Introduction to Soil

Erica Chernoh

What is Soil?

Soil: a definition

- *The unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants.*
- (Soil Science Society of America)

Photos: SSA; soils4teachers.org/around-the-world

Soil Functions

Brady and Weil, Nature and Properties of Soils

Pedosphere

- Soil (or Pedosphere) is composed of elements from the 4 spheres of Earth:
  - Atmosphere
  - Biosphere
  - Lithosphere
  - Hydrosphere

(Image: Brady and Weil, Nature & Properties of Soils, 13e)

Soil profile

- ***Soil profile*** = a vertical section of soil that shows distinct individual layers, called ***horizons***
- Each horizon holds relatively the same physical, chemical, and biological properties

Soil profile

O Horizon = Organic materials

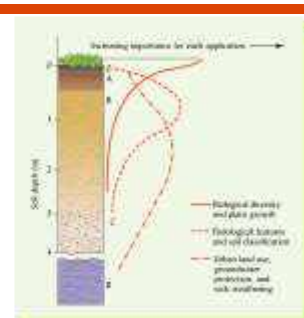
A Horizon = Topsoil

B Horizon = Subsoil (Illuvial)

C Horizon = Substratum

Soil Horizons

- Biological processes are more prominent in the O, A and B horizons

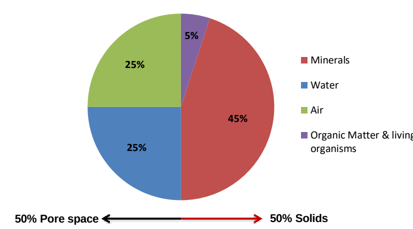


(Image: Brady and Weil, Nature & Properties of Soil)

Brainstorm

- Think back over your activities during the past week
- How have you come into direct or indirect contact with soil?
- List as many incidents as possible

What is Soil Composed of?

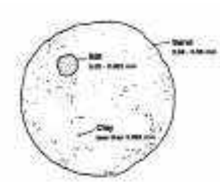


Soil Particles and Texture

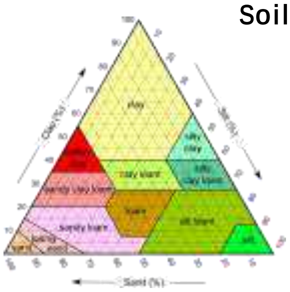
- **Soil texture** = Relative abundance of sand, silt, and clay minerals

Soil Particles

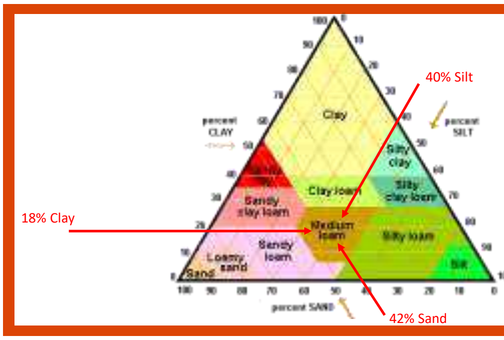
- Mineral Soil components: Classified by particle size
- **Sand:** 2.0 - 0.05 mm in diameter, can be seen by the naked eye
  - ➢Do not adhere –not sticky
- **Silt**: 0.05 - 0.002 mm diameter
  - ➢Feels smooth but not sticky, even when wet
- **Clay**: < 0.002 mm diameter
  - ➢Sticky
  - ➢Colloidal, attracts other ions and water



Soil Textural Classes



- 12 Soil textural classes
- Soil texture based on proportion of sand, silt and clay
- Texture takes hundreds of years to change
- Influences suitability for plant growth
- *Pop quiz: If a soil contains 15% sand, 15% clay and 70% silt, what is the textural class?*
  - *Silt loam*



Loam

- Loam is soil material that is medium-textured
- A loam soil contains particles of various sizes and usually a good bit of humus
- It feels as though it contains a relatively even mixture of sand, silt, and clay
- Loam tends to be rather soft and friable. It has a slightly gritty feel, yet is fairly smooth and slightly sticky and plastic when moist

Soil Texture

- Varies by horizon

Common soil textures in the WV

- **Jory**: silty clay loam (~10% sand, 30% clay, 60% silt)
- **Witzel** (Chemeketa Eola): cobbly loam (~40% sand, 20% clay, 40% silt with cobbles)
- **Bellpine**: silty clay loam (10% sand, 40% clay, 50% silt)
- **Dupee**: silt loam (10% sand, 20% clay, 70% silt)
- **Laurelwood**: silt loam (10% sand, 20% clay, 70% silt)

Importance of Soil Texture

Numerous soil properties are influenced by texture including:

Soil structure
- Soil strength
- Soil aggregation
- Erodibility
- Friability and tillage
- Infiltration and permeability

Nutrient and water retention
- Cation exchange properties (i.e. nutrient retention)
- Plant available water (water holding capacity)
- Organic matter and carbon retention
- Aeration

Pop Quiz

- What type of soil would have a the highest water holding capacity?
  A. Sand
  B. Silt
  C. Clay

Soil Texture

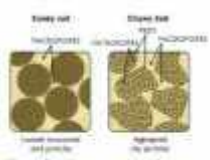
Table 4.1
Generalized Influence of Soil Separates on Some Properties and Behavior of Soils[a]

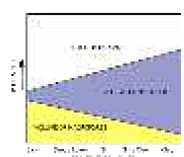
Property/behavior	Sand	Silt	Clay
Water-holding capacity	Low	Medium to high	High
Aeration	Good	Medium	Poor
Drainage rate	High	Slow to medium	Very slow
Soil organic matter level	Low	Medium to high	High to medium
Decomposition of organic matter	Rapid	Moderate	Slow
Warm-up in spring	Rapid	Moderate	Slow
Compactability	Low	Medium	High
Susceptibility to wind erosion	Moderate (high if fine sand)	High	Low
Susceptibility to water erosion	Low (unless fine sand)	High	Low if aggregated, high if not
Shrink-swell potential	Very low	Low	Moderate to very high
Sealing of ponds, dams, and landfills	Poor	Poor	Good
Suitability for tillage after rain	Good	Medium	Poor
Pollutant leaching potential	High	Medium	Low (unless cracked)
Ability to store plant nutrients	Poor	Medium to high	High
Resistance to pH change	Low	Medium	High

[a]Exceptions to these generalizations do occur, especially as a result of soil structure and clay mineralogy.

Texture and Porosity

- Porosity varies depending on particle size and aggregation
- Clay soils contain more pore space than sandy soils due to the pore space inside of the soil aggregates
- Sand has larger pores but less total pore space





Soil Texture and Structure

Soil Texture vs. Structure: What is the Difference?

- **Soil texture:** relative abundance of sand, silt and clay particles
- **Soil structure:** how the particulates aggregate

- Management can't alter texture, only mineral weathering and mixing!

