Soils 201

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Role of soil in plant growth

- Water reservoir
- Supply of nutrients
  - N P K Ca Mg S Fe Mn B Cu Zn Mo Cl
- Support, anchor
- Oxygen, O_2

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What makes a Healthy Soil?

- Soil quality and soil healthy are used interchangeably
- To me they are different. The state of health of a soil depends on other things: an arid soils cold be perfectly healthy for and arid soil but would not be considered healthy if productivity were taken into account.

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Vital Soil Functions

- Sustaining biological activity, diversity, and productivity
- Regulating and partitioning water and solute flow
- Alterning, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials including agricultural, industrial and municipal by-products and atmosperhic deposition
- Storing and cycling nutrients and other elements with the Earth's biosphere
- Providing support of socioeconomic structures and protection of archeologic treasures associated with human habitation. *Karlen et al. 1997*

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Components of soil

- Mineral (inorganic)
- Organic (living and dead, plants and animals)
- Water (and dissolved salts)
- Air (N_2, O_2, CO_2, H_2O, CH_4, H_2S)

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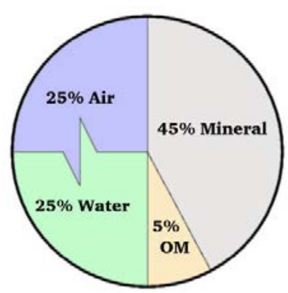

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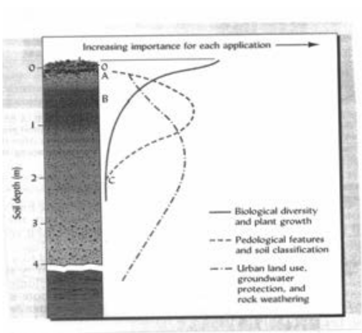
Soil development

- The 3-D soil body
  - Soil profile - a vertical cross section of soil exhibiting its horizontal layering
  - Soil horizon - layers approximately parallel to the soil surface which result from soil-forming processes

Soil development

- Pedogenic processes - develop a soil profile
  - Additions to the soil profile (example - organic matter)
  - Losses of material from the soil profile (example - soluble components)
  - Translocations with the soil profile (e.g. clay transport)
  - Transformations



Soil development

- Soil forming factors
  - Parent material: unconsolidated mineral or organic material from which the soil is formed
  - Climate: weathering agent acting on parent material
  - Relief: surface features of the land
  - Organisms: modify soil materials
  - Time: allow greater extent of process

Soils in the landscape

- Differentiation by profile characteristics
- Soil surveys delineate different soils (nearly every county in the US has one)

Soil mineral matter

- Sand (0.05 - 2 mm)
  - sand separates
    - very coarse: 1 - 2 mm
    - coarse: 0.50 - 1 mm
    - medium: 0.25 - 0.50 mm
    - fine: 0.10 - 0.25 mm
    - very fine 0.05 - 0.10 mm
  - distribution of size range - packing
  - rounded vs angular (firmness)
  - mineralogy - mostly quartz (very stable)

Soil mineral matter

- Size separates and characteristics
  - Silt (0.002 - 0.05 mm)
    - mineralogy

Soil mineral matter

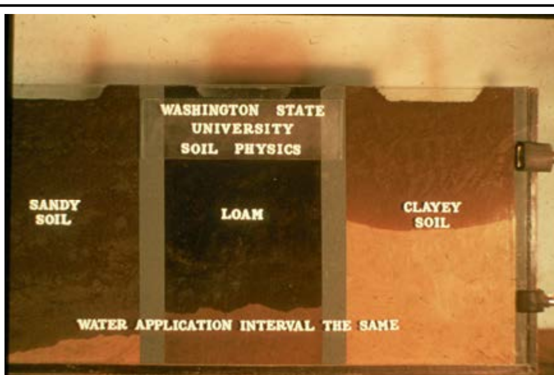
- Size separates and characteristics
- Clay (< 2 micron)
  - plate like structure
  - surface area - related to small size
  - mineralogy (secondary minerals)
  - negative charge
  - cation exchange capacity (CEC) - the sum of the exchangeable cations that a soil can adsorb
  - adhesion of water

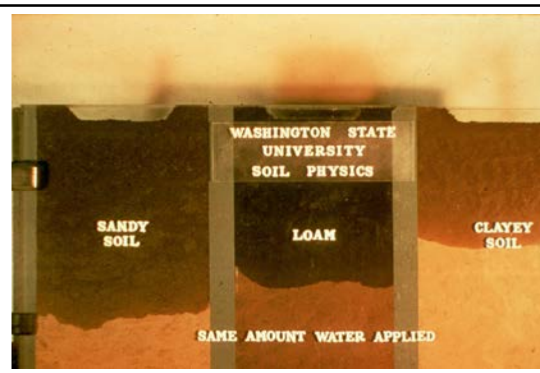
Soil mineral matter

- Soil texture - percentage of sand, silt and clay in soil
  - influenced by parent material, weathering (clay formation), transport of clay, erosion/sedimentation
  - textural classes
    - textural triangle
  - profile textural differentiation

