SOIL AS A TREATMENT MEDIA

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NOWRA CONFERENCE

Disclaimer

The materials being presented here are the opinion of the presenter and do not reflect the opinions of NOWRA.

A lot to cover in 55 minutes!

Some of this information covered in my two previous talks today

WASTER WATER POLLUTANTS

BACTERIA

VIRUSES

NUTRIENTS

METALS

SOLVENTS/CLEANERS

PERSONAL CARE PRODUCTS (PCP)

PHARMACUTICALS

WASTE WATER QUALITY

BIOCHEMICAL OXYAGEN DEMAND (BOD)

Less than 220 ppm

TOTAL SUSPENDED SOILIDS (TSS)

Less than 100 ppm

FATS OILS AND GREASE (FOG)

Less than 30 ppm

pH

6-9

FACTORS AFFECTING WASTE-WATER RENOVATION IN SOIL

SOIL TEMPERATURE

SOIL MOISTURE CONTENT

SOIL DEPTH and DRAINAGE CLASS

SOIL POROSITY and GAS EXGHANGE

MICROBIOLOGY and PATHOGEN REMOVAL

SOIL TEXTURE and STRUCTURE

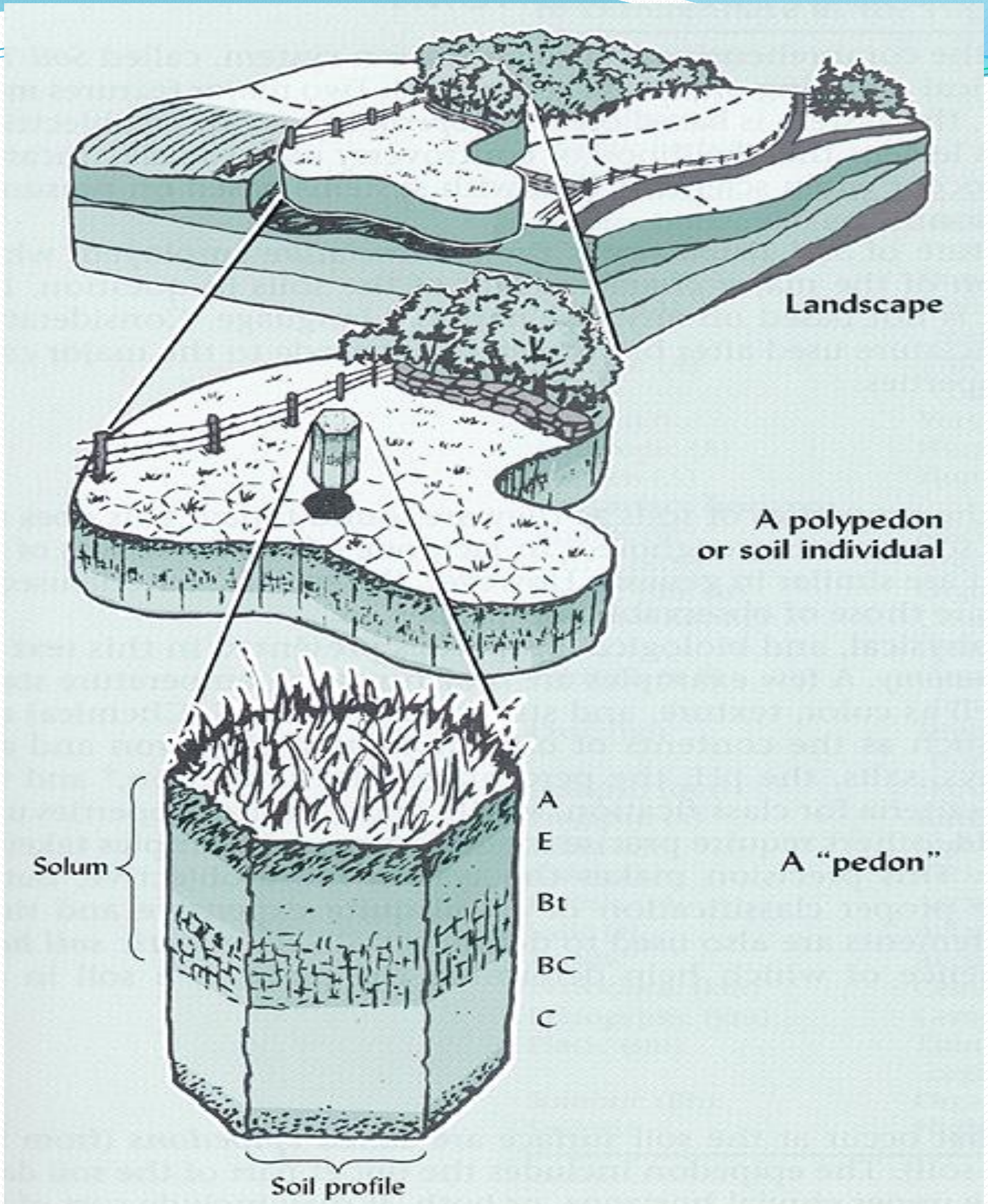
CATION EXCHANGE CAPACITY

NUTRIENT UPTAKE

SOIL AS A TREATMENT MEDIA

SOIL PEDON: A THREE DIMINSIONAL UNIT

THE SOIL PEDON PROVIDES THE THREE DIMINSIONAL MEDIA FOR WASTEWATER FOR RENONVATION



Landscape
A polypedon
or soil individual
A
E
Bt
BC
C
Solum
A "pedon"
Soil profile

MEDIA FILTERS

MAN-MADE REPLICS OF THE SOIL PEDON AS A LIVING FILTER

Advantex Filter

Sand Filter

Peat Filter

Waterloo Filter

All of these media filters have:

big pores and little pores

Need to be aerobic

Media for microbes

Resident time

THEY ALL TRY TO BEHAVE LIKE SOIL !!!

THE LIVING FILTER

INTERACTION OF FOUR SOIL DISCIPLINES

SOIL PHYSICS

SOIL CHEMISTRY

SOIL BIOLOGY

SOIL PEDOLOGY

SOIL PHYSICS

WATER FLOW

BULK DENSITY

GAS EXCHANGE/FLOW

WATER FLOW

SATURATED FLOW

UNSATURATED FLOW

VAPOR FLOW

Saturated Flow

Occurs when all the pore space is filled with water and gravity is the main directional force

Water flows downhill only under saturated flow

Is not conducive to wastewater treatment

Unsaturated Flow

- Moves from low tension to high tension
- Moves from big pores to little pores
- Macro pore flow is sometimes called by-pass flow or a "flush" event….remember this for a later discussion.
- Micro pore flow holds the water and contaminants in the soil for renovation by micro-organisms.
- Wastewater treatment requires unsaturated flow.
- Remember: Soils hold water against the force of gravity with unsaturated flow.

Vapor Flow

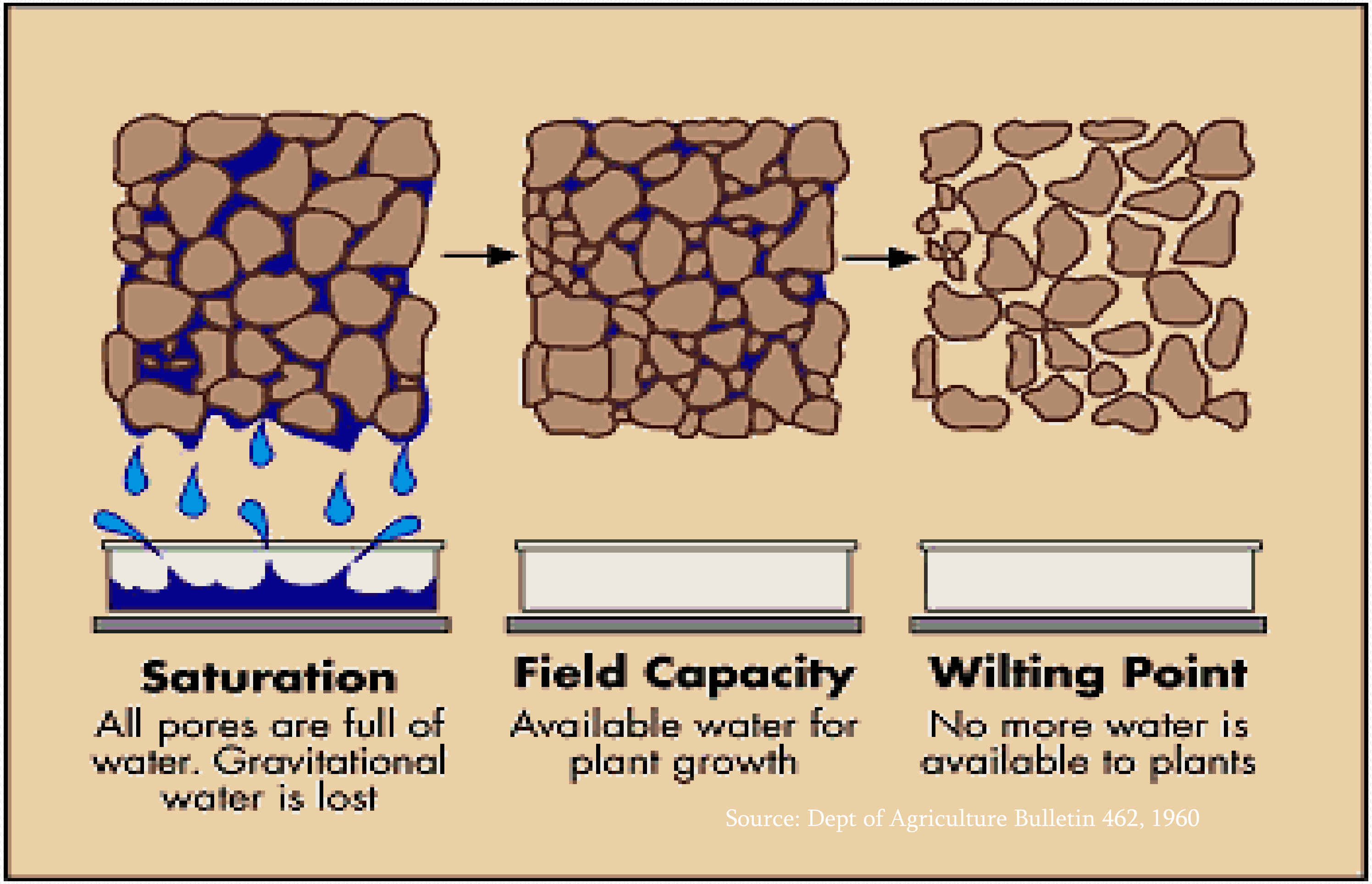
Two types of vapor flow

1. Internal: within the soil pores
2. External: loss of water to the soil surface by evaporation

Relationship to Wastewater Renovation

- Saturated flow allows for transport of contaminates through the soil by macro pore flow
- Flush events occur after a significant rainfall. This aspect was demonstrated by research at DVC
- Macro pore flow in structured soils has been demonstrated by dye tracing studies at NC State
- Unsaturated flow is what we try to achieve when siting an on-lot sewage disposal system. This allows for renovation of the wastewater in micro pores by physical, chemical and biological processes.

