Soil, when implementing a Soil Health Mgt. System

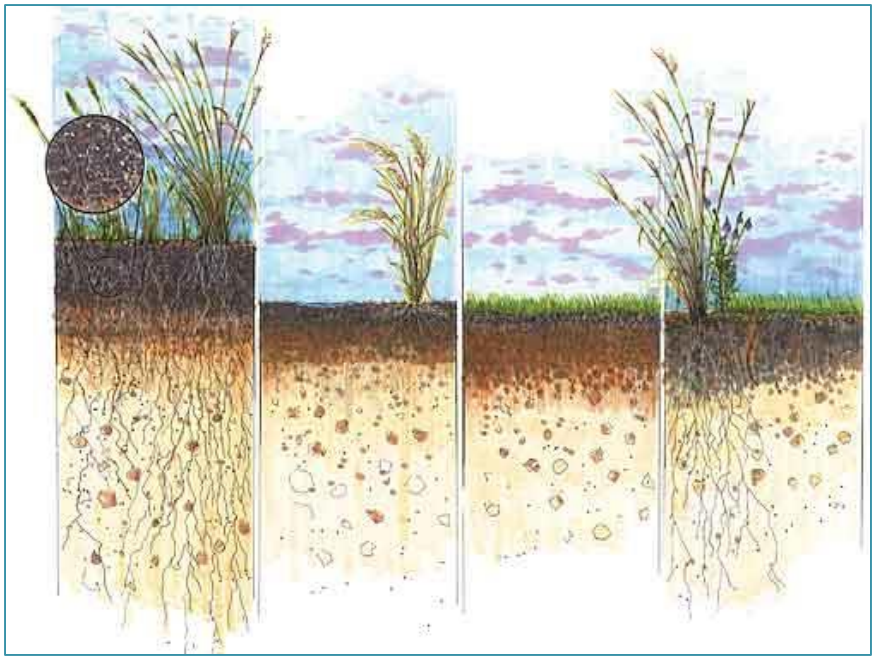
Diverse Soil Organisms = Healthy Soil
(Are you feeding & caring for your Soil Livestock?)



- Providing quality habitat for soil microorganisms should be the goal of producers interested in improving soil health.
- Soil is a biological system that functions only as well as the organisms that inhabit it.

