2.3 Soil Biology and Ecology

Appendices

Introduction: Soil Biology and Ecology

UNIT OVERVIEW

This unit introduces students to the biological properties and ecosystem processes of agricultural soils. Students will review the constituents of soils and the physical characteristics and soil ecosystem processes that can be managed to improve soil quality. Demonstrations and exercises will introduce students to techniques used to assess soils and inform decisions about soil management with the goal of maintaining crop productivity and soil health in certified organic farming and gardening systems.

MODES OF INSTRUCTION

> LECTURE (1 LECTURE, 1.5 HOURS)

Class lecture outline covers the basic biology and ecosystem processes of soils, focusing on ways to improve soil quality for organic farming and gardening systems.

> DEMONSTRATION 1: ORGANIC MATTER DECOMPOSITION (1.5 HOURS)

This exercise demonstrates how to assess the capacity of different soils to decompose organic matter. Discussion questions ask students to reflect on what environmental and management factors might have influenced the test results and what the results suggest about nutrient cycling rates and the quality/health of the soils tested.

> DEMONSTRATION 2: SOIL RESPIRATION (1 HOUR)

The demonstration outline covers the use of Draeger gas detection tubes for measuring carbon dioxide levels liberated from soils as an indicator of soil biological activity and soil quality/health.

> DEMONSTRATION 3: EARTHWORM POPULATION (1 HOUR)

The demonstration covers the preparations, material used to sample soil for the presence and abundance of earthworm types. Discussion questions ask students to consider the presence and abundance of certain earthworm types as indicators of soil quality/health.

> DEMONSTRATION 4: SOIL ARTHROPOD (1 HOUR)

The demonstration covers the preparation and materials used to collect and identify soil arthropods. Discussion questions ask students to consider the presence and diversity of soil arthropods as indicators of soil quality/health.

> HANDS-ON EXERCISE: CARBON AND NITROGEN MINERALIZATION (0.5 HOUR)

The demonstration covers the preparations and materials used in estimating how much mineral N (nitrate and ammonium) is liberated from organic matter inputs. This exercise simplifies the complex processes of the soil food web that occur during decomposition, as organic matter is converted into nutrient forms that plants can use.

> ASSESSMENT QUESTIONS (1 HOUR)

Assessment questions reinforce key unit concepts and skills.

LEARNING OBJECTIVES

CONCEPTS

- Soil quality/soil health
- Mineralization/immobilization
- Autotrophic/heterotrophic food webs
- Functional groups of soil biota
- Rhizosphere ecology
- Management effects on soil ecosystems

SKILLS

- How to assess soils for biological activity through measuring the rate of decomposition of cellulose
- How to assess soil biological activity through measuring soil respiration
- How to assess soil biological activity through earthworm census
- How to assess the soil ecosystem structure through a soil arthropod census
- How to estimate the amount of mineral N (nitrate and ammonium) that is coming from organic matter inputs

Lecture Outline: Soil Biology and Ecology

for the instructor

A. Pre-Assessment Questions

1. What is soil?
2. What forms of life exist in soil ecosystems?
3. How would you define a "healthy" agricultural soil?
4. What is a food web?
5. Can you describe a decomposer food web that may exist in the soil?
6. What might be some negative effects of the long-term practice of monoculture cropping and the use of synthetic chemical fertilizers and pest control agents on the soil ecosystem?

B. Review: What Is Soil? (should be a review in part; see Unit 2.2)

1. Soil components
   a) Mineral
   b) Organic matter
   c) Water and air
   d) Biota
2. Soil structure vs. soil texture (definitions, examples)
   a) Soil texture, a native characteristic
   b) Soil structure, a manageable characteristic

C. What Is a Healthy/Quality Soil?

1. Is soil merely a solid medium that holds nutrients for plant growth?
2. Soil health and soil quality generally synonymous
3. Definition: "Capacity of a soil to function, within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health." (For a more detailed definition, see Unit 1.1, Managing Soil Fertility.)
4. Assessment of soil quality/soil health
5. Protection of soil quality as a national priority

D. Nutrient Cycling and Decomposition

1. Mineralize/immobilize
2. Organic matter: Includes all organic substances in or on the soil
   a) Living organisms: Includes plant roots and all soil biota (<5%)
   b) Fresh and decomposing organic residues (40–60%)
   c) Resistant (recalcitrant) fraction: Humus, resistant to further decomposition (33–50%)

d) See appendix 1, Major Organic Components of Typical Decomposer Food Sources, for a comparison of the components of some typical decomposer food sources
e) Physical factors influence decomposition
f) Limiting factors
g) Plant secondary compounds may inhibit decomposition (polyphenols, tannins)

3. Nitrogen cycle
a) Proteins —> amino acids —> ammonium —> nitrate
b) Ammonification aerobic or anaerobic
c) Nitrification aerobic
d) Net mineralization > C:N 20-30 < net immobilization

4. Carbon and nitrogen mineralization exercise (handout)

E. Soil Food Webs

1. Soil food web ecology
2. Heterotrophic vs. autotrophic food webs
a) Autotrophic food webs —> begin with C fixation by plants
b) Heterotrophic food webs —> release nutrients required by all plants
c) Energy loss = 80–90% at each step in the food chain
d) Food web structure
e) Ways that soil animals interact with soil microorganisms
f) Unique food web for each ecosystem, determined by:

F. Soil Biota

1. Characteristics
2. Habitats
3. Functional classification
a) Microorganisms
b) Microfauna
c) Mesofauna
d) Macrofauna
e) Megafauna

G. Rhizosphere Ecology

1. Definitions
a) Rhizosphere (**R**) = the narrow zone of soil subject to the influence of living roots, as manifested by the leakage or exudation of substances that promote or inhibit microbial activity
b) Rhizoplane (**r**)= the actual root surface, which provides a highly favorable nutrient base for many species of bacteria and fungi
c) Edaphosphere (**S**) = soil beyond root influence
d) Rhizosphere effect = soil microorganisms and fauna stimulated
i. —> **R/S** ratio generally increases
e) Rhizosphere succession = the sequence of changes in the area surrounding a growing root

2. Roots
   a) Root environment
   b) Root form
   c) Root structure
   d) Nutrition
   e) Exudates
   f) Variations
   g) Management effects
3. Soil organisms
   a) Bacteria
   b) Fungi
   c) Protozoans
   d) Nematodes
   e) Microarthropods
   f) Rhizosphere succession
   g) Examples

H. Management Effects on Soil Ecosystems

1. No-tillage or reduced-tillage cropping systems
   a) Organic litter is retained on the soil surface
   b) Physical disturbance is minimized
   c) Surface soil stays cooler and moister
   d) More surface organic matter is available as food substrate
   e) Ratio of fungi to bacteria increases over time
   f) Earthworms and arthropods become more plentiful
2. Rotations
   a) Monocultures and clean cultivation
   b) Complex rotations
   c) Multiculture
3. Biocides
   a) Effects vary
   b) High levels of pesticide use generally reduce food web complexity
   c) Predator-release phenomenon
   d) Earthworms
4. Food web structures
   a) Fungi/bacteria ratio
   b) Dominant microbe influences other trophic levels
5. Assessment of fertility needs
   a) Measures of available nitrogen

Detailed Lecture Outline: Soil Biology and Ecology

for students

A. Pre-Assessment Questions

1. What is soil?
2. What forms of life exist in soil ecosystems?
3. How would you define a "healthy" agricultural soil?
4. What is a food web?
5. Can you describe a decomposer food web that may exist in the soil?
6. What might be some negative effects of the long-term practice of monoculture cropping and the use of synthetic chemical fertilizers and pest control agents on the soil ecosystem?

B. What Is Soil?

1. Soil components
   a) Mineral
      i. Derived from parent material
   b) Soil organic matter
   c) Water and air
      i. 1/2 soil volume = pore space
      ii. Importance of gas diffusion: When diffusion is slow, as with saturated soil, respiration byproducts accumulate and inhibit aerobic processes
      iii. CO_2 about 1% in dry soil, up to 10% in saturated soil
   d) Biota: Smallest life forms are inseparable from soil organic matter
2. Soil structure vs. soil texture
   a) Soil texture, a native characteristic
      i. Soil texture: The relative percentage of and silt and clay particles
      ii. Surface area/volume effects (e.g., influences CEC, pore space, water holding capacity, aggregate formation)
      iii. The bricks, boards, and mortar (the physical materials) that make up soil
   b) Soil structure, a manageable characteristic
      i. Soil structure: The arrangement of soil particles. The "architecture" of soil.
      ii. Determines movement of gases and water in soil
      iii. Creates small habitat spaces
      iv. Water stability: Aggregates that retain shape when wetted maintain a more stable soil structure
      v. Influences soil tilth

C. What Is a Healthy Soil?

1. Question: Is soil merely a solid medium that holds nutrients for plant growth or does soil serve other functions?
2. Soil health and soil quality generally synonymous

3. Definition: "Capacity of a soil to function, within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health." (For a more detailed definition, see Unit 1.1, Managing Soil Fertility.)
   a) Soil recognized as essential component of biosphere
   b) Soil is required for significant production of food and fiber
   c) Soil contributes to maintaining and enhancing air and water quality
   d) Soil filters and chemically alters water
   e) Definition must be broad enough to encompass the many functions of soil
4. Assessment of soil quality/soil health
   a) Analogy to monitoring human health
   b) Indicators needed to identify problems and to monitor the effects of management
   c) Requires a holistic approach
   d) Should include physical, chemical, and biological attributes of soil
   e) Indicators must be measurable by as many people as possible
   f) Definition and assessment of soil quality complicated by the fact that soil is not (typically) directly consumed by animals and humans, as are air and water
   g) Basic data set of soil quality indicators
      i. Soil texture
      ii. Rooting depth
      iii. Water infiltration
      iv. Bulk density
      v. Water holding capacity
      vi. Soil organic matter
      vii. pH
      viii. Electrical conductivity
      ix. Extractable N, P, and K
      x. Microbial biomass C and N
      xi. Potentially mineralizable N
      xii. Soil respiration
      xiii. Water content
      xiv. Soil temperature
5. Protection of soil quality as a national priority
   a) National Research Council recommendation (1993)
   b) "Protecting soil quality, like protecting air and water quality, should be a fundamental goal of national environmental policy"

D. Nutrient Cycling and Decomposition

1. Mineralization/immobilization
   a) Soil nutrients occur as parts of:
      i. Inorganic compounds: Some of these are available to plants
      ii. Organic compounds: Are part of living organisms and decaying organic matter. These nutrients are stored and temporarily unavailable.
   b) Soil organisms are constantly transforming nutrients between these 2 forms
   c) Mineralization: Soil organisms excrete inorganic waste compounds that may adhere to CEC sites and/or dissolve in soil water (soil solution) for possible uptake by crop plants. Net mineralization must be greater than net immobilization for nutrients to be available to crop plants.

d) Immobilization: Soil organisms consume *inorganic* compounds to construct living tissues. These nutrients are temporarily stored and unavailable for plant uptake.

2. Soil organic matter (SOM): Includes all organic substances in or on the soil
   a) Living organisms—includes plant roots and all soil biota (< 5% of SOM)
      i. Cellulose, the major carbohydrate structural building block for plants, is the most abundant compound on earth
      ii. Lignin second largest input into SOM
   b) Fresh and decomposing organic residues (40–60% of SOM)
      i. Easily decomposable (active, labile) fraction: Quantity changes quickly in response to management changes and is the organic matter fraction from which the majority of plant nutrients are liberated
      ii. Moderately decomposable fraction: Physically and/or chemically more complex than labile OM. Decomposition slower and therefore fewer nutrients liberated in a given season.
   c) Resistant (recalcitrant) fraction: Humus, resistant to further decomposition (33–50% of SOM). Has greater influence on the *structure/physical properties* of soils.
   d) See appendix 1, Major Organic Components of Typical Decomposer Food Sources
   e) Physical factors influencing decomposition
      i. Particle size: High surface area/volume = more rapid decomposition
      ii. Surface properties (waxes, pubescence) often decrease rate of decomposition
   f) Limiting factors in decomposition of SOM
      i. Decomposers tend to concentrate the nutrients that are in short supply
      ii. Micronutrients are not usually a limiting factor
   g) Plant secondary compounds may inhibit decomposition (such as polyphenols, tannins found in many woody perennials)
3. Nitrogen cycle
   a) Proteins —> amino acids —> ammonium (form of N useable by some plants) —> nitrate (form of N useable by most plants)
   b) *Ammonification* (aerobic or anaerobic): The biochemical process whereby ammoniacal nitrogen is released from nitrogen-containing organic compounds
   c) *Nitrification* (aerobic): The biochemical oxidation/ change of ammonium to nitrate
      i. Inhibited by low oxygen or low temperatures
      ii. Ammonium build-up in cold, wet soils
   d) If C:N < 20–30:1 = net mineralization. If C:N > 20–30:1 = net immobilization
4. See Hands-On Exercise, Carbon and Nitrogen Mineralization

E. Soil Food Webs

1. Soil food web ecology
   a) Trace the path of energy or nutrients passing from one organism to the next
2. Heterotrophic vs. autotrophic food webs
   a) Autotrophic food webs —> begin with C fixation by plants. Energy for most life is derived from sunlight that has been transformed by photosynthetic plants into organic compounds.
   b) Heterotrophic food webs —> *release* nutrients required by all plants
      i. The decomposition food web begins with waste-products from autotrophic food webs

c) Energy loss = 80–90% at each step in the food chain
d) Food web structure and properties
    i. Resilience = speed of recovery after disturbance
    ii. Resilience *decreases* with increasing number of trophic levels due to increasing complexity—takes longer to reestablish complex food web relationships
    iii. Disturbance selects for shorter food chains: In farmed soils, disturbance can be chemical (pesticides, fertilizers) or physical (cultivation, organic matter incorporation, removal of surface organic layer)
    iv. Relate to timing of agricultural inputs and other disturbances
    v. Fungi/bacteria biomass ratio characteristic
        • Productive agricultural soils ratio 1:1 or less (higher in no-till) = bacterial-dominated food webs
        • Deciduous forest, 5:1 to 10:1
        • Coniferous forest, 100:1 to 1000:1
e) Ways that soil animals interact with soil microorganisms
    i. Shredding of organic matter (comminution)—"can openers"
    ii. Spreading to new habitats and new food resources (dissemination)
    iii. Grazing: Stimulate growth, control populations
    iv. Predation: Similar effects as grazing
    v. Soil structure changes (burrowing, mixing, defecating, crumb formation)
f) Unique food web for each ecosystem, determined by:
    i. Climate
    ii. Soil/parent material
    iii. Vegetation
    iv. Land management practices

F. Soil Biota

1. Characteristics
    a) Diversity of organisms in soil can rival that of coral reef ecosystems
    b) Characterized by small size and indistinct morphologies (unlike coral reef)
    c) Due to cryptic environment, visual cues are less important—bright colors and patterns of coral reef organisms are lacking in soil organisms
    d) Biomass comparisons
    e) Abundance
2. Habitats
    a) Habitats within soil ecosystems are unevenly distributed
    b) Habitats are concentrated at organic matter sites
        i. Root zone (rhizosphere)
            • Succession of organisms as root grows
            • Some root exudates and root hairs may fuel microorganisms
        ii. Litter
        iii. Surface of soil aggregates
        iv. Incorporated organic matter

3. Functional classification
   a) Microorganisms
      i. Colonial growth forms (cells about 1/25,000 inch wide)
         - Bacteria and yeast
         - Adapted to high surface area (SA)/volume
         - Colonize surfaces, crevices, pores
         - Teaspoon of soil contains 100 million to 1 billion bacteria
         - Biomass equivalent to 2 cows per acre
         - Many functions (N fixers, nitrifiers, denitrifiers, decomposers, pathogens, promote aggregation)
      ii. Mycelial growth forms (hypha length from a few cells to many yards)
         - Fungi and actinomycetes
         - Penetrate organic matter
         - Translocation of nutrients
         - Decomposers, mutualists, pathogens, nematode-trapping fungi
      iii. Algae
   b) Microfauna
      i. Protozoans (1/5000 inch to 1/50 inch wide)
         - Small animals (acellular) living in water films
         - Feed on bacteria, other microorganisms, detritus
         - Encystment: Distinctive response to drying out
         - Inhabit transitory environments
            - *Colpoda* divide once or twice per day at 12°C
         - Several distinct types
            - Ciliates have fringe of small hairs used for locomotion
            - Amoebae have an amorphous body shape
            - Flagellates have a whip-like tail for locomotion
      ii. Nematodes (1/500 inch in diameter, 1/20 inch in length)
         - Global distribution
         - *"If all the matter in the universe were swept away, our world would still be dimly recognizable, and if as disembodied spirits, we would investigate it, we should find its mountains, hills, vales, rivers, lakes and oceans represented by a thin film of nematodes."* –Nathan Cobb, 1914
         - Soil abundance = million/m^2
         - Outer cuticle protects; resistant to toxins
         - Include microbivores, omnivores, predators, some parasites (10%)
         - Abundant at sites with high organic matter concentration
      iii. Rotifers, Tardigrades
      iv. No comminution, i.e., they don't shred organic matter into smaller pieces
   c) Mesofauna
      i. Potworms (Enchytraeida)
         - Small annelids (related to earthworms), 1mm to 5 cm long
         - Tolerate pH < 4
         - Thousands/m^2 in high organic matter soil
         - No burrows
         - Feed on hyphae, microorganisms, feces

ii. Collembolans (springtails)
iii. Mites (acari)
iv. Insect larvae
v. Regulate microorganisms by grazing (feeding)
vi. Minor comminution
vii. 500 to 200,000 per square meter, far less biomass than microfauna

d) Macrofauna
i. Earthworms
- 3 ecological types (anecic, endogeic, epigeic)
- Vermisphere concept
- Obtain a portion of their nutrition from microbes living on organic residues they ingest
- 7,000+ species
- Stimulate microbial activity through effects on SOM, microbial inoculation onto substrates, soil structure, etc.
- Mix and aggregate soil
- Increase water infiltration
- Provide channels for root penetration deep into soil
- Bury and shred organic matter
- Abundance decreases after disturbance (tillage, chemicals)

ii. Millipedes, isopods, mollusks, insects
iii. Shred and incorporate plant remains (may become pests by feeding on living plants if insufficient organic residues present)
iv. Alter soil structure

e) Megafauna
i. Large invertebrates, vertebrates

G. Rhizosphere Ecology

1. Definitions
a) Rhizosphere **(R):** The narrow zone of soil subject to the influence of living roots, as manifested by the leakage or exudation of substances that promote or inhibit microbial activity
b) Rhizoplane **(r):** The actual root surface, which provides a highly favorable nutrient base for many species of bacteria and fungi
c) Edaphosphere **(S):** Soil beyond root influence
d) Rhizosphere Effect: Soil microorganisms and fauna stimulated
i. **R/S** ratio generally greater than 1 (i.e., more biota in R than in S)
e) Rhizosphere succession: The sequence of changes in the composition and densities of soil microbes and fauna in the area surrounding a growing root (see below)

2. Roots
a) Root environment
i. Determined by above-ground processes (products of photosynthesis are translocated to roots)
ii. Exudates, sloughed hairs, and cells feed soil organisms
iii. Bicarbonate formation as a result of influences on pH
iv. Type and amount of exudates vary with species, age, soil
v. Oxygen decreases, CO_2 increases in root zone over time due to plant and R organism respiration

b) Root form
   i. Fibrous roots
      • Most monocots
      • Primary root replaced by series of adventitious roots
   ii. Tap roots
      • Most monocots and gymnosperms
      • Tap root persists and forms many lateral branches
      • Generally deeper than fibrous roots
   iii. Root depth
      • Species specific, modified by environment
c) Root structure
   i. Root cap
      • Live cells produced by meristem
      • Protects root, like a bud scale
      • Constantly replaced (5–6 day turn over)
      • Responds to gravity
   ii. Meristematic zone: 2 mm zone where most cell division happens
   iii. Zone of elongation: Rapid growth, cells from meristem
   iv. Mucilage
      • Covers root from tip to beginning of root hair zone
      • Source is part microbial, part root cap
      • Possible functions: Nutrient uptake, protection, prevent drying, fill spaces between root and soil, food for microbes
   v. Root hair (differentiation) zone
      • Root hairs have life span of days to weeks
      • Do not become roots
      • Are an outgrowth of epidermal cell
      • Rye plants can produce over 100 million per day
      • None in redwood trees, firs, some pines
      • Food sources that support rhizosphere microbes
   vi. Lateral roots
      • Originate from the vascular bundle inside cortex
      • Cortex and epidermis are ruptured by new lateral root
      • Bacteria colonize these emergence sites
d) Root nutrition
   i. Maximum nutrient uptake occurs behind meristem (elongation and root hair zones)
   ii. Water and nutrients are withdrawn from narrow band around roots
   iii. Replenished from surrounding soil by *mass flow*
   iv. If mass flow is slow (e.g., PO_D), depletion zone created resulting in lack of some nutrients
e) If uptake is slow certain ions may accumulate—all ions in solution move towards root during mass flow; those not used by plant will accumulate around root

f) Root exudates

i. Amounts

- 20–50% more C enters the soil from exudates, sloughed cells, and root hairs than is present as fibrous roots at end of growing season = substantial contribution to SOM
- Amount of exudates increased by:
  - wetting, after a drying spell
  - physical or chemical injury (i.e., mowing, grazing of perennial grass cover crop)
  - abrasion, phytotoxic residues, osmotic stress

ii. Types

- Carbohydrates and amino acids: Most-researched compounds
  - 10 sugars, glucose and fructose most common
  - 25 amino acids
- Also organic acids, fatty acids, sterols, enzymes, volatile compounds, and growth factors
- Difficult to separate plant and microbe sources

iii. Exudates released from meristem zone

- Nematodes and zoospores congregate there

iv. Foliar sprays may move into roots (depends on molecular weight)

- Herbicides, antibiotics may also move into roots
- Streptomycin moved from *Coleus* leaves to roots in 24 hrs
- Bacteria suppressed by the streptomycin

g) Variations in root exudates

i. **R** effect increases with age
ii. Decreases with senescence
iii. Annual crop plants have greater **R** effect than trees
iv. Legume **R** effect stronger than non-legume
v. **R** effect may be strongest at flowering
vi. Stronger in sandy soils than in heavier soils
vii. Highest **R** effect in dune and desert soils

h) Management effects

i. Synthetic fertilizers

- Sometimes no effect
- Sometimes increase **R/S** indirectly through stimulation of plant growth

ii. Organic manures

- Same indirect positive effect on **R/S**
- Also can decrease ratio since edaphic (non-**R**) microbes are also stimulated by organic matter input
- After 4 weeks of decomposition, **R/S** generally increases

3. Soil organisms

a) Bacteria

i. Most responsive to plant exudates
ii. 2 to 20 fold increase in bacterial populations over non-root soil
iii. *Pseudomonas* most consistently abundant in rhizosphere
iv. Also *Agrobacterium* (biocontrol agent) and *Achromobacter*

v. *Azotobacter*, non-symbiotic nitrogen fixer
    - If inoculated on seed can persist in rhizosphere
vi. *Rhizobium*, *Nitrosomonas*, and *Nitrobacter* common in **R**

b) Fungi
i. Average increase 10 to 20 fold in **R** of crop plants
ii. *Fusarium* is *a* dominant genera of **R** fungi
iii. Mycorrhizae can provide physical and chemical suppression of pathogens

c) Protozoans
i. Mainly bacteria grazers, so increases expected in **R**
ii. Example: In a wheat field, bacteria **R/S** was 23:1, protozoan **R/S** was 2:1
iii. Some large amoebae may provide biocontrol of some fungi

d) Nematodes
i. Root substances stimulate egg hatching of some parasites
ii. Host and non-host plants may stimulate hatching
iii. E.g., some crucifers and chenopods evoke *Heterodera* hatching, but don't support root invasion by larvae. Some plants will cause eggs of parasitic nematodes to hatch, but they are not susceptible to attack by the parasite. Therefore the plant stays healthy, and the nematodes fail to thrive.
iv. Nematodes tend to congregate around elongation zone
v. Degree of attraction proportional to root growth rate
vi. Some root exudates repel nematodes

e) Microarthropods
i. Some grazers consistently more abundant around roots

f) Rhizosphere succession
i. Root tip releases labile carbon
ii. Rapid increase of microbes and nutrient immobilization
iii. Grazers increase, tracking microbe increases
iv. Root hair zone, water, and carbon decrease
v. Microbes decrease, grazers cause net mineralization
vi. Further along, grazers encyst or migrate

g) Examples
i. Wheat monoculture in Washington state
    - Develops take-all disease, yields down
    - In some fields yields increase after a few years
    - *Pseudomonas fluorescens* isolated from **R** of resistant fields
    - Seeds treated with the bacteria, planted in diseased fields
    - Biocontrol and 20% yield increase resulted
ii. Beets in Idaho and California
    - *P. fluorescens* isolated from **R** of field grown beets
    - Seed treatment
    - Over 3 years 13% increase in root weight
    - Strains used inhibited *R. solani, Pythium, Erwinia,* and others
iii. Cotton
    - *P. fluorescens* isolated from cotton **R**
    - Produces a potent antibiotic
    - Protects cotton seedlings from infection by *R. solani*
    - Used as a seed treatment

iv. Fruit trees and shrubs (nursery grown)
- Crown gall caused by *Agrobacterium tumefaciens*
- *A. radiobacter* is virtually indistinguishable, except that it produces a highly specific antibody
- Young plants dipped in cell suspension of *A. radiobacter*
- Roots protected by rapidly growing *A. radiobacter*
- It may also compete for infection binding sites, thus excluding pathogen physically as well as chemically

H. Management Effects on Soil Ecosystems

1. No-tillage or reduced-tillage cropping systems
   a) Organic litter is retained on the soil surface
   b) Physical disturbance is minimized
   c) Surface soil stays cooler and moister
   d) More surface organic matter available as food substrate
   e) Ratio of fungi to bacteria increases over time
   f) Earthworms and arthropods become more plentiful
   g) Effects on nutrient cycling
   h) Effects on soil physical properties
2. Rotations
   a) Monocultures and clean cultivation
      i. Create little habitat for soil organisms, leading to less abundant and diverse soil ecosystems
      ii. Consistent plant hosts may serve to develop populations of pathogenic organisms. Uninterrupted plant-host cycle.
   b) Complex rotations
      i. Greater variety of food sources (roots, root exudates, and residues)
      ii. Likely to be greater diversity of soil organisms. Interrupted plant-host cycle.
   c) Multiculture
      i. Growing more than one crop in one field
      ii. More closely mimics natural ecosystem
      iii. Likely to support even greater diversity of soil organisms, especially invertebrates
      iv. Interrupted plant-host cycle
3. Biocides
   a) Effects vary depending on
      i. Type of chemical
      ii. Species in question
      iii. Concentration and other exposure factors
   b) High levels of pesticide use generally reduce food web complexity
      i. Methyl bromide and other fumigants are extreme examples
      ii. Eliminate most organisms
      iii. Some bacteria quickly return
      iv. Other organisms only slowly return

c) Predator-release phenomenon
    i. In cases where biocides selectively eliminate predators, lower trophic levels may become more abundant
    ii. Destabilizing effect on food webs
        - Overgrazing on food sources resulting in depletion of food sources
        - Population explosion, followed by crash, resulting in...
        - Immobilization of nutrients, followed by rapid mineralization at a rate that is not necessarily compatible with crop needs. May result in leeching of water-soluble nutrients.

d) Earthworms
    i. Most strongly effected (negatively) by fungicides and fumigants
    ii. Herbicides
        - Don't seem to be directly toxic
        - Indirect negative effect through elimination of vegetation

4. Food web structures
    a) Fungi/bacteria ratio
    b) Dominant microbe influences other trophic levels
5. Assessment of fertility needs (also see Unit 1.1, Managing Soil Fertility)
    a) Measures of available nitrogen
        i. Conventional cropping systems
            - Most N provided by additions of fertilizer
            - Measurements of nitrate reflect accurately what is available to plants
            - Key management decisions are when to apply fertilizer
        ii. Cropping systems based on organic matter management
            - Soil food web becomes primary source of N
            - Soil analysis may indicate "inadequate" levels of N at any given time because much of soil N is immobilized
            - Cumulative release of mineral N over growing season may match amounts seen in conventional system
            - Managing the timing of mineralization (through tillage, OM quality [e.g., C:N ratio], incorporation of OM/fertilizers, irrigation) by soil food web becomes more critical
            - If managed well, less risk of nutrient loss through leaching or volatilization

Demonstration 1: Organic Matter Decomposition in Litter Bags

for the instructor

OVERVIEW

To demonstrate the capacity of different soils to decompose organic matter, this exercise requires you to bury cellulose disks (Whatman filter paper) in a variety of locations. This should be done at least two weeks prior to the class to allow decomposition to proceed before the disks are retrieved on the day of the class. To accelerate decomposition, filter paper disks can be dipped in a bucket of water with some fish emulsion added just before burial.

MATERIALS NEEDED

- Whatman filter paper discs
- Plastic mesh bags*
- Flags to mark burial sites
- Flat shovel
- Litter Bag Data worksheets (see appendix 2)
- Pencils

*for plastic mesh bags, you may use pond and pool netting obtained from a local feed and seed supply. It is a 3/8-inch polypropylene mesh. Cut mesh into 6-inch x 12-inch pieces, fold in half, then fold the edges over and staple the edges shut. Other sources are the mesh bags that bulbs are sold in, garlic or onion bags, or the mesh bags that imported rice noodles are packed in. The smaller the mesh size, the smaller the organisms that will be excluded from the bag. This phenomenon can be exploited by comparing decomposition rates of organic matter buried in bags with different mesh sizes. Organic matter in bags with very fine mesh will be decomposed primarily by microflora and microfauna. Organic matter in larger mesh bags will also be decomposed by larger fauna.

PREPARATION

1. Place litter bags in soil at least two weeks prior to class. Place them vertically in soil, and place them all at the same depth. For a 10 cm disc, 0 to 10 cm is a convenient depth.
2. Flag the site, and make a note of location, or a map. A minimum of 3 bags should be placed in each habitat. Possible habitats include raised garden beds, cultivated fields, fallow fields, orchards, compost piles, vermicompost bins, soil surface (not buried), weedy borders.
3. Bags should be retrieved very gently, as the paper is likely to be very fragile. (If too rapid decomposition makes this demonstration difficult, an alternative material to use is a 50/50 cotton/polyester material. Even if the cotton is entirely degraded, the polyester matrix will remain intact. Strips would have to be weighed before and after burial to determine mass loss.)

4. Have students collect the bags and return them to a central location.
5. Ask students to observe the soil habitat that each bag is in. Suggest they note things like soil moisture, presence of any soil animals, vegetative cover and shading, knowledge of prior cultivation, and anything else they think may be important in explaining their results.
6. Gently brush soil from discs. Ask students to visually estimate percentage of the disc remaining.
7. Record results and calculate averages for each habitat selected. A sample form is provided (see appendix 2, Litter Bag Data Sheet) for recording data. Appendix 3 provides an example of what a filled-out data sheet might look like.

PREPARATION TIME

1 hour to make 24 bags, 1 hour to bury 24 bags (allow additional time for gathering materials)

DEMONSTRATION TIME

1.5 hours

DISCUSSION QUESTIONS

1. After retrieving the litter bags, ask students to offer hypotheses about why the disks decompose more rapidly in some habitats than others.
2. What environmental factors might have influenced the results?
3. What management factors might have influenced the results?
4. Can you see any signs of biological activity on the disks (e.g., fungal mycelia, soil animals, invertebrate feces, comminution)?
5. What do the results suggest about nutrient cycling rates in the soils tested?
6. Can these observations for cellulose decomposition rates be extrapolated to other types of organic matter?
7. What are the limitations of this method?

VARIATIONS

If possible, pair the litter bag demonstration with other methods of assessing biological activity, such as:

- Carbon dioxide evolution (see Demonstration 2, Soil Respiration)
- Earthworm density (see Demonstration 3, Earthworm Populations)
- Tullgren funnel extractions of microarthropods (see Demonstration 4, Soil Arthropods)
- Microbial biomass measurements

Demonstration 1: Organic Matter Decomposition in Litter Bags

step-by-step instructions for students

INTRODUCTION

The decomposition of organic matter is an important soil process for organically managed farms and gardens. Organic matter includes a vast array of compounds that can be biologically decomposed at various rates, depending on their physical and chemical complexity. Environmental factors such as temperature and moisture also determine decomposition rate.

We can use discs of filter paper to represent a uniform piece of cellulose-rich organic matter. If discs are placed in the soil for a set period and then retrieved, we can learn something about the capacity of various soils to decompose cellulose. By placing the discs in plastic mesh bags prior to putting them in soil, we can make it easier to retrieve the discs intact. Decomposition can be estimated by a visual estimate of percentage surface area remaining. A more quantitative method is to rinse and dry the discs, then weigh them to estimate mass loss (original mass must also be known).

MATERIALS NEEDED

Assemble materials as per instructor's outline

PREPARATION

Litter bags are placed in soil at least two weeks prior to class. They are placed vertically in soil, all at the same depth. For a 10 cm disc, 0 to 10 cm is a convenient depth.

Bags should be retrieved very gently, as the paper is likely to be very fragile. When you retrieve the bags, make sure to observe the soil habitat that each bag is in. Note things like soil moisture, presence of any soil animals, vegetative cover and shading, and anything else you think may be important in explaining the results.

Gently brush soil from discs. Visually estimate percentage of the disc remaining. Record results and calculate averages for each habitat selected, using the data sheet supplied.

DISCUSSION QUESTIONS

1. After retrieving the litter bags, discuss your hypotheses about why the disks decompose more rapidly in some habitats than others.
2. What environmental factors might have influenced the results?
3. What management factors might have influenced the results?
4. Can you see any signs of biological activity on the disks (e.g., fungal mycelia, soil animals, invertebrate feces, comminution)?
5. What do the results suggest about nutrient cycling rates in the soils tested?
6. Can these observations for cellulose decomposition rates be extrapolated to other types of organic matter?
7. What are the limitations of this method?

Demonstration 2: Soil Respiration

for the instructor

OVERVIEW

This demonstration uses Draeger gas detection tubes to measure carbon dioxide. See sources of supply at the end of this outline.

MATERIALS

- 6-inch diameter ring*
- Lid with rubber stoppers
- Hand sledge and wood block
- Soil thermometer
- 2 sections of plastic tubing
- 2 needles
- Draeger tubes
- 140 cc syringe
- Stopwatch or timer
- Soil Respiration Data worksheets (appendix 4)
- Pencils

*possible sources are sections of 6-inch irrigation pipe, PVC pipe with one end tapered, or coffee cans with bottom removed

PREPARATION

Microbial activity is greatest when the soil is moist (at or near field capacity). If the soil is dry, a second respiration measurement should be made at a minimum of six hours (preferably 16 to 24 hours later) after the infiltration test or wetting of the soil. If the soil is saturated, soil respiration is inhibited, and this test should not be run. If necessary to save time, rings can be placed and soils wetted the day before the demonstration. It may be useful to combine the litter bag and soil respiration measurements, in order to compare results from two different methods that measure soil biological activity.

Divide class in teams of two or more, and assign each team to one sample site. Demonstrate the technique first, à la Julia Childs. Have one ring for showing how to place it and take headspace measurements. Have a second ring already placed and capped from which to collect a CO_2 sample. Then send teams out to do their own sampling.

Note: This description of the soil respiration measurement was taken from the USDA Soil Quality Test Guide, which you may want to consult for more details. See Resources section.

1. Clear the sampling area of surface residue, etc. If the site is covered with vegetation, trim it as close to the soil surface as possible.
2. Using the hand sledge and block of wood, drive the 6-inch diameter ring, beveled edge down, to a depth of three inches (line marked on outside of ring). If the soil contains rock fragments, and the ring cannot be inserted to depth, gently push the ring into the soil until it hits a rock fragment.
3. Measure the height from the soil surface to the top of the ring in centimeters. For a more accurate measurement of soil respiration, the chamber headspace should be measured. Inside the ring, take four measurements (evenly spaced) of the height from the soil surface to the top of the ring, calculate the average, and record on the Soil Respiration Data worksheet.

4. Cover the ring with the lid and note the time. Wait exactly 30 minutes (to allow CO_2 to accumulate in the chamber). If this is the SECOND respiration measurement, briefly remove the lid and replace it before timing to allow the release of gases that have built up over the 6–24-hour waiting period.
6. Insert the soil thermometer into the soil adjacent to the ring with lid (about one inch away from ring and one inch deep). If the thermometer can easily be inserted into the rubber stoppers, insert it into one of them to a 1-inch depth into the soil.
7. Assemble the Draeger tube apparatus just before the end of the 30-minute wait. Connect a needle to one of the sections of tubing. Break open both ends of a CO_2 Draeger tube, either by using the hole at the end of the syringe handle, or by clipping the tube ends with a finger nail clipper. Connect the Draeger tube to the other end of the needle's tubing. The arrow on the side of the Draeger tube should point away from the needle. With the second piece of tubing, connect the Draeger tube to the syringe.
8. After 30 minutes, insert the Draeger tube apparatus needle into a stopper. Insert a second needle into one of the other stoppers on the lid to allow air flow into the head space during the gas sampling. The second needle should be inserted just before the head space is sampled.
9. Over a 15-second span, draw the syringe handle back to the 100 cc reading (1 cc = 1 ml). [If the reading is less than 0.5%, take four additional 100 cc samples of the head space through the same Draeger tube. To do this, disconnect the tube from the syringe to remove the air, and reconnect the tube to the syringe. Take another 100 cc sample. Repeat.]
10. On the Soil Respiration Data worksheet, record the temperature in Celsius at the time of sampling. On the Draeger tube, read the "n=1" column if 100 cc was sampled or the "n=5" column if 500 cc was sampled. The % CO_2 reading should be an estimate of the highest point that the purple color can be easily detected. Enter this reading on the Soil Respiration Data worksheet.
11. Remove the thermometer, Draeger apparatus needle, air flow needle, and the lid from the ring. If this is the first respiration measurement, leave the ring in the soil for the infiltration measurement.

CALCULATIONS

Soil Respiration (lb CO_2 - C/acre/day) = PF x TF x (%CO_2 - 0.035) x 22.91 x H

PF = pressure factor = 1

TF = temperature factor = (soil temperature in Celsius + 273) ÷ 273

H = inside height of ring = 5.08 cm (2 inches)

Calculations can be done quickly by entering data into a spreadsheet if a computer is available, or students can use hand-held calculators.

PREPARATION TIME

1–2 hours (varies depending on what materials are available)

DEMONSTRATION TIME

1–1.5 hours

DISCUSSION QUESTIONS

1. Compare soil respiration results for different sites. How may management practices on the different sites have influenced results?
2. If measurements were made before and after wetting soil, compare before and after results. How does soil moisture influence biological activity?
3. Would it be possible to estimate all carbon imports and exports to a soil system? What information would you need to start to make such an estimate?

SOURCES OF SUPPLIES

Fisher Scientific, Pittsburgh, PA
(800) 766-7000
Draeger tubes, latex tubing, hypodermic needles

Scientific Industries
227 Blue Bell Ave. Boulder, CO 80302
(303) 443-7087
Draeger tubes

Demonstration 2: Soil Respiration

step-by-step instructions for students

INTRODUCTION

Soil breathes! Soil respiration is an indicator of biological activity (i.e., microbial and root), or soil life. This activity is as important to the soil ecosystem as healthy lungs are to us. However, more activity is not always better because in some circumstances it may indicate an unstable system undergoing net carbon loss (i.e., after tillage).

Soil respiration is the production of carbon dioxide (CO_2) as a result of biological activity in the soil by microorganisms, live roots, and macroorganisms such as earthworms, nematodes, and insects. Carbon dioxide emitted from soil is a colorless and odorless gas that enters the atmosphere and annually exceeds the amount emitted by all human activities. The activity of organisms in the soil is considered to be a positive attribute for soil quality.

Soil respiration is highly variable both spatially and seasonally, and is strongly affected by moisture and temperature conditions. Because this variability can complicate interpretations, certain sampling precautions must be taken.

Knowing the history of the sampling site and characteristics of nearby soils becomes very important when evaluating respiration. Soil color may provide some assistance when interpreting respiration rates. A light colored soil with a high respiration rate may be indicative of a soil being depleted of organic matter. A relatively darker soil with the same rate could be considered healthy. The dark color indicates the presence of organic matter. Tillage or cultivation can result in loss of soil carbon (C) and increases in the amount of CO_2 released. The soil is loosened, which creates better accessibility of oxygen necessary for organic matter decomposition and respiration, resulting in the production of CO_2.

Soil respiration can be limited by moisture, temperature, oxygen, soil reaction (i.e., pH), and the availability of decomposable organic substrates. Optimum respiration usually occurs at around 60% of water-filled pore space. Soil respiration will decrease under saturated or dry conditions. Biological activity doubles for every 18˚F rise in temperature until the optimum temperature is reached (varies for different organisms). Activity declines as temperature rises above optimum. The most efficient soil organic matter decomposers are aerobic; thus, soil respiration rates decline as soil oxygen concentration decreases. Oxygen is most limiting in soils that are saturated with water. Greater oxygen flow occurs in well-aggregated soils that have many macropores.

Addition of organic materials will generally increase soil respiration. Organic matter provides the food or substrate on which heterotrophic soil microbes feed. Organic materials with low carbon to nitrogen (C:N) ratios (e.g. manure, leguminous cover crops) are easily decomposed; thus, the addition of these materials to soil will increase soil respiration. Materials with high C:N ratios (e.g., compost, sawdust) decompose more slowly but provide a more stable, long-term supply of organic material than legumes, biosolids, and manures. Soil microbes will compete with plants for nitrogen when soil is amended with products having C:N ratios higher than 25:1.

Agricultural chemicals that directly kill or otherwise impair soil microorganisms, such as fungicides and nematocides, reduce soil respiration. Although these chemicals target pathogenic

organisms, they may also impair the viability of beneficial organisms.

Organic matter decomposition provides benefits and drawbacks. Decomposition of organic matter is the primary route through which some essential nutrients (e.g., nitrogen) are released, but organic matter destruction reduces the benefits that organic matter confers to soil physical and chemical properties. The addition of organic materials to the soil must equal the loss due to decomposition for the sustainability of the system to be maintained.

MANAGEMENT FACTORS INFLUENCING SOIL RESPIRATION

INCREASES SOIL RESPIRATION

- Adding organic amendments, such as manure, biosolids, and crop residues
- Irrigating to proper moisture content

DECREASES SOIL RESPIRATION

- Removing or burning crop residues
- Continuous tillage without organic matter replacement
- Agricultural chemicals (e.g., fungicides and nematocides)

MATERIALS

Assemble materials as per instructor's outline

PREPARATION

Microbial activity is greatest when the soil is moist (at or near field capacity). If the soil is dry, a second respiration measurement should be made at a minimum of six hours (preferably 16 to 24 hours later) after the infiltration test or wetting of the soil. If the soil is saturated, soil respiration is inhibited, and this test should not be run.

1. Clear the sampling area of surface residue, etc. If the site is covered with vegetation, trim it as close to the soil surface as possible.
2. Using the hand sledge and block of wood, drive the 6-inch diameter ring, beveled edge down, to a depth of three inches (line marked on outside of ring). If the soil contains rock fragments, and the ring can not be inserted to depth, gently push the ring into the soil until it hits a rock fragment.
3. Measure the height from the soil surface to the top of the ring in centimeters (cm). For a more accurate measurement of soil respiration, the chamber head-space should be measured. Inside the ring, take four measurements (evenly spaced) of the height from the soil surface to the top of the ring, calculate the average, and record on the Soil Data worksheet.
4. Cover the ring with the lid and note the time. Wait exactly 30 minutes (to allow CO_2 to accumulate in the chamber). If this is the SECOND respiration measurement, briefly remove the lid and replace it before timing to allow the release of gases that have built up over the 6–24-hour waiting period.
5. Insert the soil thermometer into the soil adjacent to the ring with lid (about one inch away from ring and one inch deep). If the thermometer can easily be inserted into the rubber stoppers, insert it into one of them to a 1-inch depth into the soil.
6. Assemble the Draeger tube apparatus just before the end of the 30-minute wait. Connect a needle to one of the sections of tubing. Break open both ends of a CO_2 Draeger tube, either by using the hole at the end of the syringe handle, or by clipping the tube ends with a finger nail clipper. Connect the Draeger tube to the other end of the needle's tubing. The arrow on the side of the Draeger tube should point away from the needle. With the second piece of tubing, connect the Draeger tube to the syringe.
7. After 30 minutes, insert the Draeger tube apparatus needle into a stopper. Insert a second needle into one of the other stoppers on the lid to allow air flow into the head space during the gas sampling. The second needle should be inserted just before the head space is sampled.

8. Over a 15-second span, draw the syringe handle back to the 100 cc reading (1 cc = 1 ml). [If the reading is less than 0.5%, take four additional 100 cc samples of the head space through the same Draeger tube. To do this, disconnect the tube from the syringe to remove the air, and reconnect the tube to the syringe. Take another 100 cc sample. Repeat.]
9. On the Soil Respiration Data worksheet, record the temperature in Celsius at the time of sampling. On the Draeger tube, read the "n=1" column if 100 cc was sampled or the "n=5" column if 500 cc was sampled. The % CO_2 reading should be an estimate of the highest point that the purple color can be easily detected. Enter this reading on the Soil Respiration Data worksheet.
10. Remove the thermometer, Draeger apparatus needle, air flow needle, and the lid from the ring. If this is the first respiration measurement, leave the ring in the soil for the infiltration measurement.

    (This description of the soil respiration measurement was taken from the USDA Soil Quality Test Guide, which you may want to consult for more details).

CALCULATIONS

Soil Respiration (lb CO_2 - C/acre/day) = PF x TF x (%CO_2 - 0.035) x 22.91 x H

PF pressure factor = 1

TF temperature factor = (soil temperature in Celsius + 273) ÷ 273

H inside height of ring = 5.08 cm (2 inches) if not measured

INTERPRETATION OF SOIL RESPIRATION VALUES

In general, a higher respiration rate indicates better soil quality. Low respiration rate, when soil temperature and moisture are favorable for biological activity, would indicate less than desirable organic matter levels. This value must be interpreted within the context of other indicators. For example, a very low nitrate concentration plus a high respiration rate may indicate a high nitrogen immobilization rate, possibly due to the addition of crop residues or other soil amendments that possess wide C:N ratios. Some general guidelines to interpreting respiration values are presented in Table 1. These are only guidelines and should not be applied to every soil type and management situation.

TABLE 1. GENERAL SOIL RESPIRATION CLASS RATINGS AND SOIL CONDITION AT OPTIMUM SOIL TEMPERATURE AND MOISTURE CONDITIONS, PRIMARILY FOR AGRICULTURAL LAND USES (Woods End Research, 1997)

SOIL RESPIRATION (lbs. CO_2-C/ac/day)	CLASS	SOIL CONDITION
0	No soil activity	Soil has no biological activity and is virtually sterile.
< 9.5	Very low soil activity	Soil is very depleted of available organic matter and has little biological activity.
9.5 - 16	Moderately low soil activity	Soil is somewhat depleted of available organic matter, and biological activity is low.
16 - 32	Medium soil activity	Soil is approaching or declining from an ideal state of biological activity.
32 - 64	Ideal soil activity	Soil is in an ideal state of biological activity and has adequate organic matter and active populations of microorganisms.
> 64	Unusually high soil activity	Soil has a very high level of microbial activity and has high levels of available organic matter, possibly from the addition of large quantities of fresh organic matter or manure.

A high soil respiration rate, indicative of high biological activity, can be a good sign of rapid decomposition of organic residues into nutrients available for plant growth. However, decomposition of the stable organic matter is detrimental to many physical and chemical processes such as aggregation, cation exchange, and water holding capacity. Also, immediately following a tillage operation, CO_2 evolution can rise dramatically due to exposure of organic matter to organisms and oxygen. Also, soil respiration can rise dramatically after rainfall. The rise in soil respiration is affected by the length of time the soil is dry before the rainfall event.

Under dry conditions, soil respiration tends to be higher in the crop row than in the interrow. The higher respiration rates are attributed to the contribution from plant roots. Under wet conditions, there tends to be no difference in respiration between the row and interrow. When the soil interrow is compacted (wheel track) and the soil is wet, soil respiration tends to be lower than in the row. The lower soil porosity accounts for the lower respiration rate under compacted conditions.

Biological activity is a direct reflection of the degradation of organic matter in the soil. This degradation indicates that two processes are occurring: (1) loss of soil carbon and (2) turnover of nutrients. Some optimum soil respiration rate, that balances the long-term detrimental aspects of soil carbon loss and soil nutrient turnover, must be defined.

DISCUSSION QUESTIONS

1. Compare soil respiration results for different sites. How may management practices on the different sites have influenced results?
2. If measurements were made before and after wetting soil, compare before and after results. How does soil moisture influence biological activity?
3. Would it be possible to estimate all carbon imports and exports to a soil system? What information would you need to start to make such an estimate?

Demonstration 3: Earthworm Populations

for the instructor

OVERVIEW

You have a choice of two methods for this demonstration. The shovel-count method will be more tedious for the students because they will have to sort through the soil and remove all earthworms. The vermifuge method may take a little more effort at first to gather the materials needed, but it will make the students' work easier.

MATERIALS

SHOVEL-COUNT METHOD

- Shovels
- Earthworm Data worksheets (appendix 5)
- Pencils

VERMIFUGE METHOD

- Sample rings*
- Clippers
- Watering can
- Scoop
- Stirring rod
- Fresh water
- Jars
- Earthworm Data worksheets (appendix5)
- Pencils
- Ground yellow mustard seed (available in bulk from health food stores or from herb companies)**

*Sample rings define the sample area and prevent vermifuge from escaping sample area. A simple design is to cut the top 8–12 inches from a 5-gallon drum and weld on a piece of metal pipe that overhangs each side by 6 inches to use as a handle. The ring is pressed into the soil to 2–3 inches depth, and vermifuge is added within the sample ring. Sample rings can also be fashioned from sheet metal, housing duct pipes, or large clean paint cans with the bottom cut off.

**60 ml (volume) or 32 grams of yellow mustard powder to 4.5 liters of tap water = 13 ml/1 liter or 7g/liter. 4.5 liters of vermifuge is the amount required per sample area in this demonstration.

PREPARATION

SHOVEL-COUNT METHOD

For the shovel-count method, very little preparation is required. Identify sample areas, try to collect a similar soil volume at each location, and record results.

VERMIFUGE METHOD

The vermifuge method requires more preparation. Sample rings must be obtained or made. Other materials must be gathered. To minimize the amount of time needed for the demonstration, sample rings can be set out the day before. Ideally a minimum of 4 can be set out per habitat. Select areas with contrasting management regimes. Possible habitats include orchard, row crop, fallow, and uncultivated field soils.

To begin the demonstration, gather group at one sample ring to explain technique. Divide class evenly among the number of sample rings and have each "ring-team" collect their sample. Have one person in each team do a shovel-count at each site for comparison. Collect results and derive an average abundance per habitat. Observe species differences and discuss results.

PROCEDURE

1. Select sample area
2. Place sample rings on the surface of the site and push them several inches into the soil.
3. Carefully clip vegetation and removed all litter from inside sample area.
4. Slowly sprinkle 4.5 liters of vermifuge into each sample area, distributing it evenly over the entire surface.
5. After all of the vermifuge solution infiltrates the soil, wait 10 minutes, and make a second vermifuge application (4.5 liters).
6. Collect all earthworms that surface inside the sample area.
7. After 10 minutes elapse since infiltration of the second vermifuge application, use a hand spade to dig through the surface layer of soil (~5 cm deep) and collected any more earthworms found there.
8. Rinse earthworms in water, drain, and store in containers inside an insulated cooler with ice packs (unless samples are to be counted in the field and returned to the sample area).
9. An alternate method that does not require a sample ring can be found in the USDA Soil Quality Test Kit Guide, which is available on the internet (see Resources section).

PREPARATION TIME

For the shovel-count method, 0.5 hour is all that is needed. For the vermifuge method, several hours or more may needed to gather materials.

DEMONSTRATION TIME

1.5–2 hours

DISCUSSION QUESTIONS

1. Most earthworm species found in farmed soils in the U.S. were not present in those soils 400 years ago. Where do you think they came from?
2. Compare your findings from different habitats. Which habitats had the most earthworms per sample area? Which had the highest diversity (greatest number of species)? Why?
3. Determine what ecological types of earthworm were present in each sample area (see Table 2, page 34). How do you think these results were influenced by soil management practices in those areas. Consider factors such as amount and type of soil disturbance, organic matter inputs, presence of surface organic layer, etc.
4. How do these findings relate to agricultural productivity and sustainability?
5. If you were in charge of management decisions for the farm soils that were sampled, would you alter any practices based on this information? Why?

Demonstration 3: Earthworm Populations

step-by-step instructions for students

INTRODUCTION

Earthworms are representative of the many organisms that make up soil food webs, and their abundance can be an indicator of soil biological activity.

There are a number of ways to estimate how many earthworms are living in a particular field. Perhaps the simplest is the shovel-count: turn over a shovel-full of soil and count the worms present. Dig down 8 inches to a foot, and count every earthworm you can find in the shovel-full. Do this in half-a-dozen or more spots in each soil type on your land and come up with an average for each. If you find 5 to 10 worms per shovel-full, that represents a fairly healthy earthworm community. If this is done at about the same time each year the results will give some indication of how management practices are affecting earthworm populations.

Keep in mind that earthworm populations are very patchily distributed, and their location and abundance are heavily influenced by soil moisture, temperature, organic matter, time of year, and probably several other variables such as barometric pressure. For these reasons, a sufficient number of samples must be collected in order to accurately characterize earthworm populations in a particular field. Using more standardized sampling methods may also help.

Another method for sampling earthworms uses a vermifuge, or chemical irritant, which causes the earthworms to burrow to the soil surface, where they can be collected by hand. For many years the standard vermifuge has been a very dilute solution of formalin (about 8 ml formalin in 4.5 liters of water). However, recent studies have shown that mustard powder in water can be equally as effective.

Those interested in developing an even greater depth of understanding about earthworm ecology and how it interacts with farming may want to do more than just count numbers of earthworms present. Earthworms can be classified according to some simple physical characteristics that are directly related to their ecological roles in soil. Table 2 (next page) highlights the three types of earthworms.

Try using Table 2 to determine if you have more than one type of earthworm in your samples. Most California farm soils have endogeic earthworms, but epigeic and anecic species are rare. Epigeic species are more likely to be found in fields that have a permanent organic mulch on the surface. They may be added along with composts, but are not likely to thrive in the absence of an organic cover. Anecic species are desirable because of the work they do incorporating organic matter into the soil, mixing surface and deeper soil horizons, and creating deep channels for aeration, infiltration, and easy root penetration. Anecic earthworms could be introduced by direct inoculation, but transferring blocks of soil (one cubic foot each) from an area with a large earthworm population into a farm soil might work better.

Another idea is to set aside a small portion of a farm to be managed as an earthworm reservoir. If needed, the soil could be limed to bring it near pH 7, fertilized, irrigated regularly, and a cover crop established and cut periodically to provide an organic mulch as food and cover. A population of an anecic species could be introduced into this area and built up. Nightcrawlers can be purchased from bait dealers, who generally get them from nightcrawler harvesters in the Pacific Northwest.

From this reservoir, blocks could periodically be taken and introduced into the field. This might be done each year in the fall when earthworm activity is increasing. Remember to provide an organic mulch. The rate of spread would vary with species and conditions in the field. *Lumbricus terrestris,* the nightcrawler, is capable of traveling at least 19 meters on the soil surface in the course of one evening foray.

MATERIALS NEEDED

Assemble materials as per instructor's outline

SHOVEL-COUNT METHOD

1. For the shovel-count method, very little preparation is required. Identify sample areas, try to collect a similar soil volume at each location, and record results.

VERMIFUGE METHOD

1. Select sample area
2. Place sample rings on the surface of the site and push them several inches into the soil.
3. Carefully clip vegetation and removed all litter from inside sample area.
4. Slowly sprinkle 4.5 liters of vermifuge into each sample area, distributing it evenly over the entire surface.
5. After all of the vermifuge solution infiltrates the soil, wait 10 minutes, and make a second vermifuge application (4.5 liters).
6. Collect all earthworms that surface inside the sample area.
7. After 10 minutes elapse since infiltration of the second vermifuge application, use a hand spade to dig through the surface layer of soil (~5 cm deep) and collected any more earthworms found there.
8. Rinse earthworms in water, drain, and store in containers inside an insulated cooler with ice packs (unless samples are to be counted in the field and returned to the sample area).
9. An alternate method that does not require a sample ring can be found in the USDA Soil Quality Test Kit Guide, which is available in the internet (see Resources section).

TABLE 2. THREE DIFFERENT TYPES OF EARTHWORMS

GROUP	WHAT THEY LOOK LIKE	WHERE THEY LIVE	WHAT THEY EAT	MEANING OF NAME	EXAMPLE
Epigeic	small; dark red or brown; fast growing move quickly	areas with a lot of organic matter: forest litter layer; manure piles; cool compost piles	large proportion of diet is organic matter	epi = on Gaia = earth	*Lumbricus rubella, Eisenia fetida* (red worm, manure worm)
Endogeic	small to medium; light or no pig-mentation; slower moving	continous burrows in soil; often found in root ball; generally feed and defecate below ground	mixture of buried organic matter and mineral soil, decaying roots	endo = within Gaia = earth	*Allolobophora chlorotica, Aporrectodea caliginosa*
Anecic	large and very muscular; wedge-shaped tail; color on front end, less on tail end; slow growing	build permanent, vertical burrows that are very deep; raised midden of castings and residue marks burrow entrance	feed by pulling organic matter from surface down into burrow before ingesting	unknown	*Aporrectodea longa Lumbricus terrestris* (night-crawler)

Demonstration 4: Soil Arthropods

for the instructor

OVERVIEW

For this short demonstration, both of these exercises provide a hands-on, show-and-tell of soil arthropods. You should have keys to identification available, and some familiarity with what kinds of animals students are likely to find.

MATERIALS

- Cups (plastic drink cups work well)
- Small trowel
- Funnels (steep-sided funnels with no seams work well; inverted polypropylene Erlenmeyer flasks with bottoms removed are excellent. 500 millileter flasks for 5 x 5 centimeter cores, 2000 millileter flasks for compost or litter samples)
- Light source (4 to 20 watts only—7 watt "Christmas" style lights work well)
- Screen (to place in the bottom of funnel to keep sample material in the funnel)
- Jars
- Dissection microscope, hand lenses
- Soil Arthropod Data worksheets (appendix 6)

PREPARATION

PITFALL TRAPPING

Select sample areas in different habitats. Try for a minimum of 3 or 4 samples per habitat. Traps can be set 24 to 48 hours in advance of the demonstration. Traps can also be collected before demonstration if time is at a minimum, although it would be useful to show students how traps were set.

Bury the cup so that the top edge is flush with the soil surface. To prevent cup from filling with soil during this process, it is helpful to bury 2 cups together, one inside the other. When you are finished burying them, remove the top cup, and the one underneath should be free of soil. Opening may be left open, or covered with a board, leaving enough room between the pitfall and cover for free access by surface roaming creatures. If collected frequently, pitfalls may be left empty, or filled partly with water, so that live specimens are obtained.

Pitfalls left in place for more than a day or two should have a preservative added. This prevents the creatures from devouring one another. Ethol glycol (antifreeze) is commonly used, as is 70% alcohol, or 10% formalin. Each of these possesses attractive properties for certain creatures.

TULLGREN FUNNELS

Collect samples from various habitats and carefully place in funnels. If too much sample material falls through funnel, add more screens, or a piece of coarse cheesecloth.

Place a wide-mouth jar containing liquid under the funnel. Use water if you want to keep animals alive. Use alcohol (70%) with some glycerin added if you want to preserve specimens. Do not shake or disturb funnels, in order to keep sample jars as free of soil as possible. Let samples stand in funnels with no light for 1 day. Turn lights on and leave them on from second to seventh day.

Samples can be collected and extracted in advance of demonstration, although as with pitfall traps, it would be useful to demonstrate for students how samples were collected, and how extraction funnels work.

PROCEDURE

Observe collections under magnification. If live collections are made, students have the opportunity to observe behavioral adaptations of the animals (e.g., springing springtails, fast-moving predators like centipedes, or mesostigmatid mites, slower-moving fungal grazers like oribatid mites and millipedes). Have simple keys available for help with identification. For a quantification exercise, have students count species, or functional groups, and calculate a diversity index for comparing habitats.

PREPARATION TIME

1 hour or more, depending on which exercises are followed, and what materials are available or need to be obtained.

DEMONSTRATION TIME

From just 0.5 hour for a brief show-and-tell, where students observe samples previously collected, to 1 to 2 hours if students are involved in collecting samples, observing, and quantifying.

DISCUSSION QUESTIONS

1. Can you guess which animals might be predators? Which ones might be grazers?
2. What effects do each habitat that the samples were collected from have on the soil organisms found there? Think about sizes of creatures, diversity, food-web interactions, pigmentation, and so on.
3. Which habitats had greatest abundance? Which has greatest diversity? Why?
4. What effects do you think different soil management practices have on soil arthropods? Besides the various effects of organic matter inputs, think also about the influence of physical disturbance.

Hands-On Exercise: Carbon and Nitrogen Mineralization

for students

OVERVIEW

A major function of the soil food web is to convert organic matter into forms of nutrients that plants can use. The following is an exercise to estimate how much mineral N (nitrate and ammonium) is coming from organic inputs. This exercise is a simplification of organic matter composition and the complex processes that occur during decomposition. Use it as a learning aid.

(based on material from the UC Davis Sustainable Agriculture Farming Systems project)

SCENARIO

In one year, 12,000kg per hectare* of organic matter (dry weight) are added to the soil of an organic farm. These materials include cover crop residues, manure, and crop residues form the previous year. Overall, carbon (C) accounts for roughly half the weight of the added organic matter.

Ten percent of the organic matter consists of **resistant** structural components (e.g., lignin in plant cell walls) that cannot be degraded by soil microorganisms. This fraction has a very high C:N ratio (100:1 or higher). It becomes part of the soil organic matter, thereby increasing structure and water-holding capacity of the soil.

Sixty percent of the organic matter consists of cell components (such as cellulose) that are **moderately decomposable** by soil microorganisms. The 60% fraction has a relatively high C:N ration of 40:1. During decomposition of this fraction, microbes must respire 90% of the C (as CO_2) in order to incorporate 10% of the C into their cells. Similarly, microbes incorporate only 10% of the N from this fraction, so that the remaining 90% is released as mineral N. (Remember that soil microbes typically have adequate levels of N, but they are starved for C.)

Thirty percent of the organic matter consists of cell tissue components such as sugars, amino acids, and lipids, which are **easily decomposable** by soil microorganisms. The C:N ratio of this fraction is 20:1. Since microbes are more efficient in utilizing these compounds, they incorporate 20% of the C and give off only 80% as CO_2. Microbes also incorporate 20% of the N from this fraction, while releasing 80% as mineral N.

THE PROBLEM

Your task is to calculate how much nitrogen is mineralized, in order to determine if the amount of N will be adequate for crop production. Fill in the blanks in the chart on the next page with approximate amounts of C and N. Use the chart to calculate how much mineral N is released from the organic matter added over the course of one year.

**Equivalent to about 5.4 tons per acre*

Resistant Fraction	10% 100:1 C:N Total in this fraction 600 kg C/ha 6 kg N/ha	
Moderately Decomposable Fraction	60% 40:1 C:N Total in this fraction _____ C (kg/ha) _____ N (kg/ha)	_____ kg C per ha in biomass _____ kg C per ha respired as CO_2 _____ kg N per ha in biomass _____ kg N per ha in mineral N
Easily Decomposable Fraction	30% 20:1 C:N Total in this fraction _____ C (kg/ha) _____ N (kg/ha)	_____ kg C per ha in biomass _____ kg C per ha respired as CO_2 _____ kg N per ha in biomass _____ kg N per ha in mineral N

_____TOTAL KG N MINERALIZED PER HECTARE

QUESTIONS TO PONDER

- What happens to the N incorporated in the soil biomass? Is this the end of the story?
- What is the fate of mineralized N/
- How would organic and conventionally fertilized farm soils differ with respect to the timing of mineral N release?
- Why is it important to consider three fractions for organic matter inputs?

CARBON AND NITROGEN MINERALIZATION EXERCISE KEY

Resistant Fraction	10% 100:1 C:N Total in this fraction 600 kg C/ha 6 kg N/ha	
Moderately Decomposable Fraction	60% 40:1 C:N Total in this fraction 3600 C (kg/ha) 90 N (kg/ha)	360 kg C per ha in biomass 3240 kg C per ha respired as CO_2 9 kg N per ha in biomass 81 kg N per ha in mineral N
Easily Decomposable Fraction	30% 20:1 C:N Total in this fraction 1800 C (kg/ha) 90 N (kg/ha)	360 kg C per ha in biomass 1440 kg C per ha respired as CO_2 18 kg N per ha in biomass 72 kg N per ha in mineral N

153 TOTAL KG N MINERALIZED PER HECTARE

Assessment Questions

1) What is soil?

2) What forms of life exist in soil ecosystems?

3) How would you define a "healthy" agricultural soil?

4) What is a soil food web?

5) What might be some negative effects of the long-term practice of monoculture cropping and the use of synthetic chemical fertilizer and pest control agents on the soil ecosystem?

Assessment Questions Key

1) What is soil?
   - *An ecological system consisting of inorganic minerals (sand, silt, clay, and nutrients), pore spaces, water, gases, organic matter, living organisms, and plants*

2) What forms of life exist in soil ecosystems?
   - *Bacteria, fungi, actinomycetes, millipedes, isopods, mollusks, insects, insect larvae, worms and many small vertebrate animals such as gophers, ground squirrels, moles, etc.*

3) How would you define a "healthy" agricultural soil?
   - *A soil with a set of desirable physical and chemical properties which has the capacity to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health. This would include many of the following general characteristics:*

   a) adequate rooting depth for the crop(s) to be grown

   b) a 3–5% organic matter content

   c) maintains stable soil aggregates

   d) allows for rapid water infiltration without soil erosion

   e) a low bulk density (good structure with minimal compaction)

   f) pH between 6 and 7

   g) an extractable nutrient profile within the optimal range of physiological tolerance for the crops to be grown

   h) good water holing capacity and well-drained

   i) high soil biological diversity and activity (soil respiration)

   j) adequate supplies of labile organic matter with potentially mineralizable nitrogen

   k) seasonal soil temperatures from 60–85°F

4) What is a soil food web?
   - *The entire assemblage of soil organisms (producers, consumers and decomposers) in a soil ecosystem interacting among and between trophic levels*

5) What might be some negative effects of the long-term practice of monoculture cropping and the use of synthetic chemical fertilizer and pest control agents on the soil ecosystem?
   - *Loss of SOM, reduction in soil aggregation, reduction in nutrient- and water-holding capacity, reduction in soil biological diversity and activity, increased pest and disease incidence*

Resources

PRINT RESOURCES

Coleman, David, and Dak Crossley. 1996. *Fundamentals of Soil Ecology.* San Diego, CA: Academic Press.

The best textbook introduction to the subject that I know of. Gives an overview of the basics, and attempts to consider the applications.

Dindal, Daniel, ed. 1990. *Soil Biology Guide.* NY: Wiley.

A weighty tome, with chapters including taxonomic keys and basic biology/ecology on virtually all organisms found in soils.

Doran, John, and Alice Jones, eds. 1996. *Methods for Assessing Soil Quality.* Special Publication # 49. Madison, WI: Soil Sci. Soc. America.

Soil quality is the current buzzword in soil science circles. This volume explores the application of the idea to sustainable environmental management.

Gershuny, Grace, and Joseph Smillie. 1995. *The Soul of Soil: A Guide to Ecological Soil Management.* Davis, CA: AgAccess.

More hands-on and less academic than the above works, this book is aimed at plant growers and has lots of practical information.

Gibbons, Boyd. 1984 (September). Do we treat our soil like dirt? *National Geographic,* pp 351-388.

An overview of U.S. soils, from soil biota to bankrupt farmers, done in classic NG style, with lots of great photos and drawings.

Gliessman, Stephen R. 1998. *Agroecology: Ecological Processes in Sustainable Agriculture.* Chelsea, MI: Ann Arbor Press.

Provides a brief overview of the most commonly used conventional agricultural practices and the environmental and agroecological consequences of their use.

Tugel, Arlene, Ann Lewandowski, and Deb Happe-vonArb, eds. 2000. *Soil Biology Primer, Revised Edition.* Ankeny, Iowa: Soil and Water Conservation Society.

An excellent overview of soil biology, loaded with glossy photos and colorful chart. Available from soils.usda.gov/sqi/SoilBiology/soil_biology_primer.htms.

WEB RESOURCES

SOIL QUALITY

Appropriate Technology Transfer for Rural Areas (ATTRA)

www.attra.org/attra-pub/soil-lab.html#Soil%20Health°

Illinois Soil Quality Initiative (ISQI)

www.aces.uiuc.edu/~asap/resources/isqi/soil-health.html

Life in the Soil

www-crcslm.waite.adelaide.edu.au

Soil and Health Library

www.soilandhealth.org/index.html

Soil Biological Communities

www.blm.gov/nstc/soil/index.html

Soil Ecology Society

vax.wcsu.edu/ses/ses.html

Soil Quality Information Sheets

soils.usda.gov/sqi/sqiinfo.html

Soil Quality Institute—Agronomy Technical Notes

soils.usda.gov/sqi/agronomy.shtml

Soil Quality Institute—NRCS

soils.usda.gov/sqi/

Soil Quality Test Kit

soils.usda.gov/sqi/kit2.html

The Soil Foodweb: Its Importance in Ecosystem Health, Elaine Ingham

www.rain.org/~sals/ingham.html

The Health of Our Soils: Toward Sustainable Agriculture in Canada

sis.agr.gc.ca/cansis/publications/health/intro.html

Soil quality and financial performance of biodynamic and conventional farms in New Zealand. 1993. J.P. Reganold, A.S. Palmer, J.C. Lockhart and A.N. Macgregor. *Science* 260: 344-349.

www.sarep.ucdavis.edu

University of California Sustainable Agriculture Research and Education Program (UC SAREP)

www.sarep.ucdavis.edu/soil/websites.htm

SOURCES OF SUPPLIES

Fisher Scientific, Pittsburgh, PA
(800) 766-7000

Scientific Industries
227 Blue Bell Ave. Boulder, CO 80302
(303) 443-7087

Appendix 1: Major Organic Components of Typical Decomposer Food Sources

	PROTEINS	FATS	CARBOS	SIMPLE CELLULOSE	HEMI-CELLULOSE	LIGNIN	ASH
Oak leaf (young)	9	8	22	13	16	21	6
Oak leaf (old)	3	4	15	16	18	30	5
Pine needle	2	24	7	19	16	23	2
Grass leaf	2	2	13	24	33	14	0
Corn stem	1	2	15	18	30	11	8
Wood	0	4	2	22	47	22	1
Horse manure	7	2	5	24	28	14	9
Bacteria	50 to 60	10 to 35	5 to 30	4 to 32	0	0	5 to 15
Fungi	14 to 52	1 to 42	8 to 60	2 to 15	0	0	5 to 12
Earthworm	54 to 72	2 to 17	11 to 17	0	0	0	9 to 23
Arthropods	38 to 50	13 to 26	14 to 31	5 to 9	0	0	0
Steer carcass	39	50	0	0	0	0	11

Appendix 2: Litter Bag Data Sheet (for Demonstration 1)

burial date: location:

retrieval date: details:

LITTER BAG #	HABITAT	% REMAINING (VISUAL ASSESSMENT)	AVERAGE PER HABITAT	OTHER OBSERVATIONS
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				

Appendix 3: Litter Bag Data Sheet Example

burial date: location:

retrieval date: details:

LITTER BAG #	HABITAT	% REMAINING (VISUAL ASSESSMENT)	AVERAGE PER HABITAT	OTHER OBSERVATIONS
1	compost	5		
2	compost	25		
3	compost	80		
4	compost	90	50.0	
5	orchard soil	100		
6	orchard soil	100		
7	orchard soil	70		
8	orchard soil	90	90.0	
9	raised garden bed	97		
10	raised garden bed	99		
11	raised garden bed	72		
12	raised garden bed	95	90.8	
13	row crop	97		
14	row crop	95		
15	row crop	94		
16	row crop	96	95.5	
17	soil surface	100		
18	soil surface	100		
19	soil surface	100		
20	soil surface	99	99.8	

Appendix 4: Soil Respiration Data Sheet (for Demo. 2)

Soil Respiration (at Initial Field Water Content)

Sample site	Ring height	Start time	End time	Soil temp ºC	Draeger tube $\%CO_2$ (n=1)	Soil respiration lbs C/A/ day*
1						0.0
2						0.0
3						0.0
4						0.0
5						0.0
6						0.0
7						0.0
8						0.0

Soil Respiration (at least 6 hours after irrigation or soil wetting) **Date:**

	Draeger tube $\%CO_2$(n=5)	Soil respiration lbs C/A/day*
1		0.0
2		0.0
3		0.0
4		0.0
5		0.0
6		0.0
7		0.0
8		0.0

* Soil respiration = PF x ((Soil Temp C + 273)/273) x (CO_2% - 0.035) x 22.91 x Ring Ht = lbs CO_2 -C/acre/day

PF = Pressure Factor = 'raw' barometric pressure in inches Hg/29.9 inches.

Note: This adjustment is necessary at elevations > 3,000 ft.; otherwise PF = 1

H = 5.08 cm (if not measured)

Conversion: Degrees Celsius = 5/9 x (Degrees Fahrenheit - 32)

Notes:

Appendix 5: Earthworm Data Sheet (for Demonstration 3)

DATE:

SAMPLE SITE	EPIGEIC EATHWORMS	ENDOGEIC EARTHWORMS	ANECIC EARTHWORMS	TOTAL EARTHWORMS	EARTHWORMS PER SQ METER
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

NOTES:

Epigeic:small; dark red or brown color; fast growing; move quickly
Endogeic:small to medium; light or no pigmentation; slower moving
Anecic:large and very muscular; wedge-shaped tail;
color on front end, less on tail end; slow growing

Appendix 6: Arthropod Data Sheet (for Demonstration 4)

	1	2	3	4	5	6	7	8	9	10	11
sample site:											
isopods											
springtails											
spiders											
mites											
earwigs											
aphids											
beetles											
fly larvae											
fly adults											
ants											
wasps											
crickets											
millipedes											
centipedes											
slugs & snails											