SOIL WATER



Saturation
All pores are full of water. Gravitational water is lost
Field Capacity
Available water for plant growth
Wilting Point
No more water is available to plants
Source: Dept of Agriculture Bulletin 462, 1960

Summary Points OF WATER MOVEMENT

- 1) Pore size is one of the most important fundamental properties affecting how water moves through soil. Larger pores as in sand conduct water more rapidly than smaller pores in clay.

- 2) The two forces that allow water to move through soil are gravitational forces and capillary forces. Capillary forces are greater in small pores than in large pores.

- 3) Gravitational and capillary forces act simultaneously in soils. Capillary action involves two types of attractions, adhesion and cohesion. Adhesion is attraction of water molecules to solid surfaces; cohesion is the attraction of water molecules to each other. Gravity pulls water downward when the water is not held by capillary action. Gravity only influences water in saturated soils.
- 4) Sandy soils contain larger pores than clay soils, but do not contain as much total pore space.

- 5) Sandy soils do not contain as much water per unit volume of soil as clay soils.
- 6) Factors that affect water movement through soil include texture, structure, organic matter and bulk density. Any condition that affects soil pore size and shape will affect water movement.
- 7) Examples include compaction, tillage, decayed root channels and worm holes.
- 8) The rate and direction of water moving through soil is also affected by soil layers of different material. Abrupt changes in pore size from one layer to the next affect water movement. When fine soil overlies coarse soil, downward water movement will temporally stop at the fine coarse interface until the fine layer above the interface is nearly saturation.

- 9) When a coarse soil is above a fine soil, the rapid water movement in the coarse soil is greater than through the clay and water will build up above the fine layer as the water front comes in contact with the fine layer. This can result in a build up of a perched water table if water continues to enter the coarse layer.

Factors Affecting Pore Sizes and Water Movement in Soil

- Texture
- Soil Structure
- Consistency
- Slope

Texture

- Coarse fragments : greater than 2mm
- Sand: 2 mm to .05 mm
- Silt: .05 to .002 mm
- Clay: less than .002 mm

- Texture is the % sand , silt, and clay
- Textural class is a grouping of textures into 12 textural classes.
- Source of primary porosity

Soil Structure

Type, grade and size

Type:

1. Granular
2. Blocky (angular and sub-angular)
3. Platy
4. Prismatic
5. Structure less (massive and single grain)

- Grade is the durability of the structure which is produced by organic acids.
- Size affects the number of ped faces or pores between the structural units which are the macro pores or potential by-pass flow sites in structured soils

Soil Consistency

Dependent on moisture content

DRY: hard to soft

MOIST: friable to firm

WET: sticky and plastic

Consistency affects pore size and water movement

Slope

Only a factor in saturated flow

Moves water from low tension (big pores)to high tension (small pores) with unsaturated flow so slope is not a factor

Water moves down hill only under saturated flow

Landscape Loading

Landscape loading uses soil morphology and the principals of soil water movement to determine the length and width of an absorption area (Tyler 2000).

5-gallon bucket of water tipped over and measure the distance for infiltration vs. a long rain gutter with 5 gallons of water

Which one will infiltrate in the shortest distance?

This is landscape loading!

SOIL PHYSICS

GAS AND VAPOR FLOW

Same soil properties that affected water movement

Proximity to the soil surface

Atmospheric pressure

Review of Soil Water Movement

- Saturated vs unsaturated flow
- Saturated flow by gravity
- Unsaturated flow from low to high tension
- Saturated flow uses the macro and micro pores
- Unsaturated flow uses the micro pores only.....low tension or big pores to high Tension or small pores

WATER FLOW SUMMARY

Saturated water flow is by gravity

Unsaturated flow moves by tension…from low to high
Remember: Soils have suction with unsaturated flow

Field capacity is the amount of water held by soil against the force of gravity…that point right before saturated flow

Wastewater renovation is best at unsaturated flow

Bulk Density

Mass (dry weight)

Volume(solids + pores)

Sands have higher bulk densities: 1.8 mg/m3

Clays have lower bulk densities: 1.0 mg/m3

How do you take a low bulk density to a high bulk density?

Remove the pore space by compaction!

EFFECT OF PARTICLE SIZE

Small pores -

micropores

Larger pores

macropores

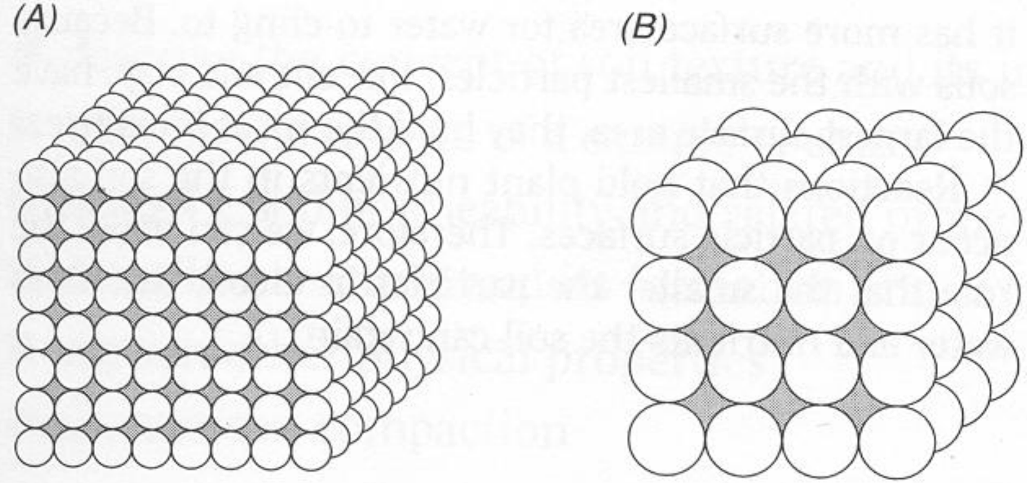


FIGURE 3-2 Size of soil particles affects pore size.
(A) Small soil particles create many small pores.
(B) Pores are larger but fewer in number between large soil particles. Micropores usually hold water, macropores hold air.

SOIL DENSITY AND PERMEABILITY

DENSITY:

MASS per VOLUME

$$D = \frac{M}{V}$$

SOIL DENSITY AND PERMEABILITY

Two densities in Soil:

Particle Density – *PD*

Bulk Density - *BD*

SOIL DENSITY AND PERMEABILITY

PD average soils ~ **2.65 gm/cu cm**

BD average range from **1.0 – 1.8 gm/cu cm**

Depends on amount of pore space

$$BD = \frac{\text{wt. dry soil}}{\text{vol. dry soil}} = \frac{g}{\text{cu cm}}$$

e.g. $$BD = \frac{650\ g}{500\ \text{cu cm}} = 1.3\ g/\text{cu cm}$$

e.g.

SOIL POROSITY

Usually expressed as a percentage; e.g. 50%

Two means determining porosity:

1) Calculate ratio water volume to total core volume
2) Calculate from bulk density and particle density

SOIL POROSITY
Examples

Water Volume to Core Volume

$$\text{Porosity} = \frac{\text{wet weight (g)} - \text{dry weight (g)}}{\text{soil volume (cu cm)}} \times 100\%$$

SOIL POROSITY

Question:

Which has greater ***porosity***, Sand or Clay?

Answer:

Clay at about 50%; Sand is lower at about 30%

Why?