Break up compacted soils

- Plant roots revers the effects of soil compaction



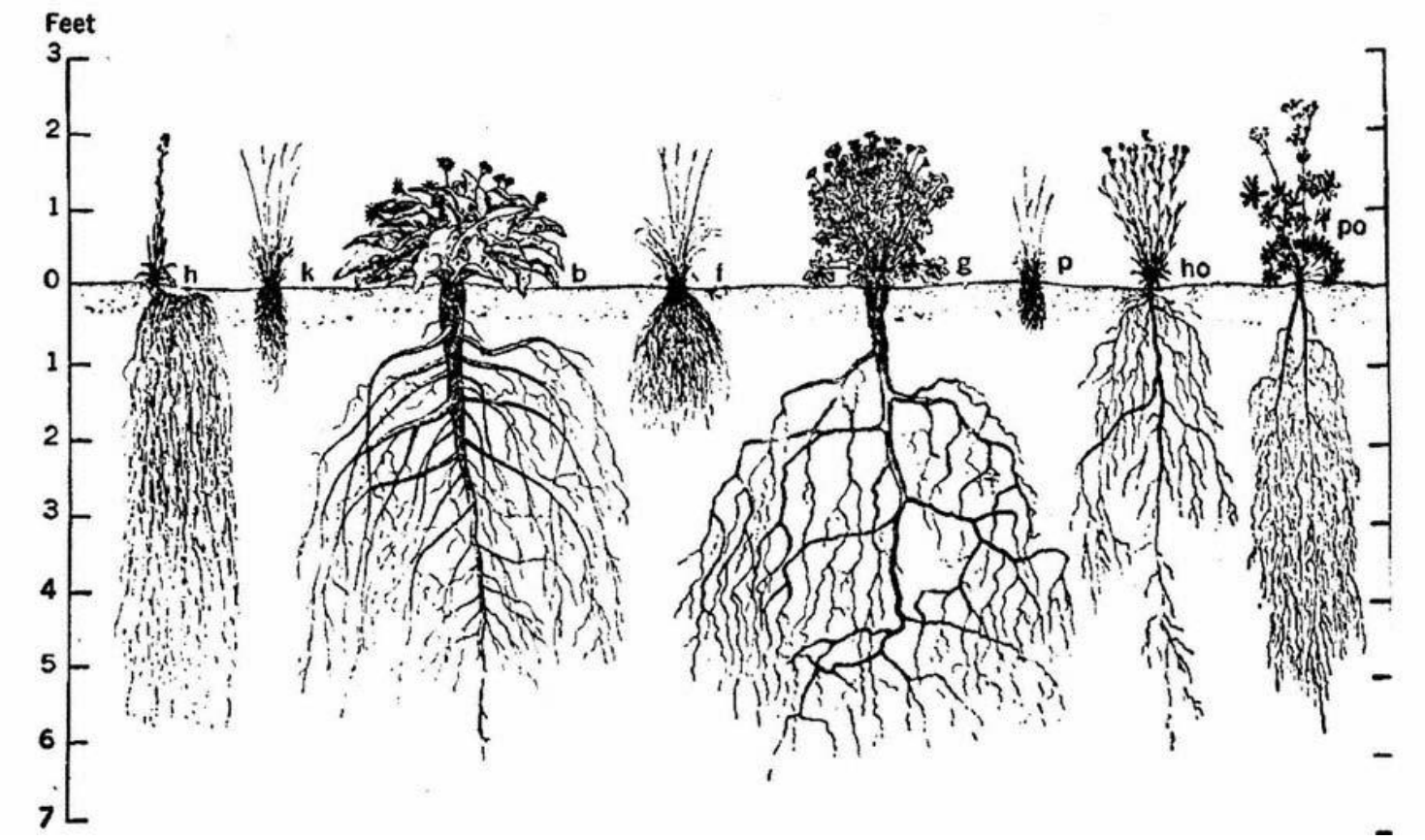
Breaking up compacted soils

- Cover crops for the job

Forage radishes for bio-drilling

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

Tap vs. Fibrous Roots



UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

Cover Crops Enhance Pollinators:

Use plant species that enhance forage opportunities for pollinators by using diverse legumes and other forbs.

Pollinators: Flowering plants that support pollinators also support beneficial predatory & parasitic insects.

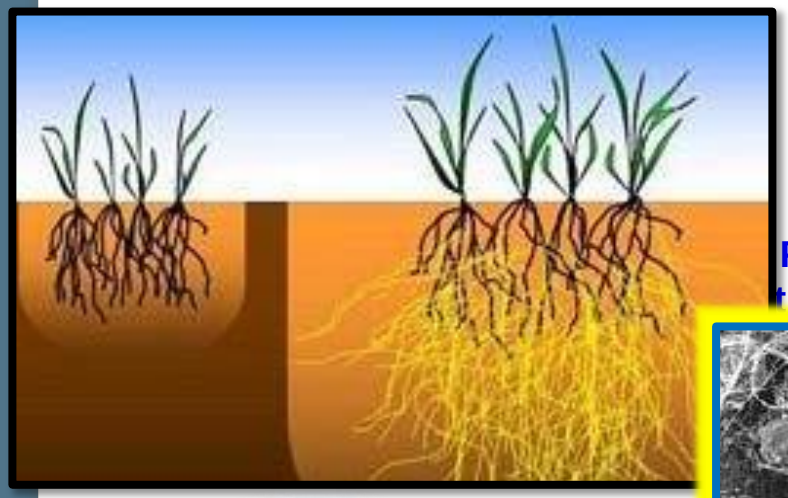
Beneficial Insectary: Many of the nectar sipping & pest-eating insects that are attracted to flower pollen will also pollinate your fruit and vegetable crops & increase your yields.