importance of texture

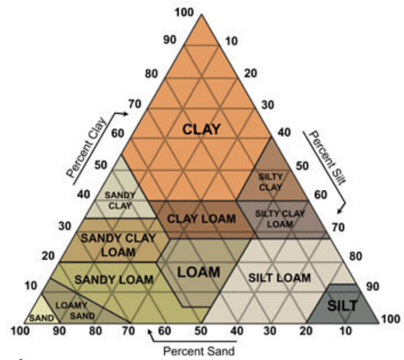
- pore space
- aeration
- water retention, available water
- water infiltration and percolation
- runoff, erosion
- cohesion, plasticity
- shrink-swell character





importance of texture

- soil structure
- management - tillage
- microbial activity, o.m. content
- soil pH (acidity)
- soil temperature
- fertility, productivity



Soil Classification

Introduction

- The principle objective of any soil classification system is predicting the engineering properties and behavior of a soil.
- This is achieved with simple laboratory and field tests.
- These tests results place a soil into a group of similar soils.

Unified Soils Classification System

- Based on the characteristics of the soil which affect its engineering properties.
- Basic classification considerations:
  - % of gravels, sands, and fines
  - Gradation of the soil
  - Plasticity and compressibility of the soil

USCS Soil Categories

- Coarse grained soils – less than 50% fines
  - Gravels and gravelly soils
  - Sands and sandy soils
- Basic classification considerations:
  - Fine grained soils – more than 50% fines
    - Silts (0.05mm to 0.005mm)
    - Clays (smaller than 0.005mm)
    - Organics
- Highly organic soils (peat)

USCS Soil Groups

- A symbol is assigned to each soil category, and categories can be combined to create a two letter designator.

USCS Soil Symbols

Soil Groups	Symbol	Remarks
Gravel	G	Primary only
Sand	S	Primary only
Silt	M	Primary and secondary
Clay	C	Primary and secondary
Organic (silts or clays)	O	Primary only
Highly Organic (peat)	Pt	Stands alone
Soil Characteristics	**Symbol**	**Remarks**
Well graded	W	Secondary only
Poorly graded	P	Secondary only
Low liquid limit (less than 50)	L	Secondary only
High liquid limit (50 or greater)	H	Secondary only

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Possible USCS Soil Types

- GW – gravel, well graded
- GP – gravel, poorly graded
- GM – silty gravels
- GC – clayey gravels
- SW – sand, well graded
- SP – sand, poorly graded

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Possible USCS Soil Types

- SM – silty sands
- SC – clayey sands
- ML – silts, low plasticity
- CL – clays, low plasticity
- OL – organics, low plasticity
- MH – silts, high plasticity

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Possible USCS Soil Types

- CH – clays, high plasticity
- OH – organics, high plasticity
- Pt – peat and other highly organic soils

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Other Soil Terms

- Loam – mix of clay, sand, and organics

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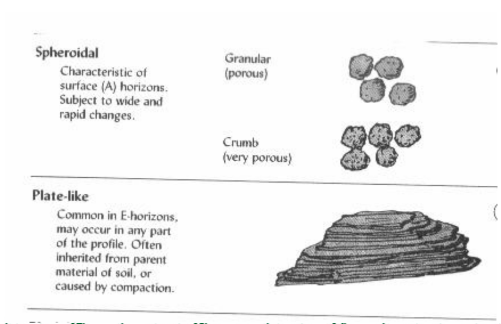
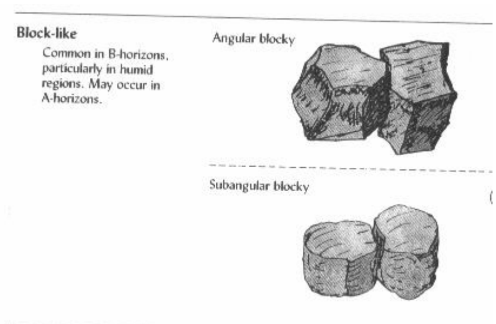
Importance of structure/bulk density

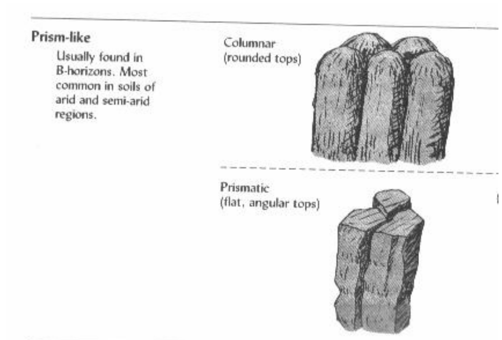
- Structure modifies the influence of texture
- Root growth and function

Importance of structural stability

- Resistance to alteration by destructive forces
- Maintain desirable growth conditions
- Load bearing ability
- Prevent erosion







Structureless soil

- Single grain (sandy soil)
- Massive (cohessive: silty of clayey)

Soil Structure Management

- Prevent compaction - limit traffic or manipulation of any kind (esp) when soil is wet, increasing water content (up to 80% saturation) increases susceptibility of soil to compaction
- Tillage (aerification)
- cropping, organic matter