STRUCTURE

Structure – the way soil particles clump together into large units called ***aggregates or peds***

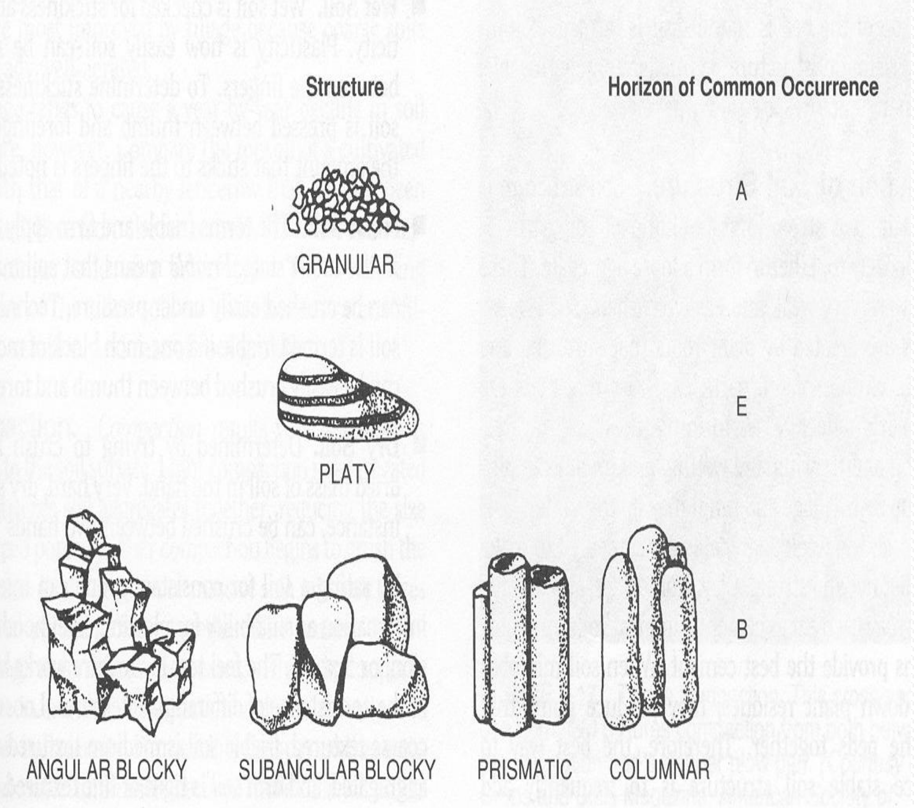


FIGURE 3-15 Types of soil structures

STRUCTURE

- Structure is classified by three groups of traits:

1) Type – refers to shape of aggregates

    e.g. Granular, Platy, Blocky, Prismatic, Columnar

2) Class – refers to size of peds

    e.g. very fine, fine, medium, coarse, very coarse

3) Grade – refers to strength and distinction of peds

    e.g. weak/not visible vs. strong/easily distinguished

ADDNL. SOIL PHYSICAL PROPERTIES

Soil Channels – continuous macro pores leading from surface to deep subsoil

Soil Pans – any layer of hardened soil; includes:

- dense till
- fragipans
- plinthite (southern states)
- petro-calcic(arid soils)

SOIL CHEMISTRY

REDOX POTENTIAL (Eh)

CATION EXCHANGE CAPACITY (CEC)

NITROGEN

PHOSPHORUS

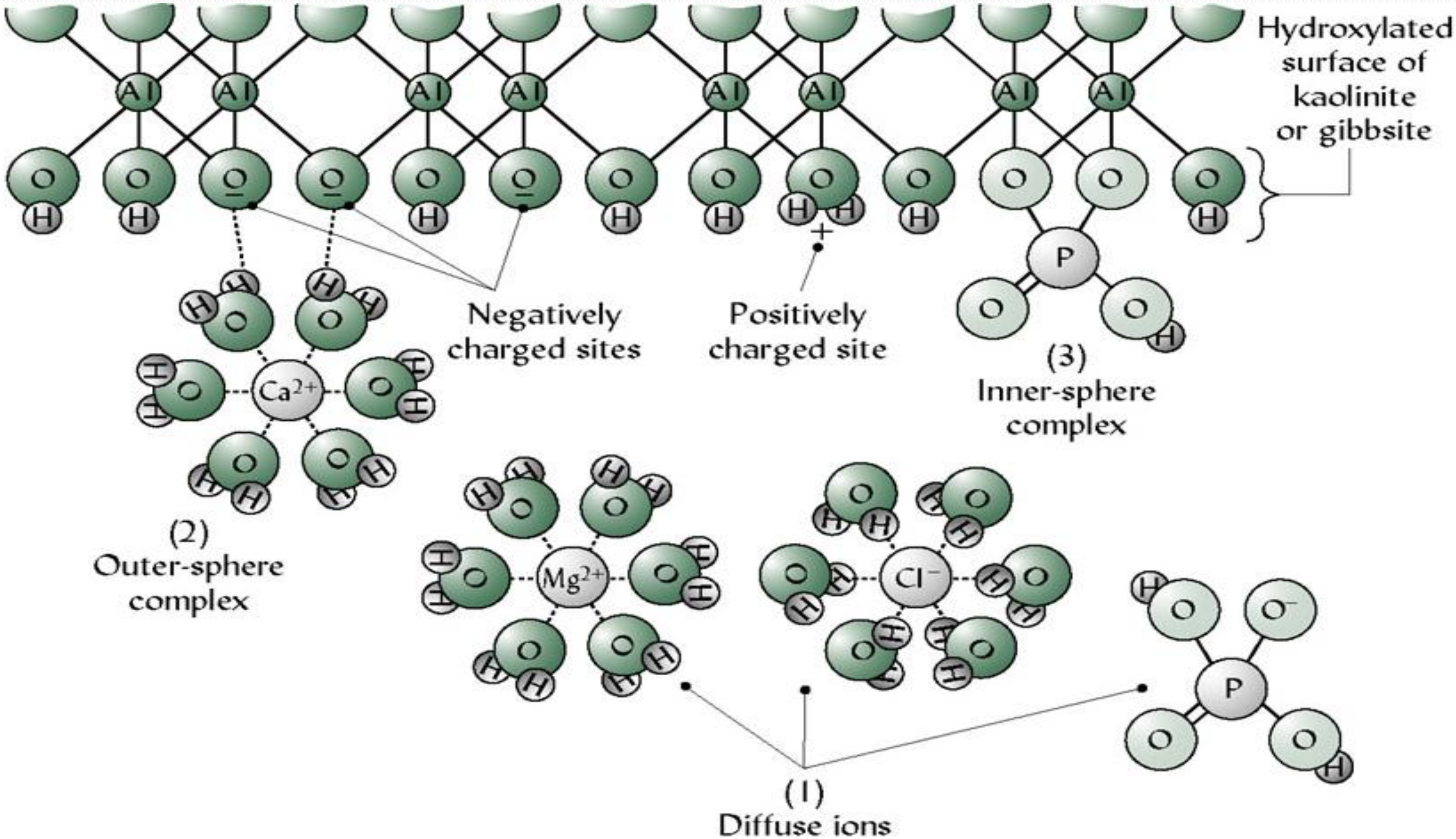
Review of Soil Chemistry and Morphology

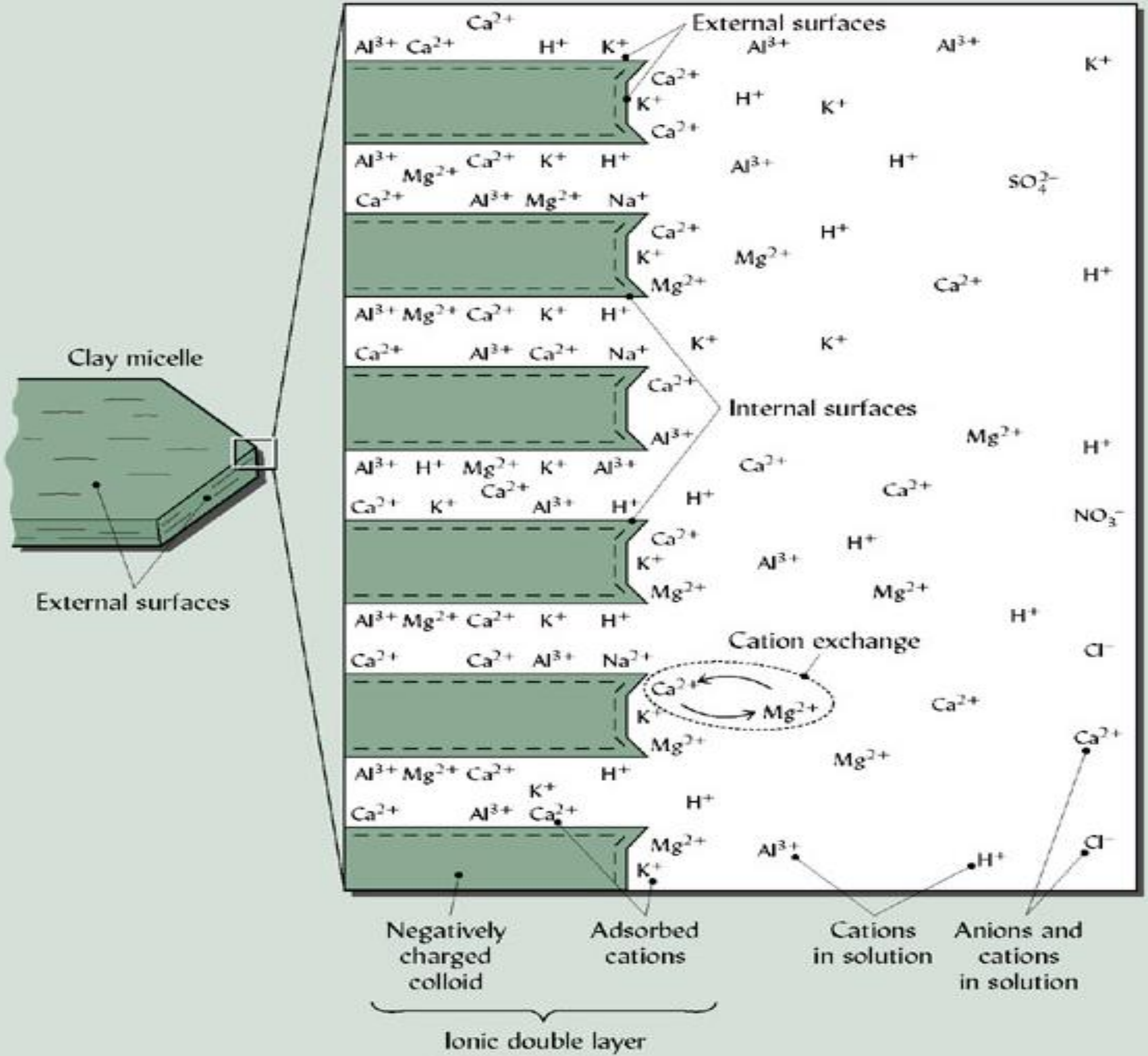
- Oxidation-reduction (Redox) reactions
- Oxidation-reduction principles
- Redoximorphic features (Fe-based)