Soil Structure

- **Soil structure** is the way individual particles/separates of soil are assembled (or glued together) into clumps called ***aggregates or peds***
- Peds/aggregates: break along natural zones of weaknesses
- **Peds** contain ***solids*** and ***pore*** space

Photo: European Union Geosciences Blog, blogs.egu.eu, courtesy of Pepe Álvarez (Technical University of Cartagena, Spain)

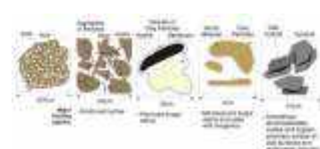
Aggregate Formation

Abiotic processes:

- Soil texture
  - Amount and type of clay
  - Fe and Al oxides (cementing agents)
- Wetting and drying cycles
- Freezing and thawing

Biotic processes:

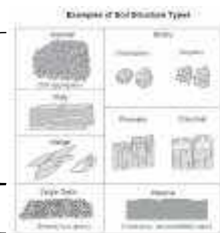
- Root network
- Soil micro-organisms
- Organic matter (food for soil fungi)



Types of Structure

Aggregated

Non-aggregated



Different structures: impact air and water flow and soil processes

Photo: DEFRA, Think Soils, http://adlib.everysite.co.uk/resources/000/263/234/chapter1.pdf

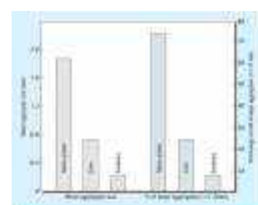
Soil Structure

Indicators of damaged or poor soil structure:
- Compaction and plow pans
- Waterlogging
- Restricted root growth
- Surface crusting

"The important physical changes imposed by the farmer in plowing, cultivating, draining, liming, and manuring his land are structural rather than textural."

(Brady and Weil, Nature and Properties of Soils)

Impact of agricultural cultivation on soil aggregation



- Soil aggregates are larger and more stable under native prairie compared to land that had been cultivated for 90 years

From the Nature and Property of Soils, Brady and Weil and based on data from Camp and Lund (1964) and Voorhees (1984)

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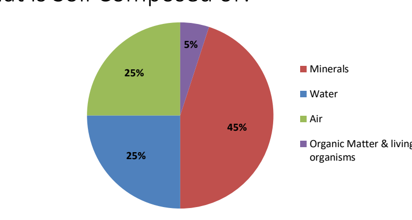

Porosity and Texture

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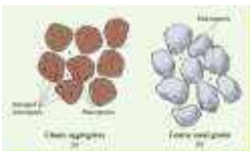
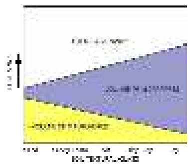
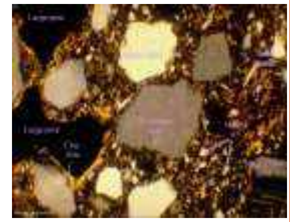
- Sand has larger pores but less total pore space





Pore Size

- Pores are various sizes
- Measurement and diliniation of size is subjective
- Pores are filled with air and water
- Soil pores occur between and within aggregates



Pore Size

Macropores:

- Large pores (larger than 0.08 mm)
- Usually found between aggregates
- Drain freely by gravity
- Habitat for soil organisms and root growth
- Allows oxygen into the soil to be absorbed by roots
- Full of air at field capacity

Micropores:

- Small pores (small than 0.08 mm)
- Usually found within aggregates
- Suction required to remove water
- Stores water for plants
- Filled with water at permanent wilting point

- A balance of large pores (for permeability) and small pores (for water storage) is ideal

Soil Color

Painting using soil colors, Painting by Janis Lang, USDA-NRCS

Soil Color

- The most obvious soil characteristic, it can be seen with the naked eye
- Important for soil classification and assessment
- Color may vary by horizon within the profile
- Little effect on behavior, more about identification/characterization
- 4 main factors that influence the color of soil:
    1. Mineralogy and degree of weathering
    2. Abundance of organic matter
    3. Moisture content
    4. Oxidation states of iron and manganese

The Iron Factor

- Iron is present in all soils
    - Fe is the 4th most abundant element after oxygen, silicon and aluminum
- Iron oxides are one of the main coloring agents in soil
- Iron can cause a variety of colors depending on soil moisture and aeration

Good drainage and aeration

- Iron is oxidized (ferric iron- Fe^{3+})
- **Red/yellow**

Poor drainage and aeration (anaerobic conditions)

- Iron is reduced (ferrous iron- Fe^{2+})
- **Grey/green/blue-grey**

Soil Color

- Most common or influential colors (in a well-drained soil):
  - **White**- prevalence of silica (quartz) or salts
  - **Red**- accumulation of iron oxides
  - **Brown and black**- level and type of organic matter
- Colors indicative of a poorly drained soil:
  - **Grey and blue-grey**- waterlogged soils

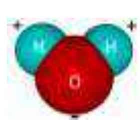
Mottles

- Mottles are spots/stains of different colors in the soil
- Usually red or 'rust' colored
- Indicator of intermittent waterlogging or anaerobic conditions

Soil Water

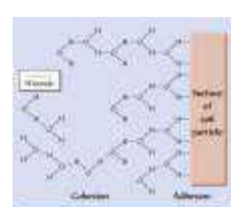
Soil Water

- Liquid water, H_2O
- Asymmetrical polarity
  - Polarity → charges not evenly distributed
  - One side of the water molecule is electropositive; the other is electronegative
- Hydrogen bonding – H atom of one water molecule is attracted to the O atom of neighboring water molecule



Soil Water

- **Cohesion** = attraction of water molecules to each other
- **Adhesion (or Adsorption)** = attraction of water molecules to solid surfaces
- The adhesive force diminishes rapidly with distance from the solid surface
- Forces of adhesion and cohesion allow soil solids to retain water and control its movement

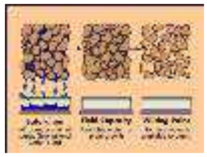


Soil Moisture Conditions

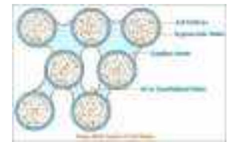
Saturation
- Water content when all pores are full of water

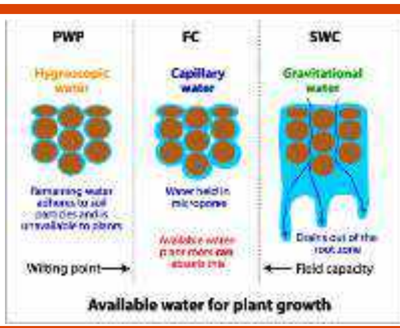
Field Capacity
- The maximum amount of water a soil can hold (in micropores) against the force of gravity

Permanent Wilting Point
- The point at which plants cannot obtain enough water to grow (and will not recover)



- **Gravitational water**
  – Water in macropores that moves through soil by gravity
  – Not considered available to plants
- **Capillary water**
  – Held in micropores against the pull of gravity
  – Most is available to plants
- **Hygroscopic water**
  – Forms thin films around soil particles
  – Not available to plants



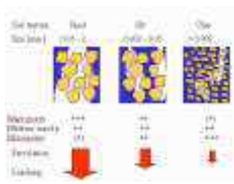


Water Supplied to Plants

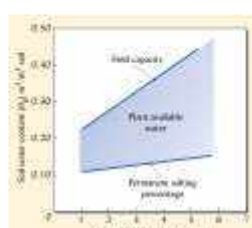
- Water is supplied to plant roots by:
  - capillary movement of the water to root surfaces
  - by the growth of roots into the soil
- Roots are in contact with <1% of the total soil surface area → most water moves from the soil to the plant roots (actual distance of movement needed is very small)

Pore Size and Texture

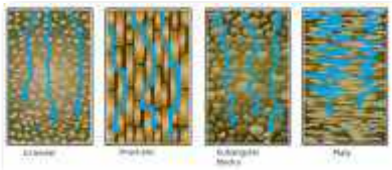
- Clay has mainly micro pores
- Sand has mainly macro pores
- Soils are a mixture of sand, silt and clay → a mixture of different sized soil pores