Cover Crops Enhance Mycorrhizae numbers:

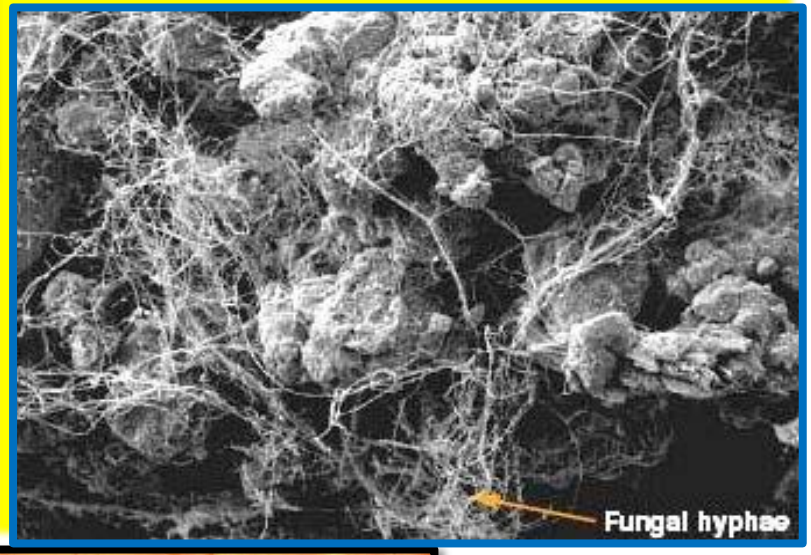
Soil Humus Formations:

1) Photosynthesis
2) Resynthesis
3) Exudation
4) Humification

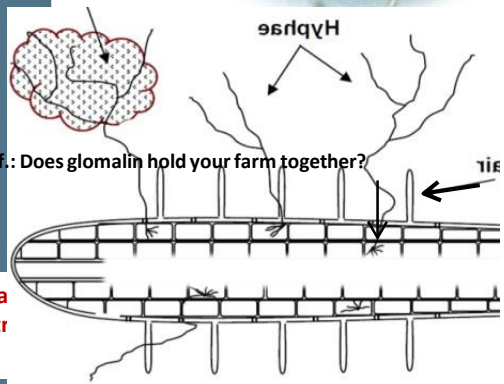
Dr. Christine Jones



Fungal hyphae binding soil
ticles together into aggregates.



Aggregate



Ref.: Does glomalin hold your farm together?

Hyphae of a
beyond nutr

Although mycorrhizae don't make humus, it is difficult to start the humification Process without them. They bring large quantities of soluble Carbon in to the soil from plant roots, which feeds the microbes involved in the complex process.

Cover Crops build Aggregates:

Soil Food Web Benefits: Formation & Stabilization of Aggregates

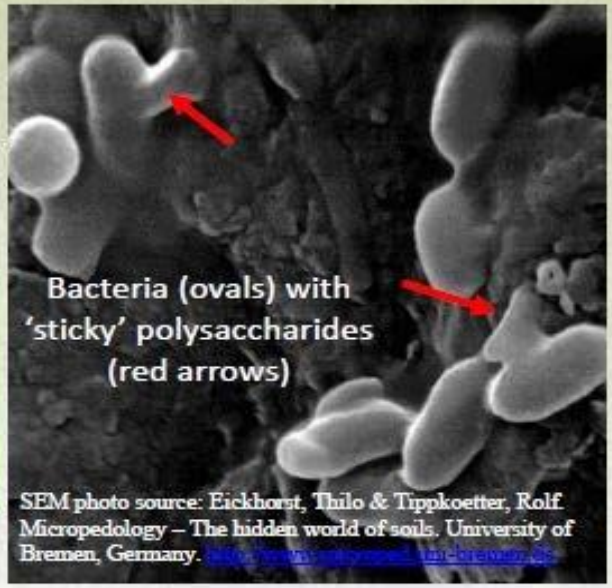
unlock the SECRETS IN THE SOIL

How do soil aggregates form?

- Chemical interactions
  - Polysaccharides (sugars) released by bacteria act like glues to bind particles
  - Glycoproteins (glomalin-related soil proteins and other proteins) act like glues

Glycoproteins on soil aggregates

Dr. Nichols, USDA-ARS



Bacteria (ovals) with 'sticky' polysaccharides (red arrows)

SEM photo source: Eickhorst, Thilo & Tippkoetter, Rolf. Micropedology – The hidden world of soils. University of Bremen, Germany.