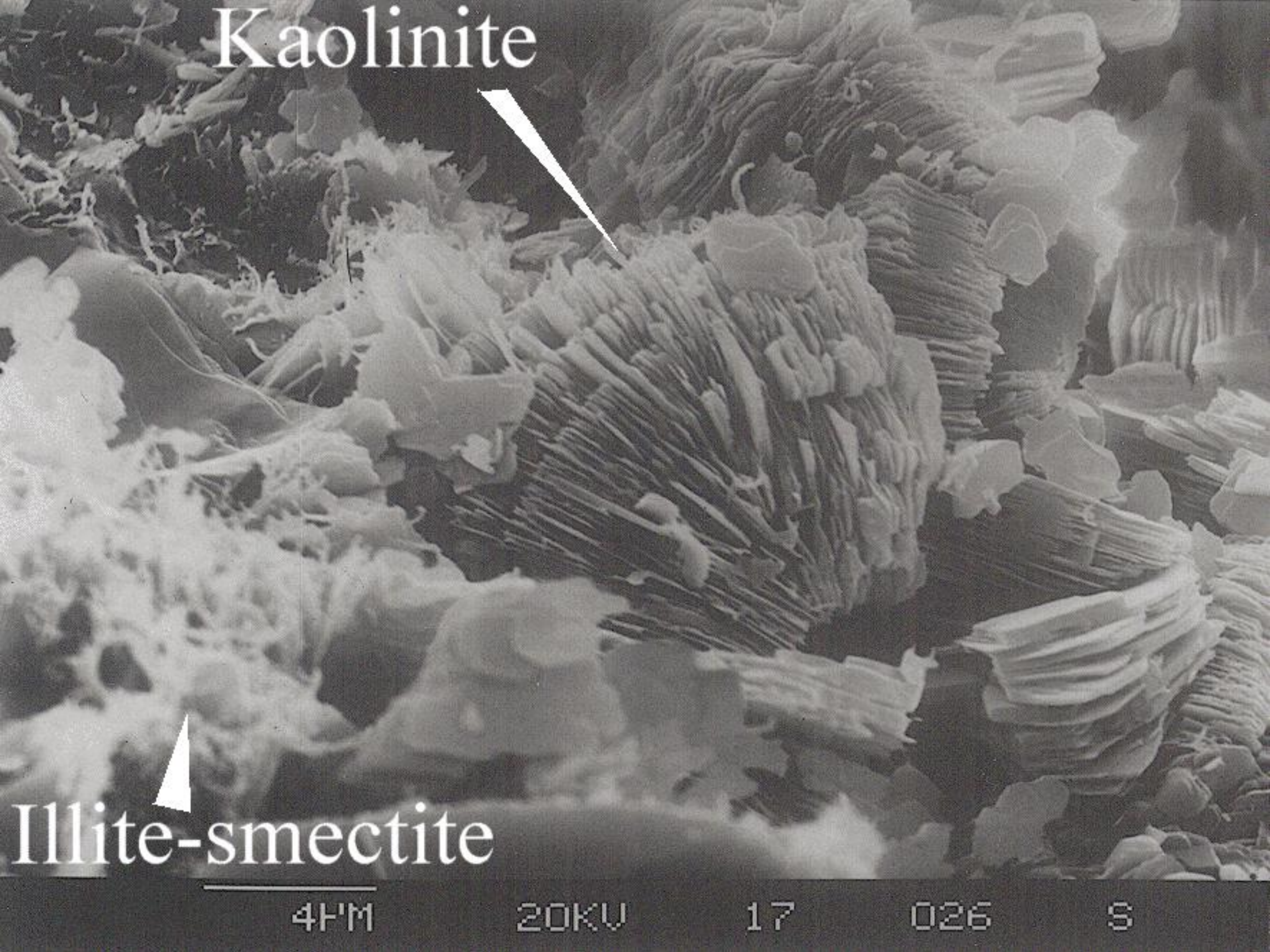
Redox Reactions

- Common reactions in all soils
- Redox reactions control
  - Soil Color
  - Organic matter contents
  - Soil water chemistry
    - O_2
    - NO_3
    - Fe
    - SO_4

Soil Colloids and Cation Exchange Capacity




Clay micelle
External surfaces
External surfaces
Internal surfaces
Cation exchange
Negatively charged colloid
Adsorbed cations
Cations in solution
Anions and cations in solution
Ionic double layer

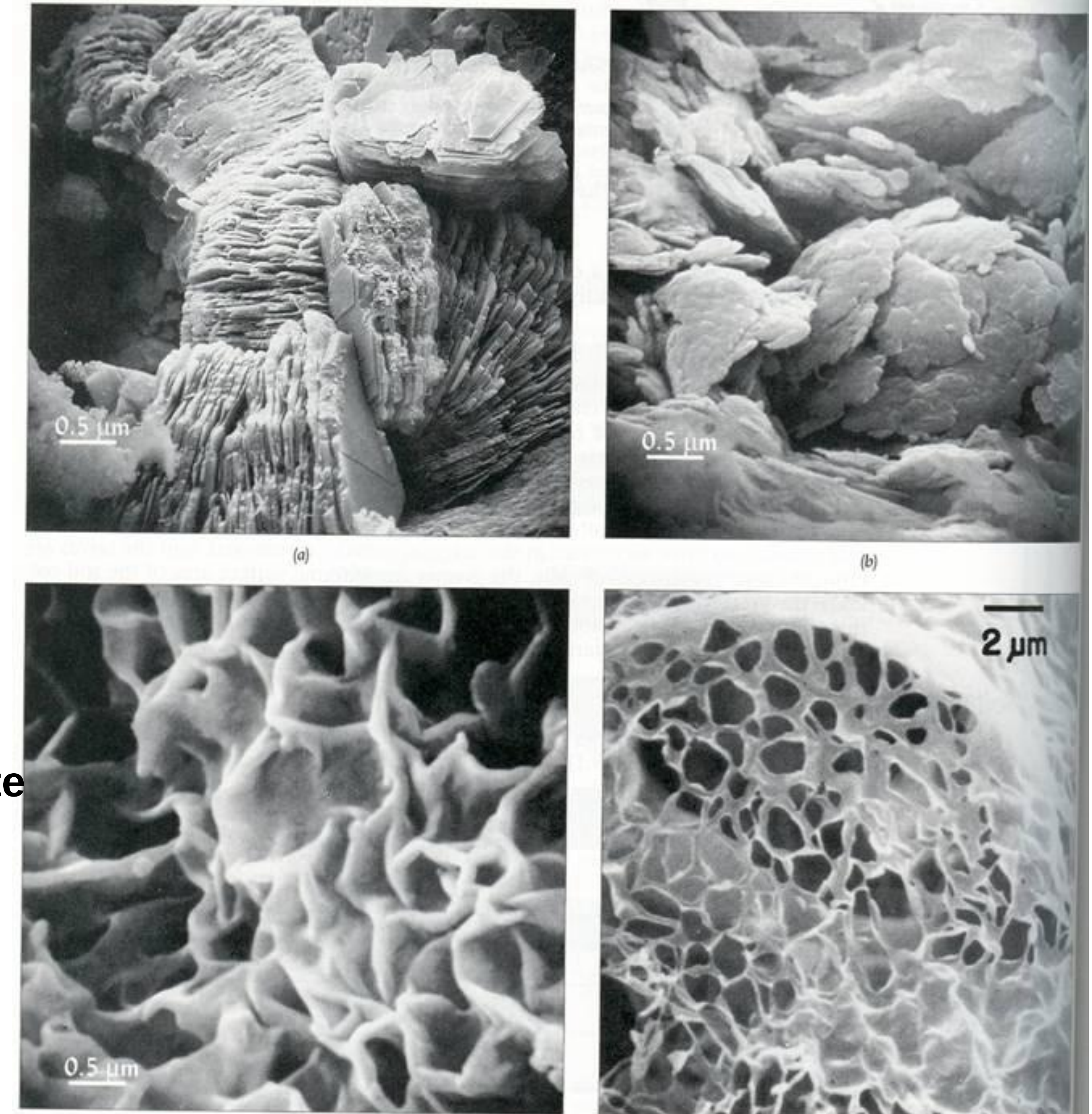

Kaolinite
Illite-smectite
4PM 20KV 17 026 S

Kaolinite (kandite)

Mica

Montmorillonite (smectite)

Humic Acid



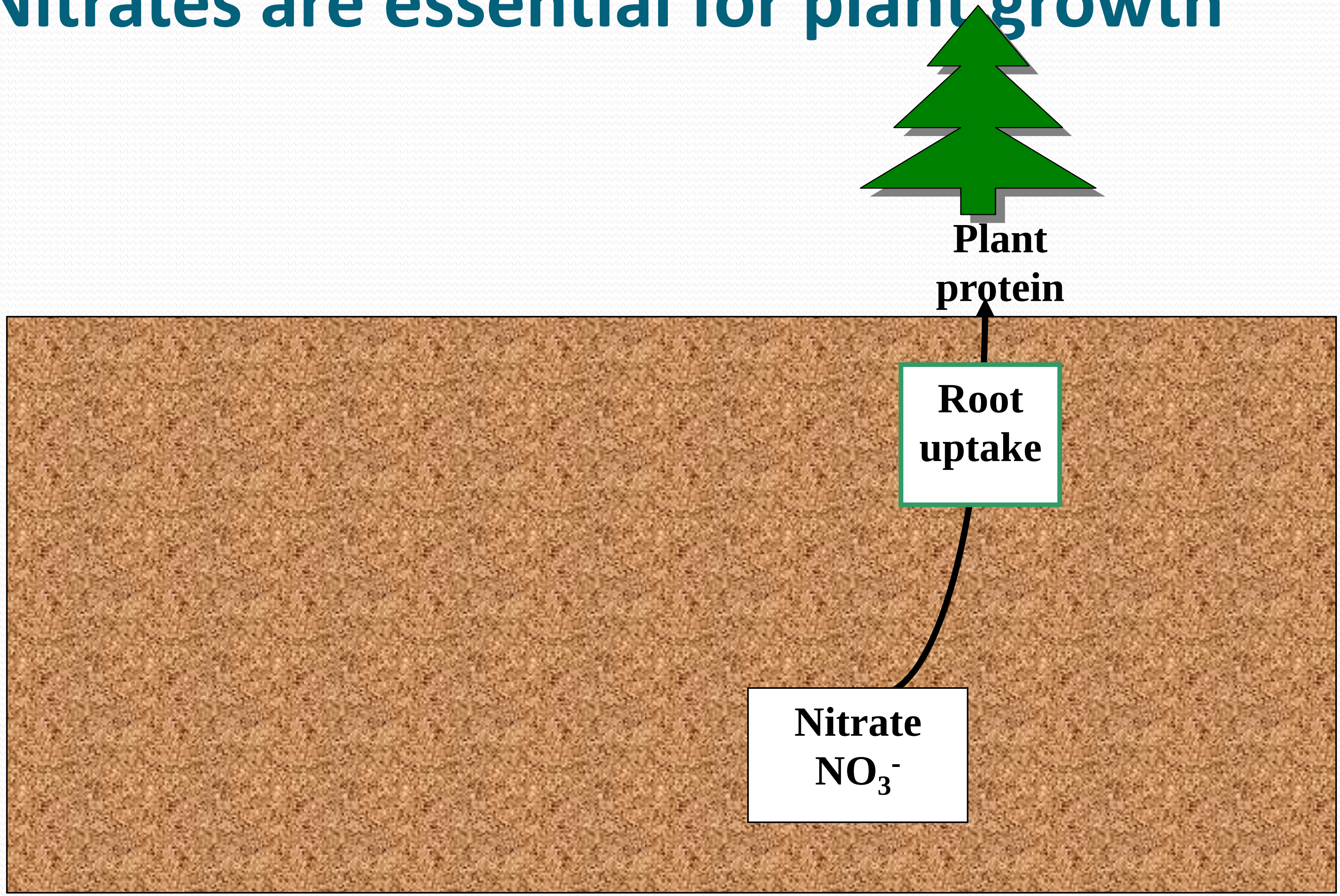
(a) (b) (c) (d)

Humus and the affect of organic carbon

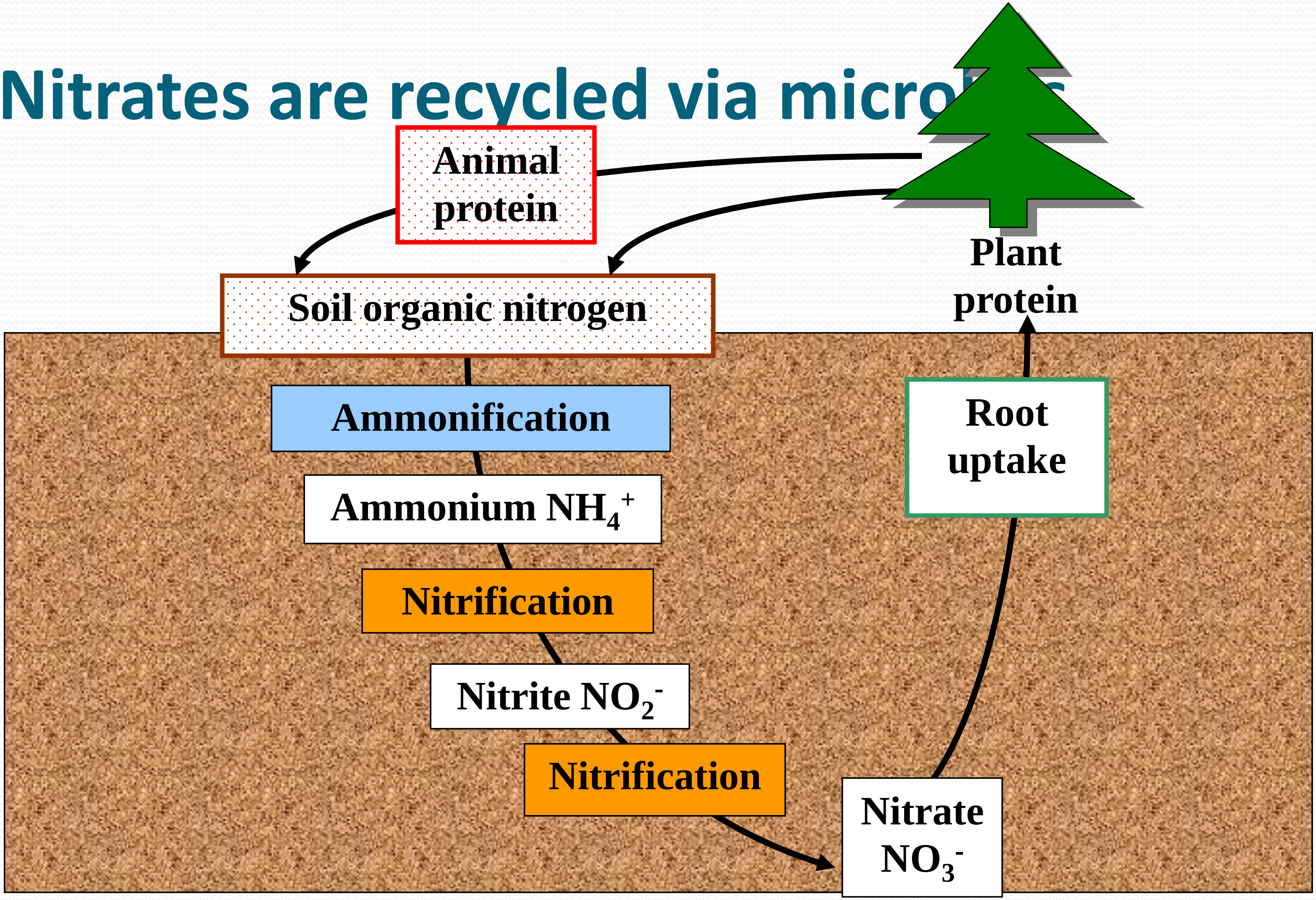
- Present in nearly all soils, especially A horizon
- Not mineral or crystalline
- Consist of chains of C atoms, bonded to H, O & N
- Very highwater adsorption capacity
- Not plastic or sticky
- Negatively charged

THE NITROGEN CYCLE

Nitrates are essential for plant growth



Nitrates are recycled via microbes



Nitrification

- This involves two oxidation processes
- The ammonia produced by ammonification is an energy rich substrate for ***Nitrosomas*** bacteria

They oxidise it to nitrite:

$$NH_3 + 1^1/_2O_2 \rightarrow NO_2^- + H_2O$$

This in turn provides a substrate for ***Nitrobacter*** bacteria oxidise the nitrite to nitrate:

$$NO_3^- + ^1/_2O_2 \rightarrow NO_3^-$$

- **This energy is the only source of energy for these prokaryotes**
- **They are chemoautotrophs**

PHOSPHOROUS

Phosphorous is generally held or *fixed* by the soil using CEC and other soil properties

Soil with high content of fixed P eroded into surface waters can become a pollutant by the over fertilization of subaqueous vegetation causing eutrophic conditions in the water body

SOIL BIOLOGY

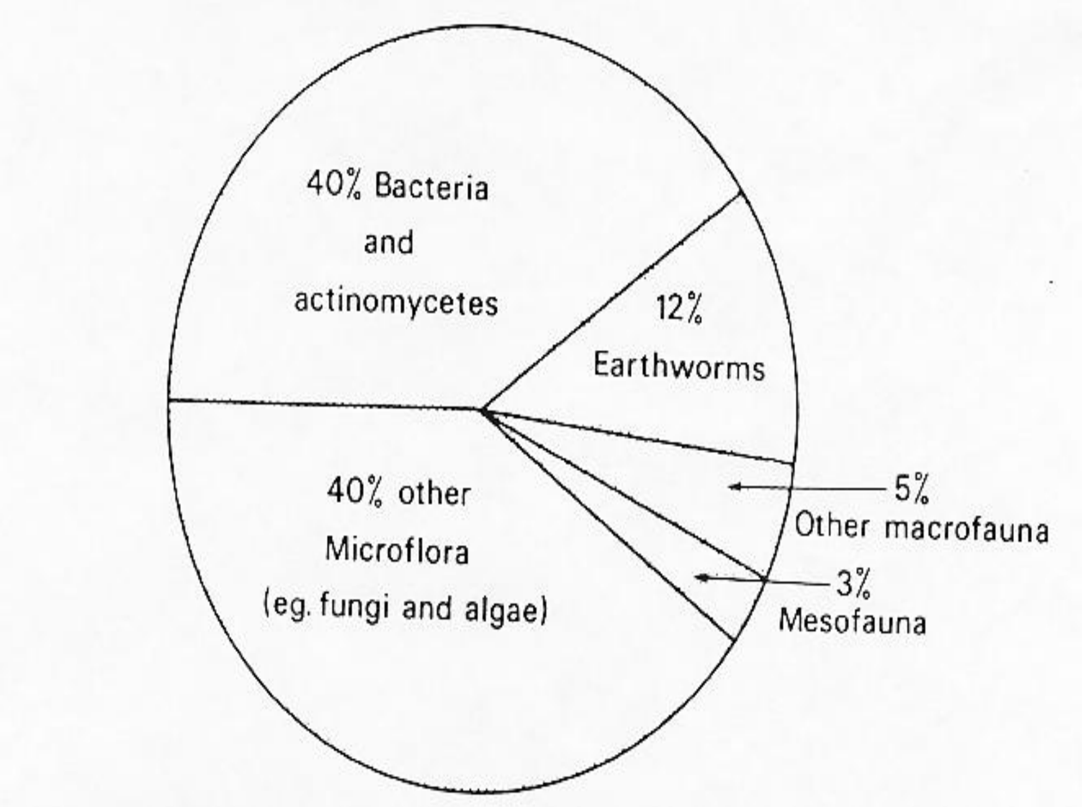
WASTE WATER PATHOGENS

- BACTERIA
- VIRUSES

SOIL MICROBES ARE IN A BATTLE WITH THESE WASTEWATER PATHOGENS

40% Bacteria and actinomycetes:

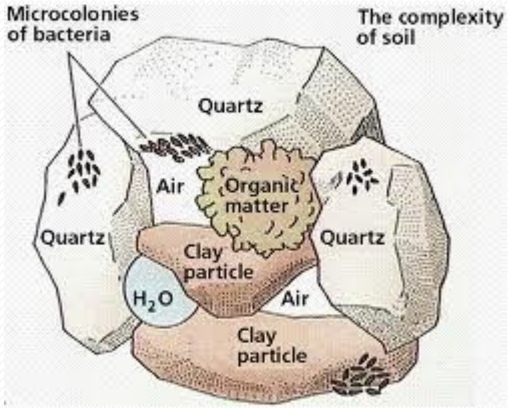
- bacteria
- actinomycetes

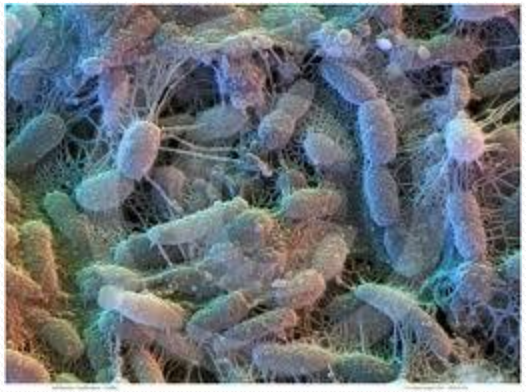


Bacteria

- Tiny (1 μm width), one-celled
  - Single cell division
    - In lab: 1 can produce 5 billion in 12 hours
      - (In real world limited by predators, water & food availability)

- Abundant in rhizosphere
  - zone surrounding root
    - dead root cells and exudate stimulate microbial growth





4 functional groups of bacteria:

1. Decomposers

- Organic chemicals in big complex chains and rings
  - Bacteria break bonds using enzymes they produce
    - Create simpler, smaller chains
- Immobilize nutrients in their cells; prevents loss of nutrients from rooting zone

2. Mutualists

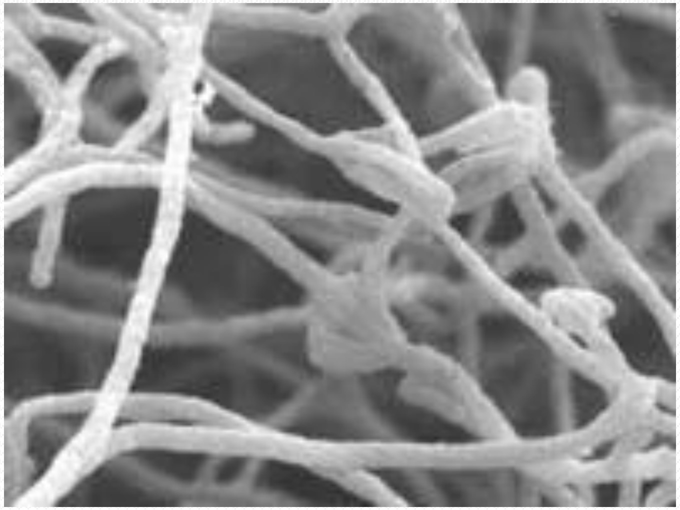
form partnerships with plants (e.g. *Rhizobium* and legumes)

3. Pathogens

cause plant galls

4. Chemoautotrophs get energy from chemical compounds other than photosynthesis

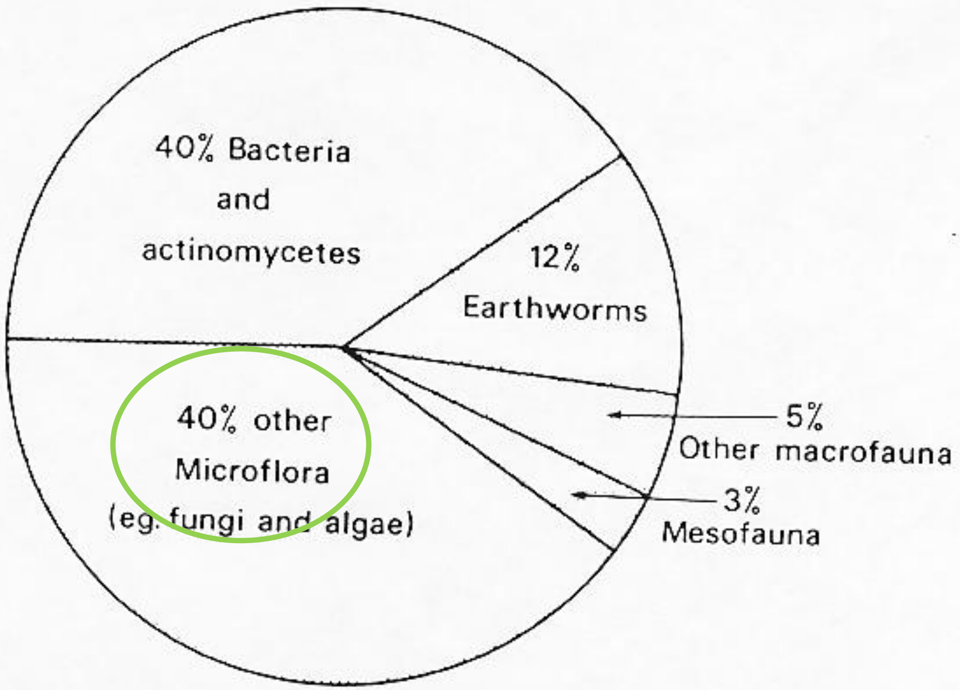
Actinomycetes: group of bacteria that grow as hyphae like fungi



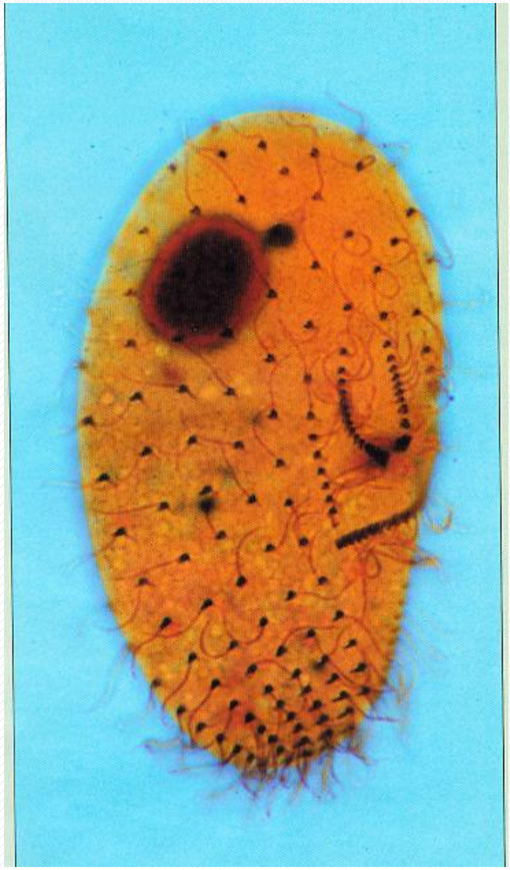
- Make “earthy” smell
  - by producing geosmin
- adaptable to drought
- Can act in high pH
- usually aerobic heterotrophs
- break down “recalcitrant” compounds
  - Hard-to-decompose (chitin, cellulose)
- Produce antibiotics, like Streptomycin

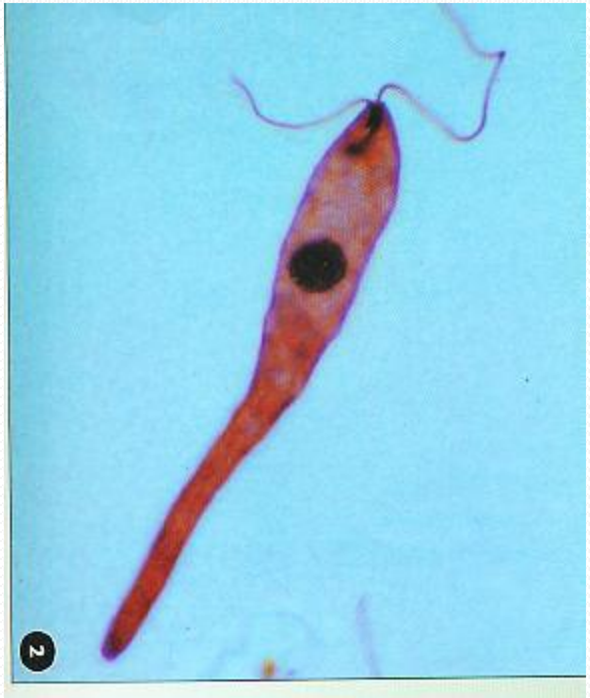
40% other Microflora

Protozoa
Algae
Fungi



protozoa





protozoa

- Unicellular; larger than bacteria
- Amoeba, ciliates, flagellates
- Heterotrophic
  - Eat bacteria

    Bacteria have more nitrogen than protozoa need, so protozoa release the excess

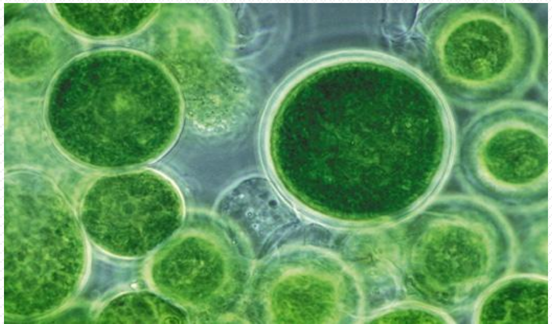
    mineralize

  Form symbiotic relationships

    e.g., flagellates in termite guts; digest fibers
- Require water
  - Go dormant within cyst in dry conditions

algae

- Filamentous, colonial, unicellular
- Photosynthetic
  - Most in blue-green group, but also yellow-green, diatoms, green algae
  - Need diffuse light in surface horizons; important in early stages of succession
  - Form carbonic acid (weathering)
  - Add OM to soil; bind particles
  - Aeration
  - Some fix nitrogen



Fungi

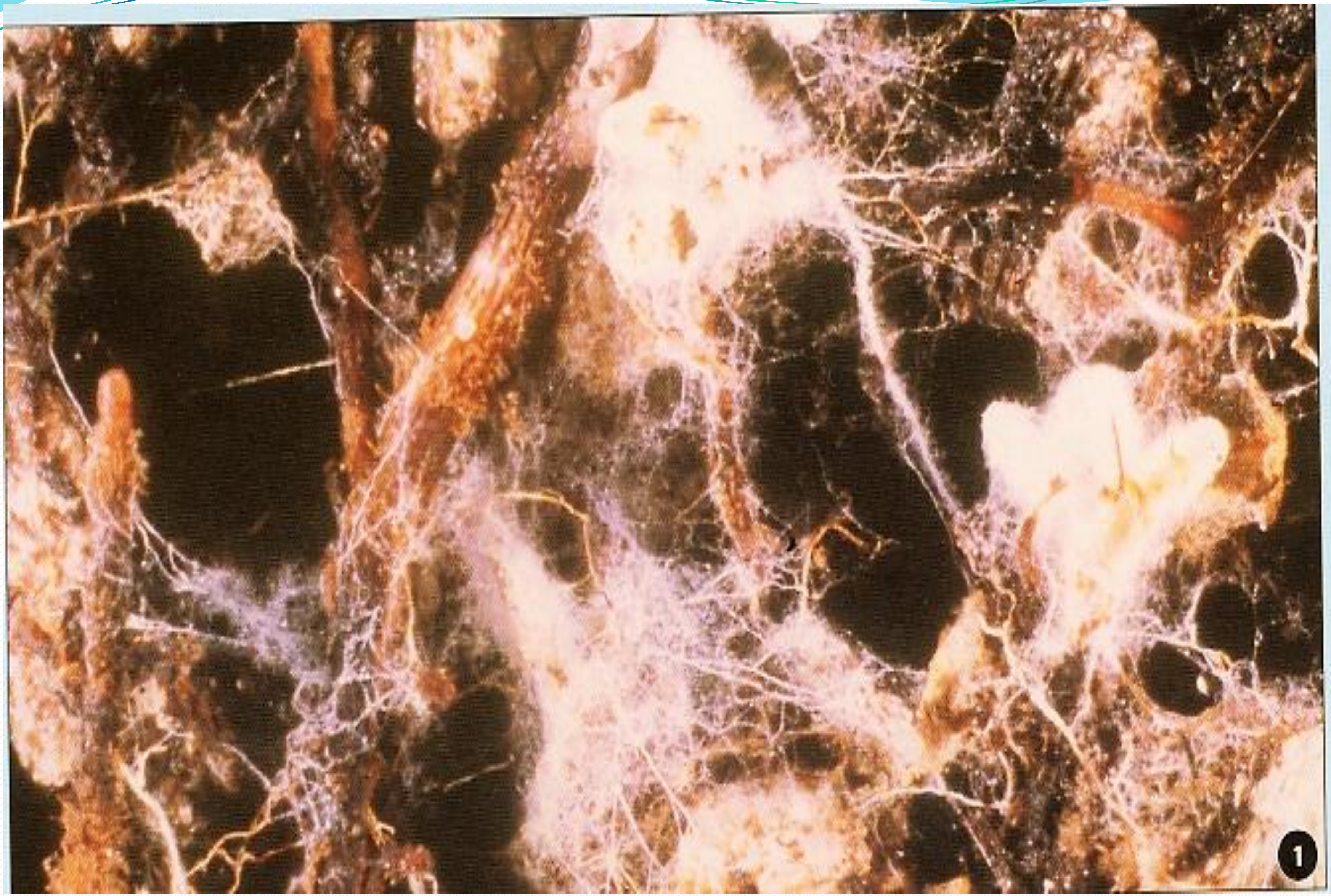
- Grow as long threads (hyphae)
  - Push through soil particles, roots, rocks
- Often group into masses called mycelium (look like roots)

- Higher fungi have *basidium* :
- club-shaped structure ,
- bearing fruiting body

Fungi

- Break down OM, esp important where bacteria are less active; low pH
- attack any organic residue
  - feed by absorbing nutrients from organic material ; no stomachs; digest food *before* it can pass through the cell wall into the hyphae.
    - Hyphae secrete acids and enzymes that break the surrounding organic material down into simple molecules they can easily absorb.
- Most are aerobic heterotrophs
- *chemosynthetic*: adsorb dissolved nutrients for energy

- Like bacteria: immobilize nutrients in soil
- Produce organic acids; increases humic-acid-rich OM that is resistant to degradation
  - Lasts in soil for 100’s of years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12% Earthworms

(Macro fauna: > 1 cm long)

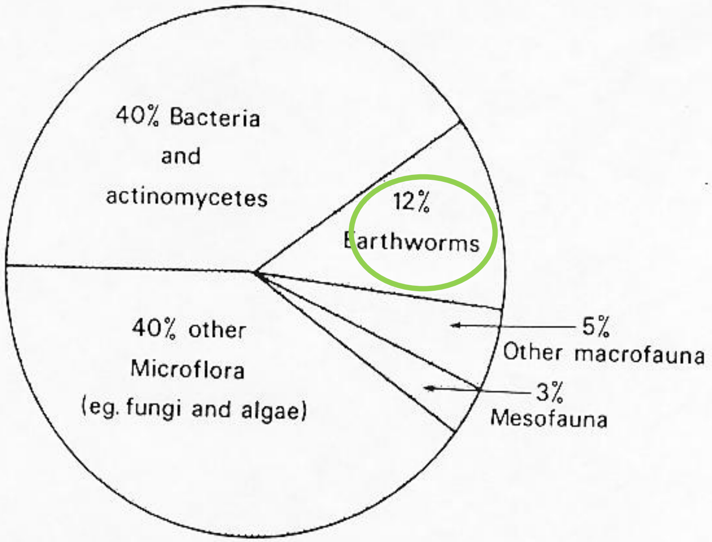
ANNELIDS

several types:

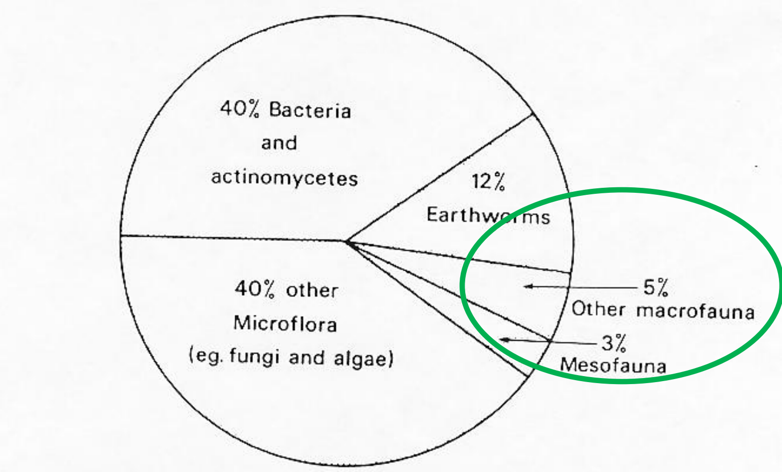
epigeic (litter)

anecic (burrow)

endogeic (in soil)



Other Macro fauna (5%) and Mesofauna(3%)



CHORDATES (vertebrates)

mammals, amphibians, reptiles

PLATYHELMINTHES (flatworms)

ASCHELMINTHES (roundworms, nematodes)

MOLLUSKS (snails, slugs)

ARTHROPODS : (insects, crustaceans, arachnids, myriapoda)

OPTIMUM CONDITIONS FOR PATHOGEN REMOVAL

- TEMPERATURE
- MOISTURE CONTENT
- RESIDENT TIME
- OXYGEN

ALL THE SAME FOR ANY WASTEWATER TREATMENT SYSTEM

Factors affecting microbial transport

- Adhesion processes
- Filtration effects
  - micropore exclusion
- Physiological state
- Porous medium properties
- Water flow rates
- Predation
- Intrinsic mobility of cells