Soil Structure Management

System	% Water Stable Aggregates	
	> 1 mm	< 1 mm
corn	9	91
corn rotation	23	77
meadow rotation	42	38
bluegrass	57	43

Bulk density

- dry weight of a given volume of soil
- Used to characterize structure
- More porespace = less weight = lower BD
- Texture influences structure and density
- Range for mineral soils: 1.1 - 1.5 g/cm^3 (68.7 - 93.6 lbs/cf)
- organic soils: 0.1 - 0.6 g/cm^3 (6.2 - 37.4 lb/cf)

Measuring Bulk Density

- Most common method is to use a core sampler. Takes core of a known volume.
- Sample is usually then weighed wet, then oven dried to a constant weight at 105 C. (usually 24 hrs).
- You now have a mass and a volume of soil
- BD = mass of OD soil (g)/ vol. soil (cm^3)

Soil Compaction

Purpose of Compaction

- Most critical component in horizontal construction.
- Durability and stability of structures is related to proper compaction.
- Structural failure can often be traced to improper compaction.

Effects of Soil Compaction

- Settlement – Compaction brings a closer arrangement of soil particles which, in turn, reduces settlement.
- Shearing Resistance – Increasing soil density usually increases shearing resistance.

Effects of Soil Compaction

- Water Movement – Compaction decreases the size and number of voids leaving less room for water.
- Volume Change – Generally not of great concern except with clayey soils.

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Design Considerations

- The degree of compaction that can be achieved is dependant on its physical and chemical properties; however, several common factors influence compaction of all soils.

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Moisture Content

- The moisture content has a great impact on a soils ability to densify.
- Optimum Moisture Content (OMC) – the percentage of water, at which a soil will achieve maximum dry density (MDD) under a given compactive effort.
- When at MDD, most of the air voids have been expelled from the soil.

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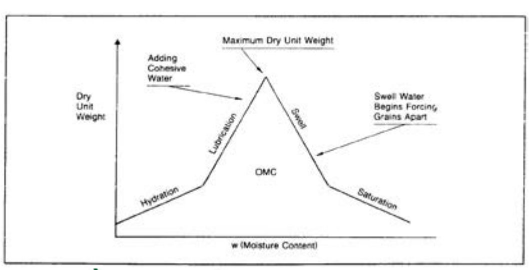
Effect Of H2O on Density



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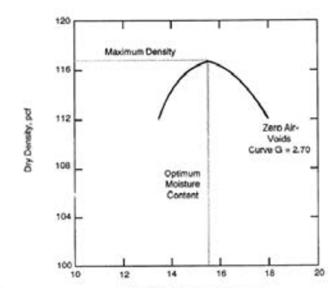
Typical H2O-Density Relationship



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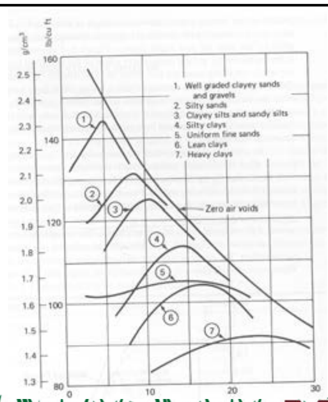
Compaction Characteristics of Various Soils

- The nature of a soil has an effect on its response to compaction.
- Light weight soils can have maximum densities under 60 pcf under a given compactive effort.
- The same compactive effort applied to clay could yield 90 to 100 pcf.

Compaction Characteristics of Various Soils

- Well graded soils can yield maximum densities up to 135 pcf under a given compactive effort.

Compaction Characteristics of Various Soils



Porosity

- the open space between particles or aggregates
- Total porosity and pore size distribution
- Macroporosity - responsible for drainage of water, aeration
- Microporosity (capillaries) - hold water against pull of gravity
- Pore continuity
- Pore tortuosity

Particle Density

- Can be measured but usually assumed to be 2.65 g/cm^3 the density of quartz
- Soils high in OM will have lower PD
- Mass of Solids (g)/Volume of solids (cm^3)
- Important in determining other physical properties such as porosity

Calculating Porosity

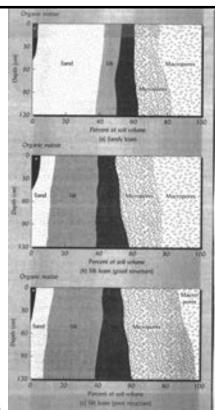
- Volume of Pores(cm^3)/Total Volume of soil (cm^3)
- If we know bulk density we know a volume of soil (solid space + pore space)
- If we know particle density we the volume of solids
- Vs/(Vs + Vp) * 100% = % solid space

Compaction

- Change in structure due to pressure, decreases pore space, increases bulk density, changes pore size distribution, platy structure may develop
- Other consequences of compaction: reduced movement of water and air, greater retention of water, buildup of toxic gases, limited root growth, root function and viability affected, alters microbial population/activity

Calculating Porosity (cont.)

- % solid space = BD/PD * 100%
- % pore space = 100 - (BD/PD * 100%)
- % pore space = % porosity
- We will talk about air filled porosity once we talk about soil water
  - USGA rootzone specs include a spec for airfilled porosity.



Sources of soil compaction

- construction practices (heavy equipment)
- foot traffic
- vehicle traffic (spinning tires, turns especially harmful)
- tillage (at the lowest depth of the tillage implement)
- water droplet impact (crusting on the surface of bare soil)

Soil color

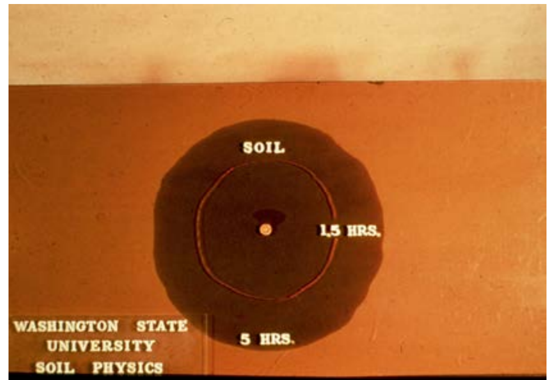
- Importance of soil color
  - Indicative of other soil properties - aeration, drainage, organic matter
  - (surface) heat absorption
- Evaluated with Munsell Soil Color Charts

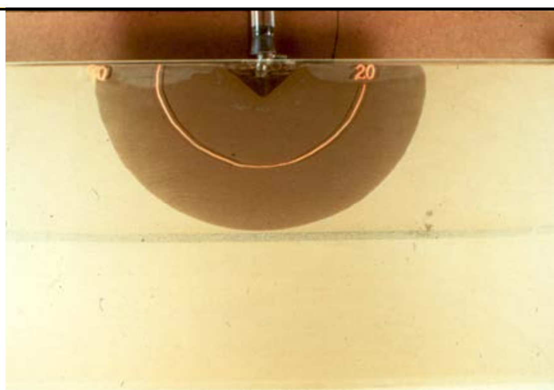
Common soil colors

- Red
- Yellow
- Grey
- Mottled
  - predominately red and yellow (orange.brown) colors indicate oxidized iron and a well oxidized zone of soil (well drained)
  - a predominately gray soil zone indicates reduced iron, which occurs under anaerobic conditions (wet/poorly drained)
  - mottling (splotches of gray and red/yellow) indicate seasonal variation of wetness (aeration status)

Soil water (solution)

- Composition
  - Water, H_2O
    - structure - gives rise to polarity (localized charge)
    - adhesion - attraction of H_2O for solid surfaces
    - cohesion - mutual attraction between





Soil water content

- gravimetric soil water content
  - GSWC = (wt H2O/wt dry soil)
- Volumetric soil water content
  - VSWC = (vol H2O/vol soil)
  - VSWC = (GSWC x BD)

Soil water potential (energy)

- water tend to a lower energy level, lower position in the soil profile, or close to mineral particles in small pores
- determinant of water retention vs drainage
- determinant of availability to plants

Soil water potential (energy)

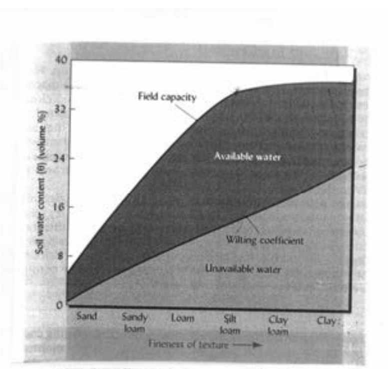
- spatial difference in potential is the driving force of water movement
- relationships of water content to soil water potential
  - texture is primary factor - surface area & pore size distribution
  - structure also influences pore size

Soil water classification schemes

- Physical scheme
  - gravitational water - drains from soil in macropores
  - "field capacity" - macropores emptied but micropores still full
  - capillary water - retained in the micropores
  - hydgroscopic water - held very tightly against evaporation

Soil water classification schemes

- Biological scheme
  - gravitational water - little use to plants, may be harmful
  - plant available - from field capacity to wilting point
  - unavailable - held tightly against plant uptake
  - "wilting point" - plants can't extract water and are permanently wilted



Changes in soil water content/potential

- saturated soil - maximum retentive capacity, all pores filled
- after drainage of ~ 2 days, macropores drained (field capacity)
- further loss of water from soil due to:
  - evaporation
  - plant uptake, transpiration

Changes in soil water content/potential

- availability to plant decreases with decreasing potential
  - wilting when plant demand exceeds supply rate
  - but plants may recover during periods of low demand (night)
- wilting point - plants can't extract water and become permanently wilted

Seasonal changes in soil water content

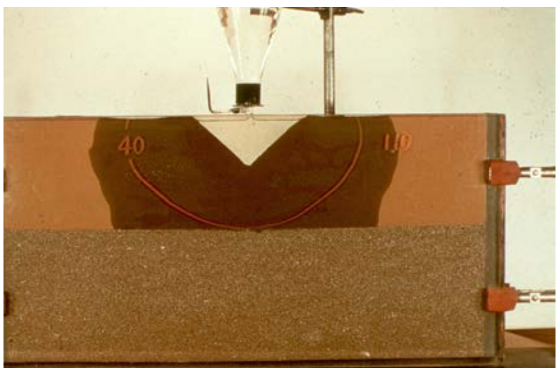
- period of recharge (input)
  - replenish water supply - precipitation, runon, irrigation
- period of surplus
  - leaching, surface storage, runoff
- period of utilization
  - evaporation and transpiration
- period of deficit
  - potential ET greater than actual ET

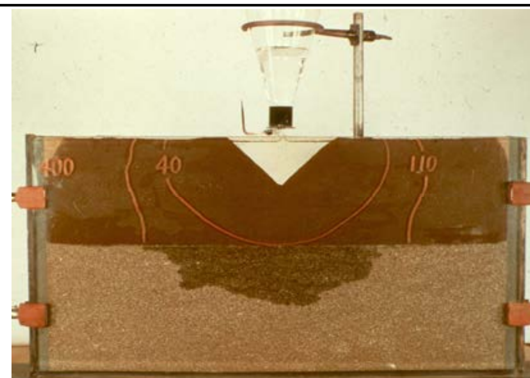
Soil Water Movement

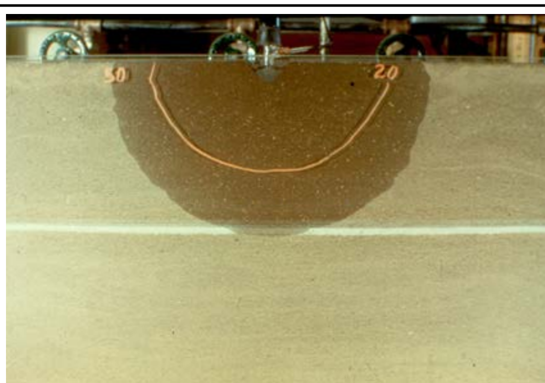
- Driving force - water potential gradient
- Control of rate
  - pore size distribution
  - pore continuity
  - pore tortuosity
- Saturated hydraulic conductivity (Ks)
  - texture influence

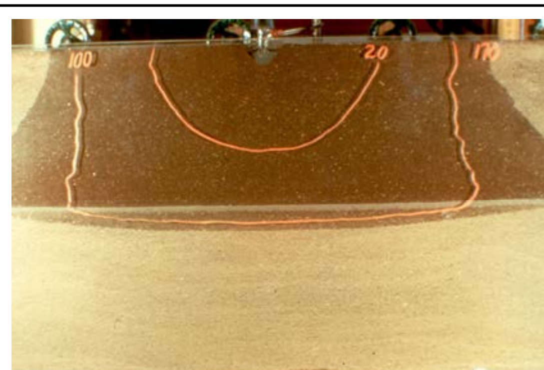
Soil Water Movement

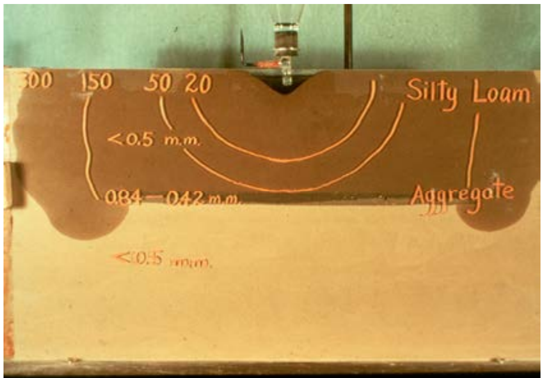
- Unsaturated hydraulic conductivity
  - rate related to soil water potential/content
  - texture influence - water film thickness, size of filled pores
  - textural discontinuity in the profile
    - case 1: coarse-textured soil over fine-textured soil - ‘perched’ water table
    - case 2: fine-textured soil over coarse-textured soil - ‘hanging’ water table





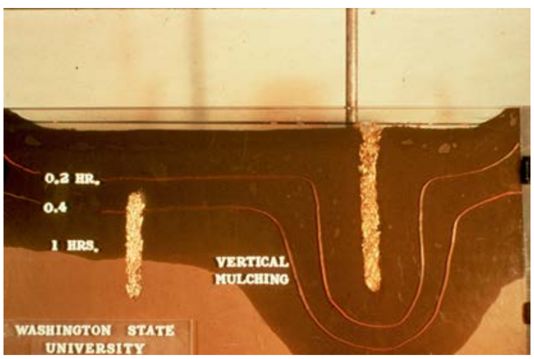


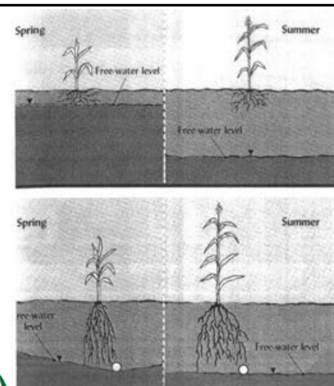




Soil drainage

- Channels or large "pores" to move **gravitational** water laterally intercepting, drawing down water table





SOIL AIR

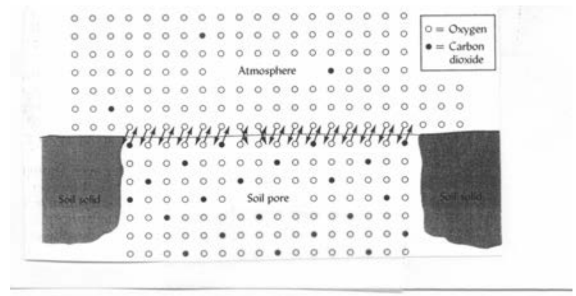
- The degree of aeration depends on
  - Total porosity
  - Amount of water in pores
    - volume of water
    - pore-size distribution - soil texture, soil structure

Composition of soil air

- Major differences relative to atmosphere above ground
  - because soil minerals and water impedes gas exchange
  - in soil, O_2 consumed by plant roots and aerobic microbes
  - CO_2 produced during respiration

Gas exchange

- Rate of gas exchange depends on
  - total porosity
  - volume of air filled pores
  - continuity of pores
- Mass flow - involves all gases uniformly; important only for top few inches of soil
- Diffusion - movement of individual gases due to concentration (partial pressure) gradients



- Aeration profile
  - Affected by changes in soil with depth; total porosity, macroporosity, water content, microbial activity
- Soil microsites (heterogeneity) deviations from ‘average’ due to local concentrations of organic matter (microbial activity), aggregates, coatings
- Annual patterns
  - Dependence on water content; biological activity patterns
- “Well-aerated soil” - an amount of air, of proper composition, which does not limit plant growth

Poor aeration

- Results from poor soil drainage, and/or poor soil structure (perhaps due to compaction)
- Effects of poor aeration
  - anaerobic conditions as O2 used up
  - aerobic biological activity declines
  - decreased rate of organic matter breakdown
  - lower redox potential
  - build-up of toxic gases, e.g. $CO_2 > 10\%$
  - detrimental to root activity

Aeration management

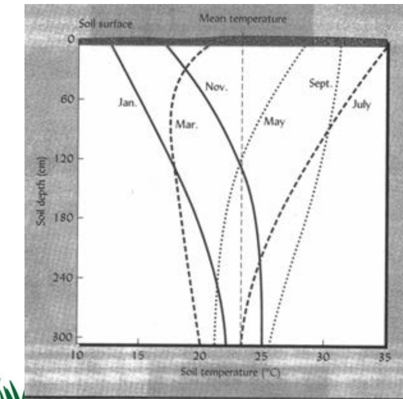
- selection of texture (for constructed rootzones)
- prevent compaction!
- maintain/enhance soil structure
- control of water content (drainage/irrigation)

Soil Temperature

- Importance - affects soil process
  - Physical (freezing/thawing, water viscosity, evaporation, solubility)
  - Chemical (all types of rates and reactions)
  - Biological (microbial activity, seed germination, root activity)

Soil Temperature

- Soil temp is a result of the heat energy gained and lost by the soil
  - Radiation
    - solar radiation - input of short wavelength (UV, visible) energy to the soil surface
    - Re-radiation by soil - output of long-wavelength (IR) energy
  - Conduction - primary processes of heat transfer in soil
    - Thermal conductivity: rate of energy transmission



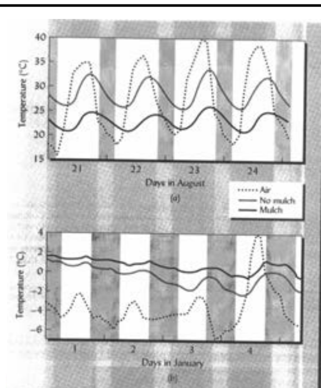
Specific heat

- amount of heat energy required to change temperature 1☜ C

soil minerals	0.2 cal/g ☜C
water	1.0 cal/g ☜C

Temperature Control

- Cover - vegetation, mulch (organic residue or plastic)
- Water content - drainage, tillage



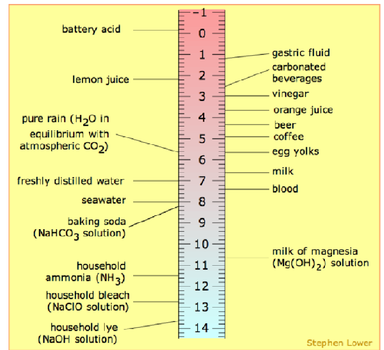
Soil Reaction (pH)

- measure of the acidity or alkalinity of the soil solution
- $pH = -\log[H^+]$

Soil pH

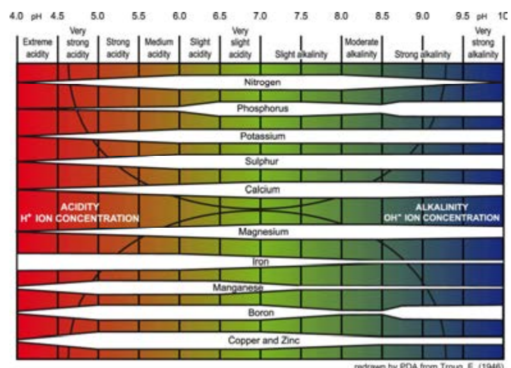
pH	[H+]	[OH-]	
7	10^{-7} or 0.0000007	10^{-7}	neutral
3.5	$10^{-3.5}$ or 0.00032	$10^{-10.5}$	acidic
9	10^{-9} or 0.000000001	10^{-5}	alkaline

- note that the exponents of [H+] and [OH-] add to -14.
- When both are -7 the ions are in equal concentration,
- therefore the system is neutral.



The importance of soil pH

- indication of weathering (parent material, leaching)
- availability of nutrients
- toxicity of metals, esp, Al^{3+}
- oxidation of reduced S



Active acidity in soil solution

- H^+ [measured as pH]
- Exchangeable acidity (Reserve)
- Residual acidity (Bound)

$$Al^{3+} + H_2O \rightarrow Al(OH)^{2+} + H^+$$

$$Al(OH)^{2+} + H_2O \rightarrow Al(OH)_2^{+} + H^+$$

$$Al(OH)_2^{+} + H_2O \rightarrow Al(OH)_3 + H^+$$

Processes increasing soil acidity

- CO_2 (from respiration) + H_2O + HCO^{3-} + H^+
- Organic acids
- H^+ releases upon cation uptake by the root
- leaching of anions (Cl^- , SO_4^-) requires leaching of equal + charge
- Oxidation of reduced substances (e.g. sulfide minerals, organic matter, ammonia fertilizers)
- Acid rain

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Buffering capacity of soils

- Resistance to change in pH of soil solution
- Exchange site equilibrium with soil solution
- Higher the CEC, the greater the buffering capacity

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Processes increasing alkalinity

- Reduction of Fe^{3+}, Mn^{4+} consumes H^+ or releases OH^-
- $Fe(OH)_3 + e^-$ ⌛ $Fe(OH)_2 + OH^-$ (anaerobic situations)
- Recycling of basic cations by deep-rooted plants - maintains B.S.
- Liming

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Modifying Soil pH

- Raise pH – add lime (carbonates, oxides or hydroxides of Ca, Mg
  - Limestones (carbonates) – calcitic, dolomitic, dolomite
    - $CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2O$
    - $MgCO_3 + 2H^+ \rightarrow Mg^{2+} + CO_2 + H_2O$
  - Burned or Quicklime (oxides) – produced by heating limestone
  - Hydrated lime (hydroxides) – water added to burned lime

TURFGRASS MANAGMENT STATE

Lime Requirement – Factors determining amount to add

- pH change desired
- soil's buffer capacity
- chemical composition and purity – guarantee
  - Compare H^+ neutralizing power per weight
- Calcium Carbonate Equivalent (CCE)
  - fineness of lime

TURFGRASS MANAGMENT STATE

Lower pH

- Add organic matter
- Elemental sulfur
  - $2S + 3O_2 + 2\,H_2O \rightarrow 4H^+ + 2SO_4^{2-}$
  - $FeSO_4 \rightarrow Fe^{2+} + SO_4^{2-}$

$Fe^{2+} + 2H_2O \rightarrow Fe(OH)_2 + 2H^+$

Ferrous sulfate

$4Fe^{2+} + 6H_2O + O_2 \rightarrow 4Fe(OH)_2^+ + 4\,H^+$

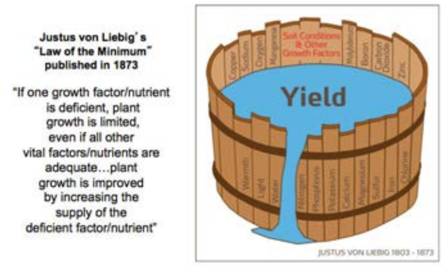
Aluminum sulfate

$Al^{3+} + 3H_2O \rightarrow Al(OH)_3 + 3H^+$

TURFGRASS MANAGMENT STATE

Soil Fertility & Plant Nutrition

- Liebig's concept of the limiting factor (Law of the minimum)
- Plant production is constrained by the essential element (or other factor) that is most limiting.
  - Increasing a non-limiting factor will not improve plant production and only increases the imbalance.
  - Other factors that can be limiting include light, temperature, water



Soil Fertility & Plant Nutrition

- Relation of soil content to plant availability
- Soil testing and tissue analysis
- Deficiency – hidden hunger – critical range – sufficiency range – toxicity

Soil organic matter

- organically derived fraction of soil, including plant, animal, & microbial residues in various stages of decomposition
- Organic residue degradation and formation of humus
  - residue addition to soil – plant, animal, microorganisms
  - microbial activity (decomposition)

C:N Ratios

Fungi	9:1
Actinomycetes	5:1
Bacteria	4:1
Young Legumes	12-20:1
Young Grasses	20-40:1
Oat/Wheat Straw	80-90:1
Tree Leaves	60-100:1

- With additions of residue, N becomes the limiting nutrient
- If residue C:N < 20:1, excess N is released as residue decomposes
- If residue C:N > 30:1, microorganisms require soil N, (competing with plants)
- Residue C is respired (CO_2↑) during decomposition, but N is recycled as microorganisms die; so C:N decreases

- residue is transformed
- humus results – relatively stable modified organic molecules resistant to further breakdown
  - C 50-60%
  - N 5%
  - P 0.6-1.2%
  - S 0.5%

Characteristics of Soil Organic Matter

- low bulk density
- negative charge; high CEC compared to mineral fraction
- buffering capacity
- water holding capacity
- source of N, P, S, micronutrients

Organic matter in soils

- Amount
  - range in A horizon 0.5-7.0%
  - subsoils have less: 0.25-1.75%

Significance of Soil OM

- Soil bulk density, porosity
- Soil structure stability, resilience
- Water holding capacity
- Fertility (N, P, S contents, CEC, chelates)
- pH buffer
- supports microbial biomass
- adsorbs some pesticides
- heat absorption (color)

Soil Organisms

- Plants
- Primary producers
- Add organic matter
- Root growth – forms channels, withdraws water, takes up nutrients
- High concentration of active microorganisms in immediate vicinity of the root

Soil Organisms

- Animals
  - large range of sizes
  - Mixing soil
  - channeling
  - physical breakdown of organic matter

Soil Organisms

- Protista
  - amoeba
  - cilliates
  - protozoa

Soil Organisms

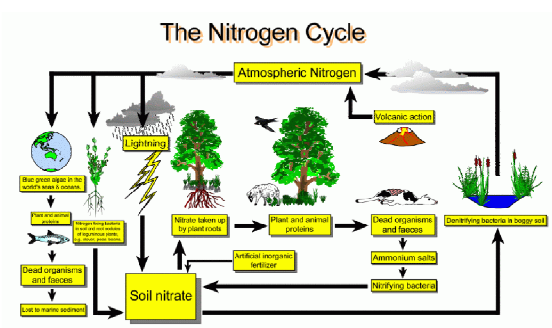
- Fungi – (mildews, molds, yeasts, mushrooms)
  - 10^5-10^6/g soil
  - exceed other microorganisms in weight
  - tolerant of acid conditions
  - decomposers
  - symbiosis
  - pathogens

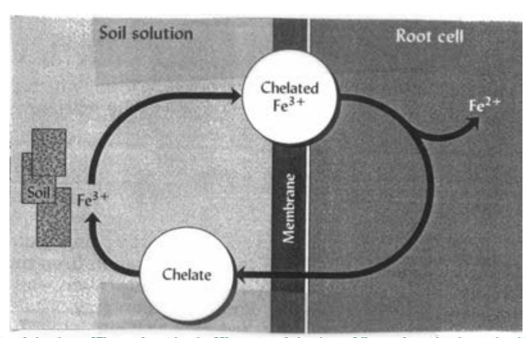
Soil Organisms

- Actinomycetes
  - 10^7/g soil
  - slow growing
  - tolerates low soil moisture, high temperature; intolerant of low pH
  - Decompose cellulose & other resistant compounds
  - Symbiosis with diverse plant families –
    - N_2 fixation
  - Soil aggregate stability
  - Antibiotics (e.g., streptomycin)

Soil Organisms

- Bacteria
  - Most numerous in soil 10^8-10^9/g soil
  - Procaryotic, unicellular ~1 µm
  - Very diverse metabolism
  - *Rhizobium* – Symbiosis with legumes
  - N_2 fixation
  - Nitrifiers – oxidation of
    - $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$
  - Denitrifiers – anaerobic reduction of
    - $NO_3^- \rightarrow N_2, N_2O$





Soil Quality

- A simple definition would be "the capacity of soil to function.
- It includes physical, chemical and biological characteristics.
- USDA has defined a simple kit for measuring soil quality

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Soil Quality

- Bioligical properties are soil respiration rate and a simple count of earthworms.
- Physical properties measured are bulk density, water content, infiltration rate, aggregate stability, slaking, and morphological characteristics
- Chemical properties measured are pH,
- electrical conductivity (EC), and soil nitrate levels

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General soil respiration class ratings (Woods End Research, 1997)

Soil respiration rate (lbs CO2 – C/ac/day	Class	Soil condition
0	No soil activity	Virtually sterile
<9.5	Very low soil activity	Soil is depleted of organic matter and has little activity
9.5-16	Moderately low soil activity	Soil somewhat depleted of organic matter and activity is low
16-32	Medium soil activity	Soil is approaching or declining from ideal state
32-64	Ideal soil activity	Soil in ideal state of biological activity
>64	Unusually high activity	Very high activity usually do to application of large quantities of fresh OM

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General relationship of BD to root growth based on soil texture

Soil Texture	Ideal BD g/cm^3	BD affecting root growth	BD restricting root growth
Sands, Loamy Sands	< 1.60	1.69	> 1.80
Sandy loams, loams	< 1.40	1.63	> 1.80
Sandy clay loams, clay loams	< 1.40	1.60	> 1.75
Silts, silt loams	< 1.30	1.60	> 1.75
Silt loams, silty clay loams	< 1.40	1.55	> 1.65
Sandy clay, silty clay, some clay loams	< 1.10	1.49	> 1.58
Clays < 45% clay	< 1.10	1.39	> 1.47

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