Soil image with worm: Aaron Roth, NRCS-OR

Cover Crops build Aggregates:

Healthy soils are held together by soil glues, or glomalin, that are produced by fungi. Soils rich in soil biota hold together, while soils devoid of soil life fall apart and form a layer of sediment in the bottom of the jar. Pictured above, the soil on the left is from a field that has been managed using no-till for several years. The soil on the right is from a conventionally-tilled field.

Crumbly soils (left) have more pores and channels than cloddy soils (right). Pores and channels allow air and water to move into the soil.

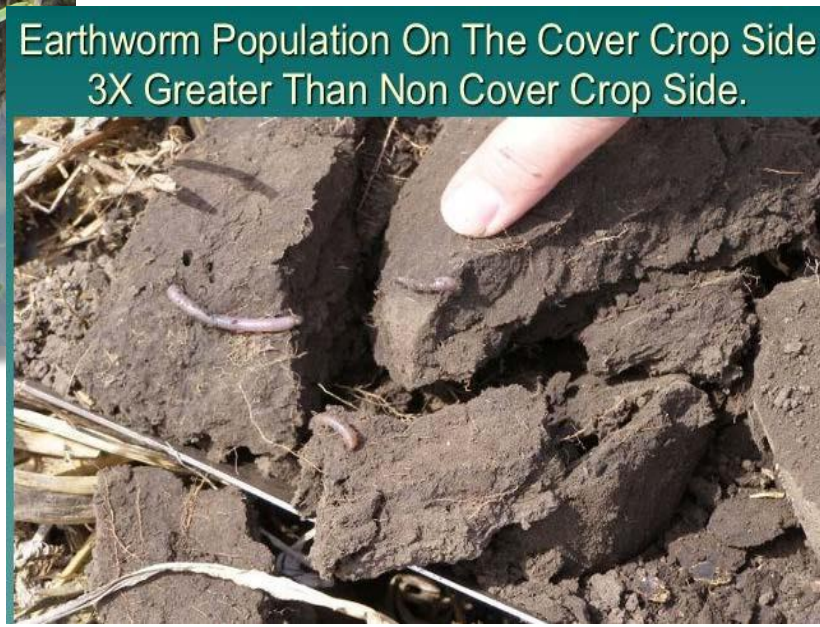
Rhizosphere…where roots meet soil

Zone of concentrated biological activity adjacent to the root.

- Bacteria
- Fungi
- Protozoa
- Nematodes
- Microarthropods
- Earthworms

Ref.: Jon Stika, ND

Cover Crops Increase Earthworms:



Earthworms consuming cover crops and making healthy soil

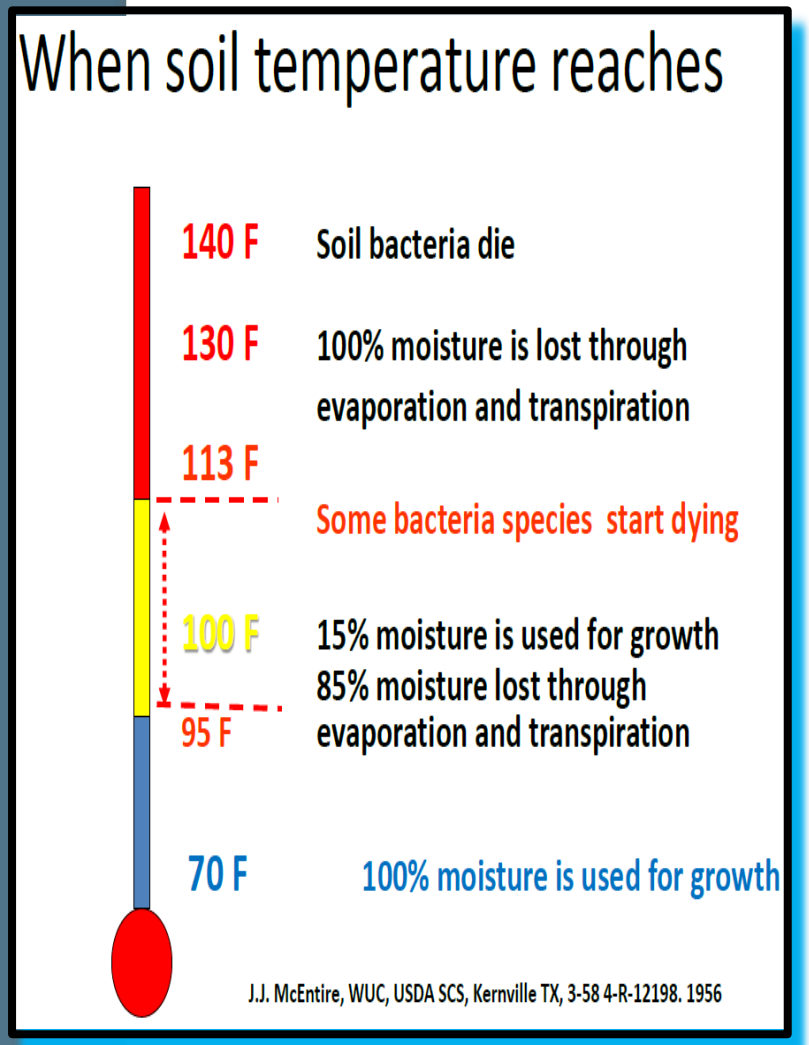
Cover Crops Suppress Weeds:

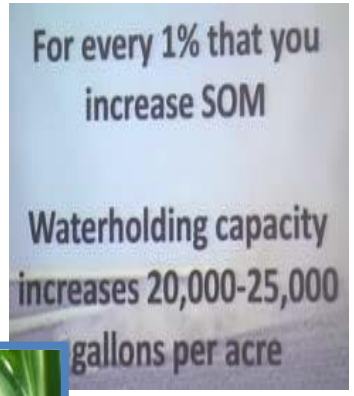
- A healthy stand of cover crops can out-compete weeds for light and nutrients.
- The mulching effect of some types of cover crops can reduce weed pressure.
- Some types of cover crops produce chemical exudates that can inhibit weed growth.
- In addition to controlling weeds cover crops can help break pest cycles
- Terminate cover crop before they produce viable seed
- Cover crops can become weeds if not properly managed
- Site preparation: Early weed control is essential

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

Cover Crops used to Manage Soil Moisture:

In areas of limited soil moisture, terminate growth of the cover crop sufficiently early to conserve soil moisture for the subsequent crop. Cover crops established for moisture conservation shall be left on the soil surface





(Cover Crops used to Manage Soil Moisture:

Competition or Collaboration?

- Stress Gradient Hypothesis (Bertness and Callaway , TREE, vol. 9, no. 5,1994)
  - As environmental stress increases, plants in a community collaborate rather than compete.
  - Diverse cover crop mixes are more productive under good or bad conditions.

Turnip cover crop July 2006 Bismarck, ND

Radish cover crop

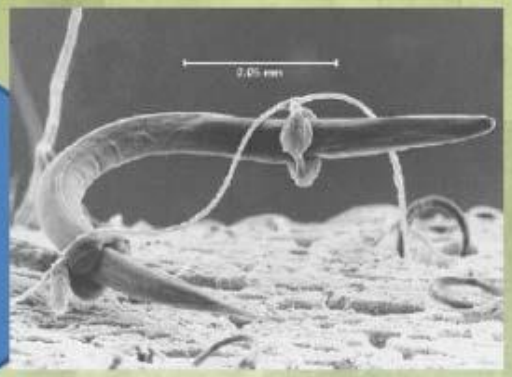
Six specie cover crop July 2006 Bismarck, ND 1.8" growing season precip to date

Cover Crops are used for Disease Mgmt./Suppression:

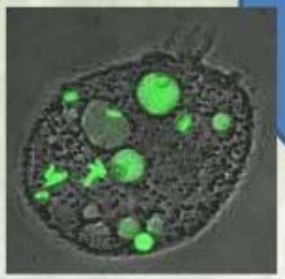
Soil Food Web Benefits: Population Control (Predation)

unlock the SECRETS IN THE SOIL

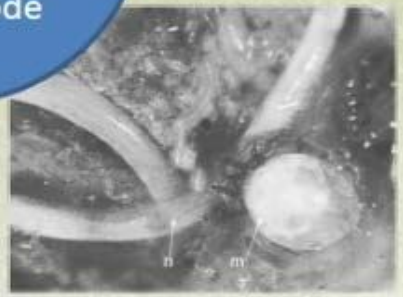
Nematode trapping fungi



Predation Mite consuming springtail and a nematode



Predation Protozoa consume billions of bacteria; some consume fungi



Cover Crops help support Wildlife:

Wildlife winter food & shelter

Provide food and cover for wildlife habitat management.