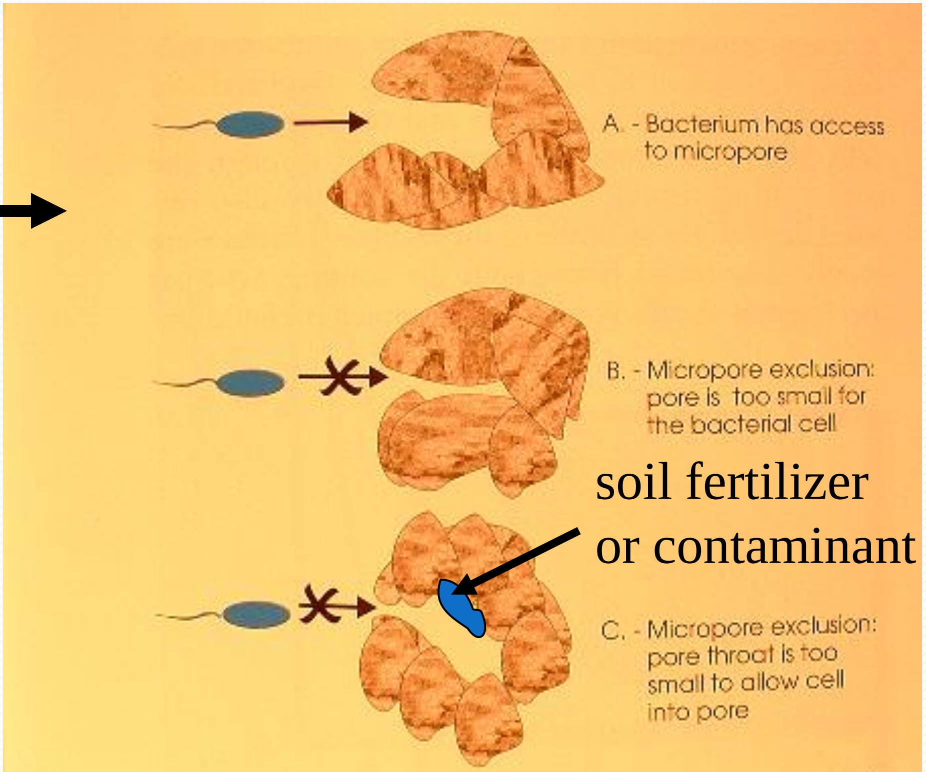
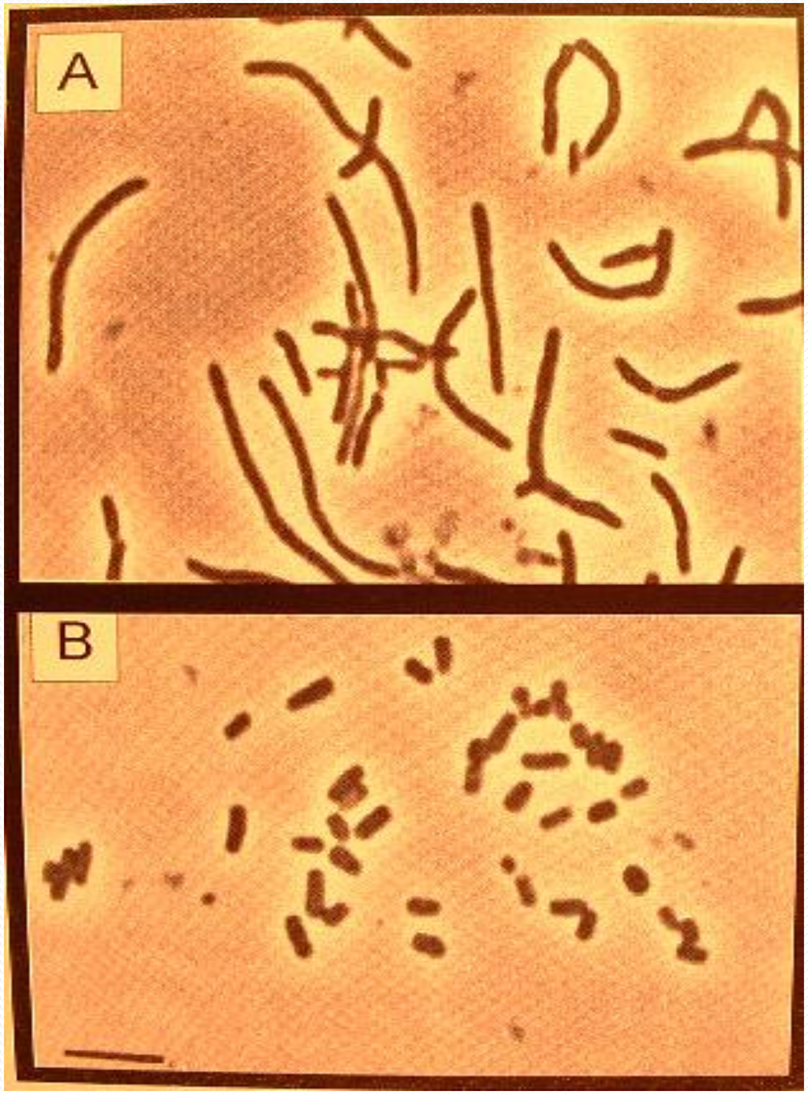


FIGURE 7.1 Exclusion of a bacterial cell from microporous domains in structured porous media.

EDB (1,2-dibromoethane persisted in soil for 19 years through this mechanism.

Physiological State

- Rapidly-growing cells are generally larger than slow-growing or starved cells
  - Large cells move slower through small pore spaces than small cells

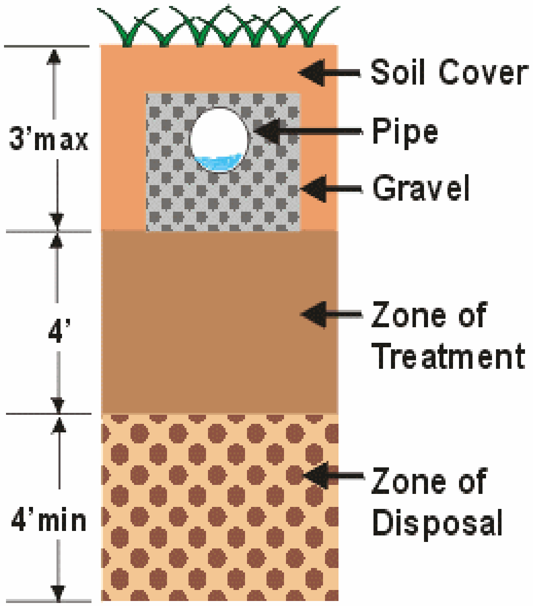


Potential Contaminants in Wastewater

- Bacteria and viruses
- Nitrate
- Phosphorous
- Odors
- Anything else that goes into the system
  - Cleaners, medicine, drain cleaners, paint, …

Wastewater Renovation in the Soil

- Phosphorous is “fixed” and immobile in soils
- Bacteria and viruses
  - Greatest threat to human health
  - Removal by "filtering" and die-off
  - Movement in most soils <2’
  - Reports of movement >100’ in sandy s
    with high water table



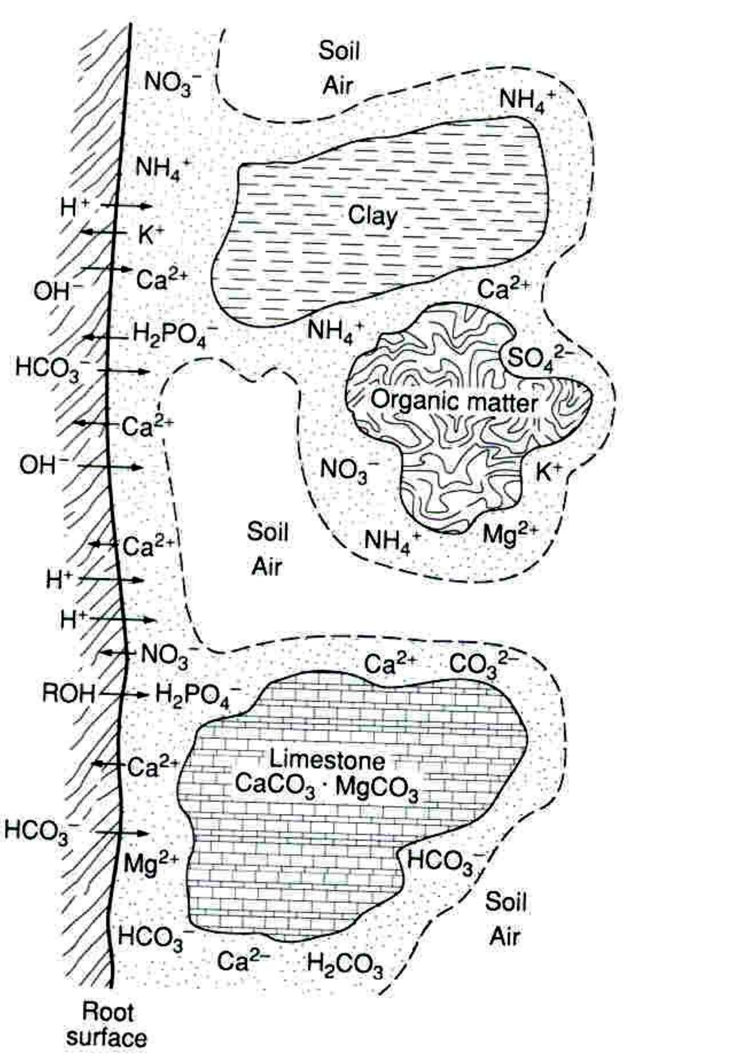
Wastewater Renovation in the Soil

- Natural soil processes
- Rapid organic matter decomposition
- Organic N in wastewater converted to nitrate in an aerobic environment
  - Nitrate is mobile in soil
  - Dilution – only mechanism to keep groundwater nitrate levels low

What Makes It All Work!

Soil!

- Habitat (mixture of solid, water, and air)
- Holds minerals and metals
- Acts as a filter



Adapted from Tisdale et al, 1993

TAKE HOME MESSAGE
SOIL AS A TREATMENT MEDIA

- UNSATURATED FLOW IS NEEDED

- TO PROMOTE UNSATURATED FLOW WE NEED TO DESIGN TO A PEAK FLOW WHICH IS MOST LIKELY 50% GREATER THAN THE AVERAGE FLOW.

An at-grade absorption area sized on a percolation test failed when the flow of 400 gpd was applied daily making it the average flow. (DVC Project)

SOIL MUST DRY OUT BETWEEN DOSES (SO DO MEDIA FILTERS)

TAKE HOME MESSAGE
SOIL AS A TREATMENT MEDIA

- SOILS ARE LIKE PEOPLE….THEY NEED TIME TO REST
- OXYGEN IS YOUR FRIEND CARBON DIOXIDE IS NOT
- WASTEWATER SHOULD BE APPLIED TO THE SURFACE HORIZONS WHERE BIOLOGICAL ACTIVITY IS THE GREATEST
- SUB-SURFACE INSTALLATIONS HAVE A GREATER POTENIAL FOR BY-PASS FLOW

TAKE HOME MESSAGE
SOIL AS A TREATMENT MEDIA

At the end of the day…soil as a three-dimensional living filter has been protecting our surface and sub-surface waters for eons. It is a sustainable method of wastewater treatment that provides an effective method of wastewater treatment if we apply the principals of soil science that were discussed here today.

Acknowledgement

The information presented here today came from many sources including but not limited to:

- Dr. David Lindbo, USDA-NRCS
- Dr. Aziz Amoozegar, NC State University
- Larry Hepner, DVC emeritus professor
- *Soil-Based Wastewater* Treatment

  by Amador and Loomis (2018)
- *The Nature and Properties of Soils 15th ed.*

  by Weil (2017)

SOIL AS A TREATMENT MEDIA

DISCUSION AND QUESTIONS

THANK YOU

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