Organic Matter & Soil Water



Water movement through different soil structures



Water Movement in Soil

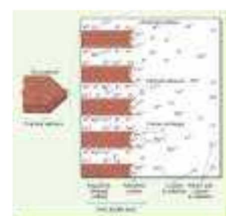
http://youtu.be/vmo0FRAVgkM

Pop Quiz

- What type of soil would have a higher nutrient holding capacity?
  A. Sand
  B. Silt
  C. Clay

Soil Colloids

- **Colloidal fraction** = clay and organic matter (humus)
- Very small size
  - < 0.000001 mm or 1 μm
- Electrically charged - carry net negative (-) charge, but also some positive (+) charges
- Attract or repulse ions of the opposite charge
- Important for nutrient and water exchange with roots



Basic Chemical Charges

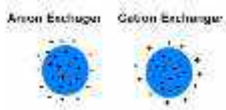
- **Ions** are atoms that are electrically charged with either a positive (+) or negative (-) charge
- **Cations** = ions with positive (**+**) charges
  - Al^{3+}, Ca^{2+}, Fe^{3+}, H^{+}, K^{+}, Mg^{2+}, NH_4^{+}
  - These are all important plant nutrients
- **Anions** = ions with negative (**-**) charges
  - Cl^{-}, OH^{-}, NO_3^{-}, PO_4^{3-}, SO_4^{2-}
  - Nitrate, phosphate, sulfate and chloride are important plant nutrients

Colloid Binding

- Can bind to:
  - Nutrient ions
  - Water molecules
  - Viruses
  - Toxic metals
  - Pesticides
  - Radioactive materials
  - Etc.
- Important ecosystem service

Ion exchange

- Soil particles *adsorb* and *exchange* ions
- Ion exchange is when a ion in the soil solution replaces an an ion on soil
- The charges associated with the soil attract ions of opposite charge
  - i.e. (+) charge attracts (−) charge
- Soil minerals exibit negative and positive surface charges
- Cation (+) exchange is generally much larger than anion (-) exchange

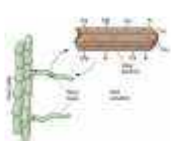


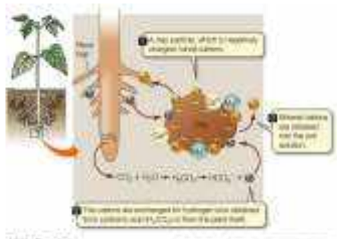
Cation Exchange Capacity (CEC)

- **CEC** = the total available negative (-) charges on mineral surfaces that can attract positive cations (+) in the soil solution
  - Measure of the soil's ability to store & release nutrients (specifically positively charged ions)
- Expressed in milliequivalents (meq) per 100g of dry clay *or* $cmol_{charge}$/kg soil
- The higher the CEC the greater the soils nutrient holding capacity

Soil Type	CEC (meq/100g)
Sand (light colour)	3 - 5
Sand (dark colour)	10 - 20
Loam	10 - 15
Silt loam	15 - 25
Clay and Clay loam	20 - 50
Organic soils	50 - 100

Cation Exchange Capacity (CEC)





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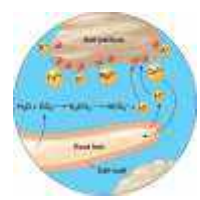
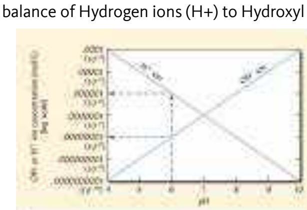


Soil pH

- Soil pH is considered one of the most important soil properties
- **Soil pH affects:**
  - Availability of micro and macro nutrients
  - Population and activity of soil microorganisms
    - which effects the transformation of N, S and P to plant-available forms
  - Movement of toxins/pollutants
  - Leaching of base cations
  - Plant options (i.e. sensitive vs. tolerant species)

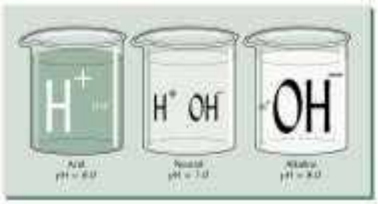
Soil pH

- **Soil pH** is a measure of the acidity or alkalinity of a soil
  - or the number of hydrogen ions (H^+) in a soil solution
- Constant balance of Hydrogen ions (H+) to Hydroxyl ions (OH-)



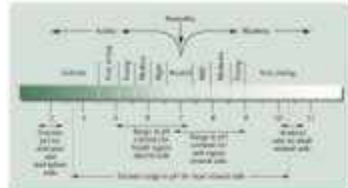
Soil pH

- In **acidic** soils **H^+ ions** (hydrogen) predominate
- In **alkaline** soils **OH^- ions** (hydroxyl) predominate



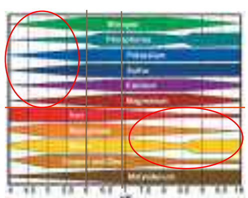
Soil pH

- Ranges from 1 to 14, with pH <7.0 being acidic and pH >7.0 being alkaline
- Every pH unit represents a 10 fold change
  - e.g. a soil with a pH of 5 is 10x more acidic than a soil with a pH of 6



pH and Nutrient Availability

- Nutrient availability is optimal between pH 5.5 and 7.5
- As pH decreases, the availability of macronutrients is reduced
- As pH increases, micronutrients become less available *(except molybdenum)*
- Note: deficiencies of P occurs at both extremes



Acidification

Sources of acidity:

- **Precipitation** (leaching of base cations from the soil)
- **Acid rain** (sulfuric and nitric acid in rainwater from industrial processes)
- **Fertilizers and nutrient transformation** (e.g. process of nitrification and mineralization releases H^+ ions and leaching of nitrate)
- **Nutrient uptake** (when uptaking cations exchange H^+ ions from the root)
- **Weathering of minerals** (soils formed from sandstone or shale tend to be acidic)
- **Soil Organic Matter** (organic acids and inorganic acids formed during the decomposition of organic matter)
- **Root respiration** (root respiration dissolving in soil water to form a weak organic acid)
- **Continuous cropping or grazing** (removal of crop residues from soil)

Essential Plant Nutrients

- All the nutrients needed to carry out growth and reproductive success – a full life cycle
  - Omission of the element will result in abnormal growth
  - The element cannot be replaced or substituted
  - The element must exert its effect directly on growth

  - (Arnon and Stout, 1939)

- **Essential Elements (nutrients)** – required by the plants for their normal growth and development and which are not replaceable in their function by any other nutrient

  -(Mengel, 1982)

Plant Essential Elements

- There are 17 elements essential to plant growth
- Cabon (C), Oxygen (O) and Hydrogen (H) are most abundant in plants
- 14 remaining essential nutrients

Macronutrients (needed in large amounts by plants):

- Nitrogen (N)
- Phosphorus (P)
- Potassium (K)
- Sulfur (S)
- Calcium (Ca)
- Magnesium (Mg)

Micronutrients (needed in trace amounts by plants):

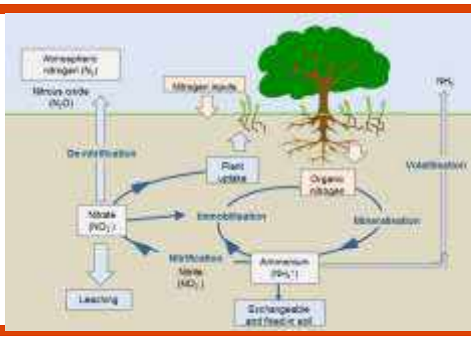
- Iron (Fe)
- Manganese (Mn)
- Zinc (Zn)
- Copper (Cu)
- Chlorine (Cl)
- Molybdenum (Mo)
- Boron (B)
- Nickel (Ni)

Nutrient cycles

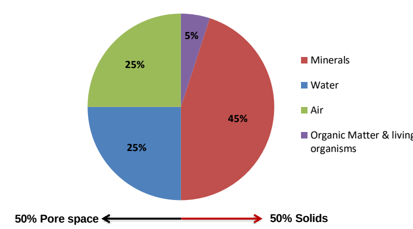
- Nutrients cycle and are present in many forms
  - Some are plant available and some aren't
  - Some forms are easily leached
- Cycles can be complex and be biologically mediated
  - Nitrogen, Phosphorus and Sulfur
- Other cycles are predominantly simply due to weathering of minerals
  - Mg^{++}, K^{+}, Ca^{++}

Forms of Nitrogen

Form of Nitrogen	Formula	Availability to plants
Nitrogen gas	N_2	78% of our atmosphere is nitrogen gas, however this form must be transformed to usable forms before it is available for plant uptake
Ammonia	NH_3	Ammonia, a gas, can escape from the surface of the soil under certain conditions and is harmful to plants in high quantities.
Ammonium	NH_4^+	Soil particles attract and retain ammonium via CEC. **Ammonium may be directly taken up by plants.** The basic building block of commercial nitrogen fertilizers.
Nitrate	NO_3^-	**Nitrate is the 2nd form of nitrogen which is available for plant uptake**. In most soils, nitrate is highly mobile and easily lost via leaching. In highly weathered soils, nitrate is stored via AEC and becomes less mobile.
Nitrite	NO_2^-	Nitrite is an intermediate product in the transformation of ammonium to nitrate (nitrification). It is usually present in low quantities, but is toxic to plants.
Organic Nitrogen	Various compounds	Organic nitrogen must be transformed to ammonium (mineralisation) before it is available to plants.



What is Soil Composed of?



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Soil Organisms

The Soil Habitat

- Soil is a complex habitat containing soil particles, organic matter, water, roots, and soil organisms
- Soil organisms live within and between particles
- Changes in pH, moisture, pore size and food types create diverese soil habitats

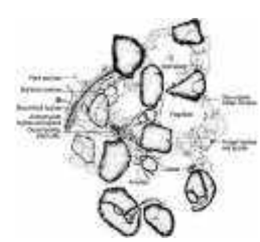


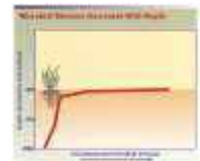
Image: S. Rose and E.T. Elliot, FAO

- Arrows represent conversions of energy and nutrients as one organism eats another

Image source: USDA, NRCS

The Soil Habitat

- The majority of soil organisms are found in the top 2-3 cm of soil
- Each species exists where they can find sufficient food, space, nutrients, and moisture
- Most are concentrated:
  - around roots (i.e. the rhizosphere)
  - in plant litter
  - on humus
  - on soil aggregates
  - in spaces between soil aggregates



Factors that affect microorganism populations

- **Aeration**: there are aerobic and anaerobic organisms
- **Soil moisture**: conditions that are too dry or too wet inhibit growth
- **Soil temperature**: Activity of microorganisms is limited below 5°C (or ~40°F)
- **Sufficient Carbon**: Organic matter is a food source
- **Soil pH**: Different species work in specific pH ranges
- **Other organisms**: Microbes are particular to the types of organisms that are around them

Benefits of Soil Organisms

- Soil organisms play an important role in plant health:
  - Decompose organic matter
  - Nutrient cycling
  - Nitrogen fixation
  - Nutrient retention (immobilisation)
  - Enhance soil structure and infiltration
  - Control populations of beneficial and harmful soil organisms
  - Break down pollutants

Functions of Soil Organisms

Soil Organism Type	Organisms	Major Functions
Photosynthesizers	• Plants • Algae • Bacteria	Capture energy
Decomposers	• Bacteria • Fungi	Break down residues
Mutualists	• Bacteria • Fungi	Enhance plant growth
Pathogens	• Bacteria • Fungi	Promote disease
Parasites	• Nematodes • Microarthropods	
Root-feeders	• Nematodes • Macroarthropods	Consume plant roots
Bacterial-feeders	• Protozoa • Nematodes	Graze (e.g. release ammonium, etc.)
Fungal-feeders	• Nematodes • Microarthropods	Graze (e.g. release ammonium, etc.)
Shredders	• Earthworms • Macroarthropods	Break down residues and enhance soil structure
Higher-level predators	• Nematodes • Larger arthropods	Control populations

Superstars of the Underworld

Micro- organisms

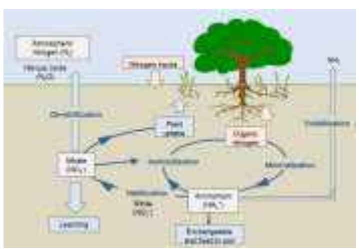
Bacteria

- Very small, single-celled organisms
- Most abundant microbes in the soil
    - a gram of soil may contain 20,000 different species!
- Mainly found in soil aggregates where they are protected from soil animals such as protozoa and mites
- Anaerobic and aerobic (but most are aerobic)
- Important roles of soil bacteria:
    - Decompose organic compounds
    - Mineralization of nutrients such as N and S to plant available forms
    - Biological nitrogen fixation (fix atmospheric N)
    - Act as pathogens (e.g. *Erwinia*)

bacteria at root tip
Photo: USDA-NRCS, Soil Biology Primer

Bacteria

- Nitrogen exists in many forms in the soil
- Soil micro-organisms (primarily bacteria) responsible for converting N to plant available forms



Rhizobium bacteria

- Nitrogen fixing bacteria that have a symbiotic relationship with leguminous plants
- In exchange for Carbon, rhizobium convert atmospheric nitrogen (N_2) into a plant available form
- The bacteria form nodules on the roots of host plants where they fix N
- Most plants are associated with a specific Rhizobium species

rhizobium bacteria nodules
Photo: USDA-NRCS, Soil Biology Primer

Crops	Genus	Rhizobia species
Alfalfa, sweet clovers, fenugreek	*Medicago, Melilotus, Trigonella*	*Rhizobium meliloti*
Clovers	*Trifolium*	*R. leguminosarum* (biovar. *trifolii*)
Peas, vetch, fababean, lentil	*Pisum, Vicia, Lens*	*R. leguminosarum* (biovar. *vicia*)
Common bean (various)	*Phaseolus*	*R. leguminosarum* (biovar. *phaseoli*)
Leucaenas and various other tree and shrub legumes	*Leucaena, Sesbania, Calliandra*	*Rhizobium* spp.
Chickpea and Soybean	*Cicer, Glycine*	*Bradyrhizobium japonicum*
Cowpea, peanut, lupin, pidgeon pea, lima bean, winged bean, various tropical pasture legumes	*Vigna, Arachis, Lupinus, Cajanus, Phaseolus, Psophocarpus*	*Bradyrhizobium* spp.

Adapted from Connor et al., Crop Ecology, 2011

Fungi

- Microscopic cells that form long strands of hyphae that can extend for several meters through the soil
- Dominate at low pH (due to low competition)
- Groups: yeasts (anaerobic soils), molds, and mushrooms
- Important roles:
    - Decompose hard-to-digest organic compounds (e.g. cellulose, lignin) into forms that other organisms can use
    - Immobilize and retain nutrients in soil
    - Form symbiotic relationships with plants (Mycorrhizae)
    - Bind soil particles into stable aggregates
    - Act as pathogens (e.g. *Verticillium*, *Rhizoctonia*)

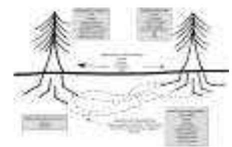
Mycorrhizal hyphae and fruiting body in Jack pine stand (photo by Dr. S. Grayston)

Mycorrhizal Fungi

- Mycorrhiza is a symbiotic association between fungi and plant roots
- In exchange for Carbon, mycorrhizal fungi colonise and extend the surface area of plant roots and help roots reach soil nutrients & water
- Particularly important for phosphate uptake because P is not soluble
- Two major groups:
  - *Ectomycorrhizae* (grow on root surface)
  - *Endomycorrhizae* (grow in root cells)
    - include Arbuscular mycorrhiza

ectomycorrhizae fungi

Photo: USDA, Forest Service, PNW Research Station, Corvallis, Oregon



https://www.ted.com/talks/suzanne_simard_how_trees_talk_to_each_other

Myccorhizal Fungi & Soil Management

- Some inoculums of mycorrhizae are commercially available and can be added to the soil
- Most agriculture crops depend on mycorrhizae
  - except non-host plants, e.g. brassicas and chenopods
- Management practices that may *negatively* affect mycorrhizae:
  - Long-term fallow
  - Tillage
  - Broad spectrum fungicides and soil fumigants
  - High levels of N and P fertilizers (may reduce inoculation of roots)
  - Long crop rotations with non-host plants (e.g. Brasicas)

Actinomycetes

- Actinomycetes are a broad group of bacteria
- Form thread-like filaments in soil
- 2nd most abundant soil micro-organisms (> 1 million/g soil)
- Give soil fresh, moist distinctive 'earthy' smell
- Active at high pH levels
- Important roles:
  - Decompose organic matter
  - Form associations with non-leguminous plants to fix N
  - Produce a large number of antibiotics that kill other organisms (e.g. Streptomycin)

actinomycetes

Photo: USDA-NRCS, Soil Biology Primer

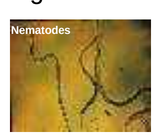
Protozoa

- Single-celled organisms
- Larger than bacteria (5 to 500 μm)
- Feed on primarily bacteria, but also other protozoa, soluble organic matter, and some fungi
- Most abundant near plant roots
- Three groups (based on shape): ciliates, amoebas and flagellates
- Important roles:
  - Release excess N and other nutrients in their waste
  - Mineralise nutrients
  - Help control populations of bacteria

ciliate protozoa

Photo: Cells Alive

Meso- organisms



Photos: USDA-NRCS, Soil Biology Primer and commons.wikimedia.org

Nematodes

- Tiny roundworms
- Both beneficial (feed on other organisms) and parasitic (penetrate plant roots)
- Grouped by feeding habit: bacterial feeders, fungal feeders, predatory feeders, omnivores, and root feeders
- Live in soil water and move through soil in water films around soil particles (become dormant in hot and dry conditions)
- Important roles :
  - Bacterial and fungal feeding nematodes mineralise and release excess N in plant available form
  - Disperse organic matter and decomposers around soil

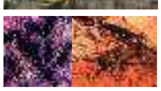
beneficial nematodes
Photo: USDA-NRCS, Soil Biology Primer

Collembola (Springtails)

- Microarthropods, wingless
- Live in plant litter or pore space in top 10-15 cm of soil
- Probably the most abundant group of insects on Earth
- Feed mainly on fungi, bacteria and algae in decomposing plant litter
- Important roles:
  - Soil surface decomposers

springtail
Drawing: J.W. Folsom, FAO

Macro- organisms



Photos: USDA-NRCS, Soil Biology Primer and commons.wikimedia.org

Arthropods

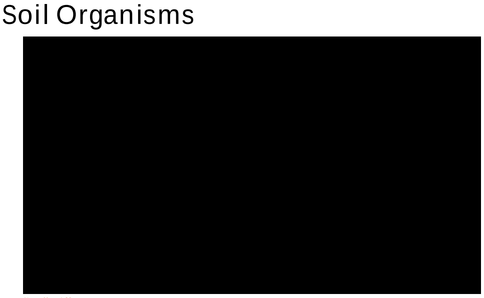
- Can belong to the macro or meso group
- Includes: insects, arachnids, crustaceans
  - e.g. ants, termites, larvae, centipedes, spiders, etc.
- Grouped as: shredders, predators, herbivores, and fungal-feeders
- Important roles:
  - Shred plant residues (early decomposition of organic matter)
  - Mineralise plant nutrients
  - Burrow (improving pore space, water infiltration, drainage, and aeration)
  - Enhance soil aggregation
  - Contol pests

Earthworms

- Prefer moist, aerated, fine textured soils with pH ~ 6.5
- Grouped into several categories based on behavioural ecology:
  - *Epigeic*- live in or near plant litter on surface soil
  - *Endogeic*- live and feed in the upper soil, ingest large amounts of soil
  - *Anecic*- deep burrowing species- feed on suface litter and mix it into soil
- Important roles:
  - Shredders
  - Mix and aggregate soil
  - Enhance porosity (increase aeration, permeability, rooting)
  - Enhance soil fertility

Photo: Chika Watanabe, Flickr.com,
https://creativecommons.org/licenses/by/2.0/

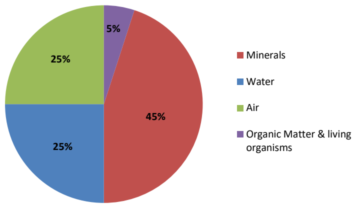
Soil Organisms



Note: skip to 1:20

Organic Matter

- Only ~5% of soil is composed of **organic matter**…
- But soil organic matter has a significant impact on many soil properties



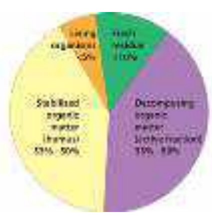
Benefits of Soil Organic Matter

SOM

- **Improves soil structure**
  - Aggregation
  - Aeration
  - Water infiltration
- **Increases CEC**
  - 20-80% of CEC
- **Increases Nutrient Availability**
- **Forms stable organic compounds**
  - Can increase availability of micronutrients
- **Increases microbial biodiversity**
  - Provides food and energy for micro-organisms
- **Increases water holding capacity**
  - 3 - 4x more water holding capacity than clay
- **Buffers pH**
- **Moderates soil temperature**

Soil Organic Matter (SOM)

- A complex, dynamic mixture of substances:
  - **Living organisms**
  - **Fresh residues**
  - **Decomposing organic matter**
  - **Stabilised organic matter**
- Includes all organic components of the soil

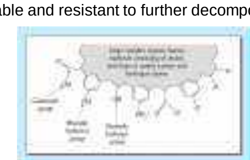


SOM → Dynamic + Transforming

Soil Humus

What is it?

- "The final end product of decomposition" (Connor *et al.* 2011)
- Complex mixture of *chemical building blocks* (e.g. carbohydrates, fats, amino acids, amides, tannins, lignin, etc.) plus *by-products of microbes* (e.g. organic acids, aldehydes, alcohols, ketones, enyzmes, vitamins, etc.)
- Chemically stable and resistant to further decomposition



Decomposition of SOM

- SOM is primarily broken down (*decomposed*) in the soil by bacteria and fungi
- C is burned as a source of energy, and CO_2 and heat are released (*respiration*)
- Microorganisms *mineralise* and release nutrients
- Complex compounds transformed into humus (*humification*)

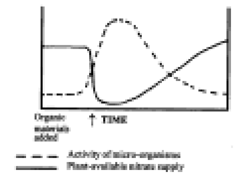
C:N ratios of Organic materials

- The C:N ratio of organic materials influences the rate of decomposition of soil organic matter
  - which influences immobilisation and mineralisation of soil N, P and S
- C:N ratio of micro-organisms is 8:1 (or 8)
- Soil organisms need N and C and must acquire enough to maintain 8 ratio
  - Carbon is energy, and N provides microbes with proteins to build their bodies and reproduce
- Because micro-organisms burn about 1/3 of C for energy and respire some, they need a diet with a C:N ratio of 24:1 to meet their N needs
- Meaning they need about 1 N atom for every 24 C atoms
- 24:1 considered ideal C:N ratio for decomposition

Relation of C:N ratio in SOM to decomposition & available N

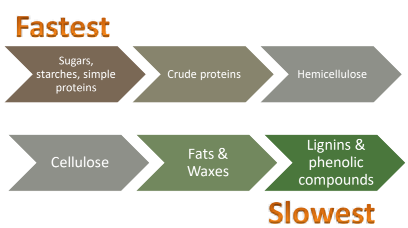
High C:N ratio	Intermediate C:N ratio	Low C:N ratio
• (> 24) • N is low • Microbes lack N • Decomposition is slow • Microbes complete with plants for what little N is present in the soil	• (= 15 - 24) • Balanced N content • Sufficient N for microbes • No N deficiency	• (< 15) • N is high • Decomposition is fast • Excess N is released into soil during decomposition

Temporary N loss due to the incorporation of high C:N ratio materials into the soil



- Soil microorganisms immobilise ('tie up') soil N

Decomposition Rates



C:N ratios of Organic materials

- C:N ratio of soil is relatively constant (=12)
- Ratio of plant residues is highly variable

Slower ↑ Decomposition Rate ↓ Faster

Material	C:N ratio
Rye straw	82:1
Wheat straw	80:1
Oat straw	70:1
Corn stalks	42:1
Rye cover crop (anthesis)	37:1
Pea straw	29:1
Rye cover crop (vegetative)	26:1
Mature alfalfa hay	25:1
Ideal Microbial Diet	**24:1**
Barnyard manure	20:1
Legume hay	17:1
Cow manure	11-30:1
Young alfalfa hay	13:1
Vetch cover crop	11:1
Soil Microbes (average)	**8:1**

Table: USDA-NRCS, 2011 soils.usda.gov/sqi

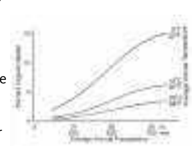
Natural Factors that Influence

Temperature

- ➢ Decomposition rate doubles with every 8-9°C increase in temperature
- ➢ Warm temperatures ideal (25 - 35°C or 77- 95°F)
- ➢ Decomposition more rapid in the tropics, thus have lower SOM levels than temparate areas

Moisture

- ➢ SOM increases as mean annual precipitation increases
- ➢ Optimal microbial activity occurs at 60% water-filled pore space
- ➢ Saturation leads to reduction in oxygen which reduces decomposition (most microorganisms become inactive or die)



Soil organic matter as influenced by temperature and rainfall (Troeh, 2005)

Natural Factors that Influence SOM

Soil texture

- ➢ SOM of clay soils > sandy soils
  - ➢ Humus binds strongly to clay particles
  - ➢ Sandy soils well aerated which increases decomposition

Topography

- ➢ SOM higher at bottom of hills/slopes (due to higher moister)
- ➢ In the Northern Hemisphere - SOM higher on north facing slopes than south-facing slopes (due to lower temperatures)

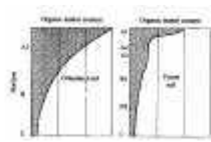
Natural Factors that Influence SOM

Soil pH

- In strongly acidic or highly alkaline (and saline) soils, SOM is lower (due to poor conditions for micro-organism production caused by lower nutrient availability)
- Fungi less sensetive than bacteria to acidic soils

Vegetation

- SOM in grasslands > forests
- SOM dependent on quantity and quality of vegetative inputs



"All natural resources...are soil or derivatives of soil. Farms, ranges, crops, and livestock, forests, irrigation water and even water power resolve themselves into questions of soil. Soil is therefore the basic natural resource."

Aldo Leopold

Soil Degradation

- Soils around the world are at risk;
- About 17% of land surface has been 'strongly' degraded;
  - Degradation by erosion, salinity, contamination, overgrazing, compaction, etc.
- Degradation decreases soil productivity;
- Marginal lands put into production by population pressure are especially affected.

Soil Degradation and Erosion

What is it?

Soil degradation

- A change in the soil health status (FAO, Soils Portal, 2015)
- Degradation can be caused by various activities that cause adverse changes to soil properties

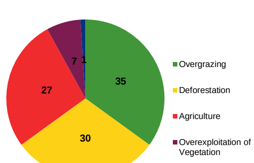
Soil erosion

- Often confused with soil degradation, but is only one type of degradation
- Erosion refers to soil loss (or removal from one place to another)
- Erosion is a natural process, but often made much worse by poor soil management practices

Soil Degradation

The underlying causes of soil degradation include:

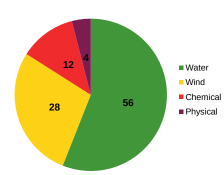
- Overgrazing
- Deforestation or removal of natural vegetation
- Agricultural activities
- Overexploitation of vegetation for domestic use
- Industrial activities



Types of Soil Degradation

The four main types of soil degradation:

- Water erosion
- Wind erosion
- Chemical degradation
- Physical degradation



Wind and water erosion account for 84%!!

Soil Erosion Process

Erosion is a 3 step process:

1. Detachment
- Particles detached from soil by impact energy of wind or water

2. Transport
- Particles carried by wind or water (overland flow and runoff)

3. Deposition
- Sediments deposited away from site
- Lighter particles (e.g. clay) carried further than heavy particles

Soil Management practices that reduce or prevent erosion

- Vegetative cover
- Residue management
- Conservation tillage
- Countour cropping
- Structures (e.g. terraces)
- Grassed waterways
- Barriers (e.g. windbreaks, vegetative strips)

The effect of percent ground cover on the soil loss ratio (compared to a bare, fallow soil)

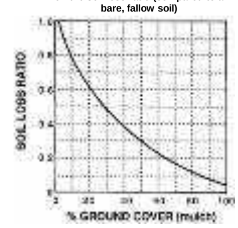
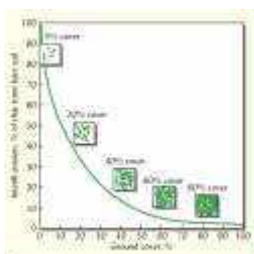


Image: University of Missouri Extension, http://extension.missouri.edu/p/G1650

Soil Cover

- Soil cover (via cover crops, mulch, crop residues, etc.) is one of most important conservation practices



Cover crops

- **Cover Crops:** plants grown to prevent erosion by covering the soil with vegetation and increase or maintain SOM
- Typically includes nitrogen fixing legumes
- Often incorporated into the soil before they mature, but can also be killed and left on the surface as mulch
- Can be grown as an annual, biannual or perennial crop, or as intercrop
- Normally grown during dry season (in the tropics) or in winter (in temperate climates)

Mulch

- **Mulches:** 'materials placed on the soil surface to protect it against raindrop impact and erosion, and to enhance its fertility' (FAO, 1995)
- **Organic materials** (crop residues, straw, maize stalks, palm fronds and stubble; manures and compost)
  - ➢ Temporary- decompose over time

Crop Residues

- **Crop residues:** the part of the plant that remain in the field after removal of the harvestable portion, and act as a mulch
- Often removed for pest control, burning, or for use as livestock feed
- Protect the soil, provide an important source of soil organic matter, and recycle nutrients to the soil

Sustainable Soil Management

- To keep soils productive and feed an evergrowing population, it is important that soils are managed in a way that:
  - Conserve and protect the soil;
  - Maintain and replenish organic matter and nutrients;
  - Improve soil structure, water and nutrient holding capacity;
  - Reduce soil lost by erosion and runoff.

Sustainable Soil Management

Healthy Soil = **Healthy Crop**

Fertilizers

Plant Essential Elements

- There are 17 elements essential to plant growth
- Cabon (C), Oxygen (O) and Hydrogen (H) are most abundant in plants
- 14 remaining essential nutrients

Macronutrients (needed in large amounts by plants):
- Nitrogen (N)
- Phosphorus (P)
- Potassium (K)
- Sulfur (S)
- Calcium (Ca)
- Magnesium (Mg)

Micronutrients (needed in trace amounts by plants):
- Iron (Fe)
- Manganese (Mn)
- Zinc (Zn)
- Copper (Cu)
- Chlorine (Cl)
- Molybdenum (Mo)
- Boron (B)
- Nickel (Ni)

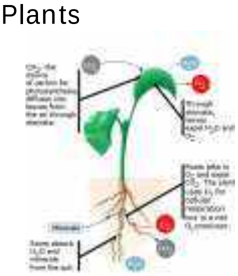
Table 13-2
MINERAL NUTRIENTS ESSENTIAL FOR PLANT GROWTH AND SOME EXAMPLES OF THEIR ROLES

	Nutrient Element	Function in Plants
PRIMARY NUTRIENTS	Nitrogen (N)	Synthesis of amino acids, proteins, chlorophyll, nucleic acids.
	Phosphorus (P)	[illegible]
	Potassium (K)	[illegible]
SECONDARY NUTRIENTS	Calcium (Ca)	[illegible]
	Magnesium (Mg)	[illegible]
	Sulfur (S)	[illegible]
MICRONUTRIENTS	Boron (B)	[illegible]
	Copper (Cu)	[illegible]
	Chlorine (Cl)	[illegible]
	Iron (Fe)	[illegible]
	Manganese (Mn)	[illegible]
	Molybdenum (Mo)	[illegible]
	Nickel (Ni)	[illegible]
	Zinc (Zn)	[illegible]

From Practical Horticulture 5th ed., 2011 McMahon et al.

Uptake of Nutrients by Plants

- Nutrient uptake occurs in both the roots and leaves
  - Water and minerals
  - Carbon Dioxide (CO_2)
- CO_2 comes from atmosphere
- Water and minerals from soil
  - Nutrient ions usually dissolve in water



What is a "fertilizer"?

- **Fertilizers** are compounds given to plants with the intention of promoting growth
- Any material of natural or synthetic origin added to the crop system to apply one or more plant nutrients
- Usually applied via the soil (for uptake by plant roots), but can also be by foliar feeding (for uptake through leaves)
- Fertilizers typically provide, in varying proportions, the:
  - Three major plant nutrients (N,P,K)
  - The secondary plant nutrients (Ca, S, Mg)
  - And, sometimes, micronutrients (or trace elements)

Types of Fertilizer

Fertilizers can be grouped several different ways:
- Complete vs. Incomplete
- Dry vs. Liquid
- Organic vs. Inorganic

"Complete" or Incomplete

- **"Complete"**
  - Contains NPK
  - Common ratios = 1:1:1, 3:1:1, 3:1:2, or 3:1:3
- **Incomplete**
  - Lacks at least one of N, P, or K
  - Can be used separately or combined
  - Usually cheaper than complete

Granular or Liquid fertilizers

- **Dry granular (Solid)**
  - Apply to soil only
  - Requires irrigation or rain to be soluble
- **Liquid**
  - Can apply to soil or foliage
  - Soluble (nutrients immediately available)
  - Usually costly

Organic vs. Inorganic Fertilizers

Organic fertilizers
(organic, i.e. carbon/hydrogen-based)

Naturally occurring organic fertilizers:
- e.g. manure, urine, feces, worm castings, peat, seaweed and guano

Manufactured organic fertilizers:
- e.g. compost, blood meal, bone meal and seaweed extracts, fish meal

Inorganic fertilizers
(synthetic or mineral, i.e. not carbon based)

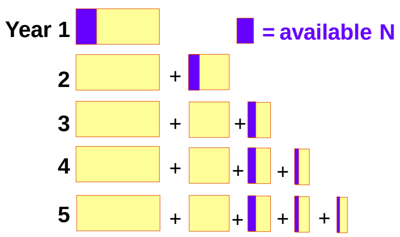
Naturally-occurring inorganic fertilizers
- e.g. Chilean sodium nitrate, mined "rock phosphate", and limestone

Manufactured or chemically synthesized inorganic fertilizers:
- ammonium nitrate, potassium sulfate, superphosphate, etc.

Organic: *Advantages*

- Slow release
  - Requires fewer applications
  - Reduced risk of over-fertilization
- Can be cheap (manure)
- Recycles products that would otherwise become waste (compost, manure)
- Feeds soil microbes (OM)
- Contains Carbon- improve nutrient and water holding capacity

Cumulative PAN from Organic Source



Slide Courtesy of Dan Sullivan OSU Crop & Soil Science

Organic: *Disadvantages*

- Usually very expensive (packaged blends)
- Can be difficult to apply (manure)
- Low analysis means large amounts are required
- Complete blends may contain small amounts of one or more nutrients
- Don't always know exact amount of nutrients

Inorganic/Synthetic: *Advantages*

- Relatively cheap.
- Easy to apply
- High analysis means smaller amounts are required
- Fast acting, so plant response is quick
- Complete blends (and custom blends) are easy to come by

Inorganic/Synthetic: *Disadvantages*

- Accidental over-fertilization is easy
- Production usually creates, rather than prevents, waste
- Production requires large energy inputs
- Don't always know what is in them- may contain fillers
- Leaching common

The Organic Debate in Review

- The choice is *yours*, so don't let others make it for you!
- On the other hand, gather the information you need to make an informed decision!

Types of Organic Fertilizers

1. Animal manures and compost
2. Cover crops/green manures
3. Commercial fertilizers

Animal Manures

Type of Manure	N	P_2O_5	K_2O	Moisture	Weight
		lb/cubic yard		%	lb/cubic yard
Chicken with litter	24	30	30	36	600
Dairy manure, separated solids	4	1	2	88	1400
Horse	6	4	11	70	1400
Sheep	13	6	22	75	1400
Rabbit	11	7	15	75	1400
Beef	8	6	13	75	1400

NOTE: nutrient content can vary significantly!

Source: PNW 646

Compost

	N	P	K	Dry Matter	Density	Total N	C:N ratio	Available N		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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From PNW 533

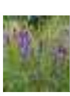
Types of spreaders

Cover Crops

Cover crops greatly increase the ability to maintain soil quality and fertility

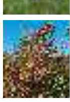
- Legumes fix Nitrogen
- Grasses produce heavy biomass
- Reduce soil erosion and N leaching
- Decrease pest pressure

Types of Cover Crops



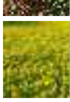
Legumes: Nitrogen fixing crops that form symbiotic relationships with Rhizobia bacteria, recycle nutrients, increase organic matter

Examples: vetch, alfalfa, clover, cowpea, peas, fava beans



Grasses (including cereals): Produce large amounts of residue and protect soil from water and wind, scavange nutrients

Examples: rye, ryegrass, oats, Sudan grass



Brassicas: Act as biofumigants supressing soil-borne pests, add organic matter, breaks up soil compaction

Examples: mustards, rape (canola), radish

Legume Nitrogen Credit

Table 1. Green manure nitrogen credits[1]

Crop	Growth at the time of killing	
	< 6"[2]	> 6"[2,3]
	lb N/a to credit	
Alfalfa	40	80 – 100
Clover, red	40	50 – 80
Clover, sweet	40	80 – 120
Vetch	40	40 – 90

[1] From UWEX Publication A2809 *Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin*.
[2] Reduce credits by 20 lb N/a on sandy, coarse textured soils.
[3] Use the upper end of the range for spring seeded green manures that are plowed under the following spring. Use the lower end of the range for fall seedings. If top growth of vetch is more than 12" before killing the cover crop, credit 110 – 160 lb N/a.

Commercial Organic Fertilizers

- **Dry fertilizers**
  - Blood meal
  - Soybean meal
  - Fish meal
  - Cottonseed meal
  - Alfalfa meal
  - Bat and bird guano
  - Rock phosphate

- Applied on soil surface or root zone at planting, or mixed into soil pre-planting
- Generally, slow release

- **Liquid fertilizers**
  - Fish emulsions
  - Kelp extracts
  - Fermented products

- Applied to roots or foliar applied
- Quicker release than dry fertilizers

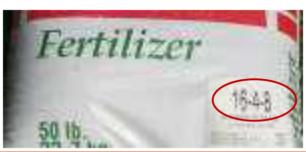
Nutrient Analysis of Common Organic Fertilizers

Material	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Alfalfa meal	4	1	1
Blood meal	12	0	0
Bone meal	2	5	0
Chicken manure, pelleted	2-4	1.5	1.5
Feather meal	12	0	0
Fish meal or powder	10-11	6	2
Kelp	<1	0	4
Cottonseed meal	6-7	2	1
Processed liquid fish	4	2	2
Seabird and bat guano	9-12	3-8	1-2
Soft rock phosphate	0	16	0
Soybean meal	7	2	1

Source: UC ANR publication 3509

Fertilizer Label

- Information usually provide minimum guaranteed amounts of the fertilizer (or the composition)
  - e.g. it defines how much N, P and K are present (always in that order!)
  - Really the percentages are telling you the amount of N, P_2O_5, K_20
- Information is provided as three percentages, e.g. 10-10-10 or 21-0-0



1. Total percentage nitrogen (N) in the bag
2. Total percentage available phosphate (P_2O_5) in the bag
3. Total percentage soluble potash (K_2O) in the bag
4. Other nutrients, if any, will follow the soluble potash
5. The total percentage of the bag that is slow release nitrogen (water insoluble and other water soluble nitrogen sources combined)
6. Total percentage of fast release nitrogen (ammoniacal nitrogen and urea nitrogen)
7. Ammoniacal nitrogen and sulfur nutrients provide fast early leaf development

What's not on the label?

- The Guaranteed Analysis will never add up to 100%. This is primarily because C, H and/or O are present too.
- Example:
  - Ammonium sulfate, 21-0-0, $(NH_4)_2SO_4$
    - 21% N
    - 24% S
    - 6% H
    - 49% O

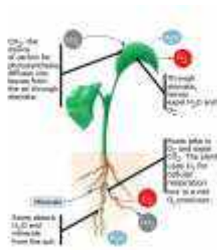
Managing Soil Fertility

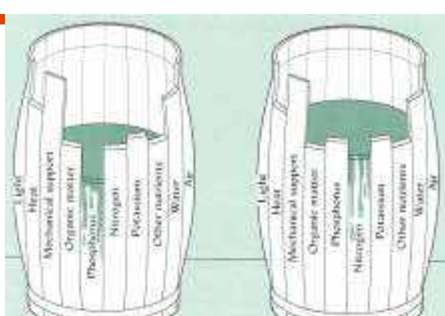
Growth Factors
What do plants need to grow?

- Light
- Water
- Nutrients
- Oxygen
- Carbon Dioxide
- Temperature

Uptake of Nutrients by Plants

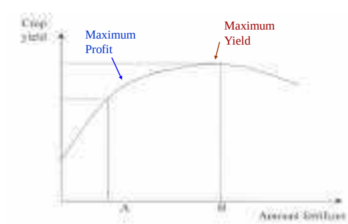
- Nutrient uptake occurs in both the roots and leaves
  - Water and minerals
  - Carbon Dioxide (CO_2)
- CO_2 comes from atmosphere
- Water and minerals from soil
  - Nutrient ions usually dissolve in water





Source: Brady, N.C. and R.R. Weil. 1999. The nature and properties of soils.

Yield response to fertiliser applied



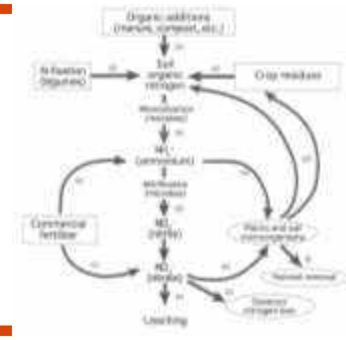
Up to point A, the increase in yield is linear to the addition of fertiliser.
Beyond rate B, additional fertiliser application can become toxic.

Source: Jönsson *et al.* (2004)

Nutrient Mobility in Soil

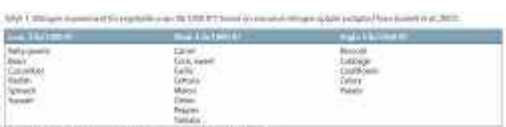
- The mobility of nutrients in soil affects management practices.
- Mobile: "feed the plant"
  - N (nitrate), B
- Somewhat Immobile
  - N (ammonium), K, Ca, Mg
- Immobile: "feed the soil"
  - P, Fe, Mn, Cu, Zn, Mo

The N Cycle



Handbook.

Nitrogen Requirement for Vegetables



Source: OSU PNW 646

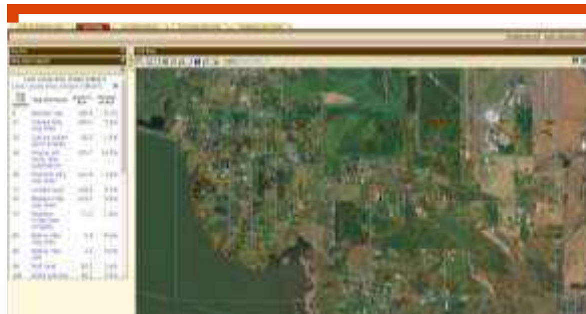
Selecting Fertilizers

- **Soil tests**
- Test every 3 years
- Test soil pH!!!
- If high or excessive levels of certain nutrients, select products containing lower concentrations of these nutrients

Extension Publications

https://catalog.extension.oregonstate.edu/

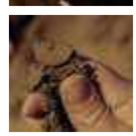
Books



Soil Activity

Activity: Soil Texture

Sandy loam with about 15% clay: gritty, non-cohesive appearance and short ribbon.



Silt loam: smooth, dull appearance and crumbly ribbon characteristic.

Clay: smooth, shiny appearance and long, flexible ribbon.

Soil texture field testing

https://www.youtube.com/watch?v=GWZwbVJCNec&t=116s

Soil texture- The jar test