Increase Organic Matter

- Rhizosphere
- Fungi
- Bacteria
- Nematodes
- No roots = no community
- Microbes work harder to survive

Living Soil vs. Dead Soil

- Living Soil
  - Earthworms
  - Residue
  - Microorganisms
  - Cover crops
- Dead Soil
  - Bare or naked soil
  - Erosion
  - Chemical imbalance
  - Defenseless against pests

Planting/Seeding Cover Crops:

Get 4 Things Right

1. **The Right Species**
2. **The Right Inoculants**
3. **The Right Seeding Rates**
4. **The Right Seeding Time**

- **Select plants from all functional groups (diversity).**
- **Select at least two plant species within each functional group to provide some redundancy and insurance against failure of one species.**

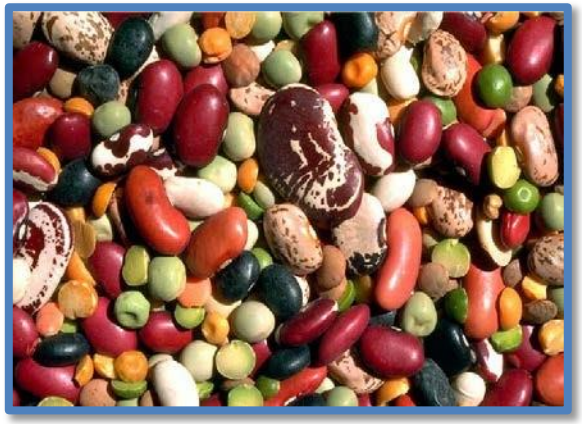
OTHER Cover Crop Planning/Management Considerations:

- **Become a "committed" student and a observer**
- **Be Patient: Do not go cold turkey…..**
- **Find a mentor or community of believers of this type of holistic thought and planning process**
- **At least a two year break between crop types**
- **Plant the opposite crop type for your cover crop rotation**

Considerations for successful cover crop planning

- Economics (yields, cost of establishment, soil improvement)
- Establishment of next cash crop
- Residue management (cash crop) before and after cover crop emergence
- Timing and species (adequate growing season)
- Site and moisture conditions
- Seeding method/seed-soil contact (broadcast vs. drilling; adequate equipment)
- Crop rotation (diversity)
- Herbicide carryover (i.e., Label restrictions on herbicide use)
- Site preparation: Early weed control is essential

Cover Crop Seed Mix



Why soil health matters?

- High-performing productive soils
- Increased resilience to extremes
- Reduced production costs
- Improved profits
- Protected natural resources
- Improved air and water quality
- Improved biodiversity and wildlife habitat

Cover Crop and Residue Management Tools

- Roller crimper
- Flail mower
- Others?

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

Equipment for Vegetable

- Rototiller
- Disk harrow
- Spaders
- Others?

"When you farm in nature's image – everything gets easier." ~ Gabe Brown, Browns Ranch

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

"Land, then, is not merely soil: it is a fountain of energy flowing through a circuit of soils, plants, and animals." ~ Aldo Leopold, 1949. A Sand County Almanac.

Questions

- How can you increase the quantity of roots growing in your field?
- Are there times of year when you don't have a crop growing, when you could plant a cover crop?
- Which cover crops might work best for you with your cropping system?
- What are the limitations to doing these practices on your farm and how can they be overcome?

- References and Resources:
- Cover Crop Selection • eVeg Guide: https://www.calflora.org/nrcs/index.html • SARE: https://www.sare.org/product_search/results/(crop_production)/Cover%20Crops
- https://ucanr.edu/sites/covercrops/
- https://www.rma.usda.gov/en/Topics/Cover-Crops

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

Questions?

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources