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*Shaping Lives...
Empowering Communities...*

ASAC 1101 : FUNDAMENTALS OF SOIL SCIENCE (2+1)

Level : B.Sc (Ag), I semester

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SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

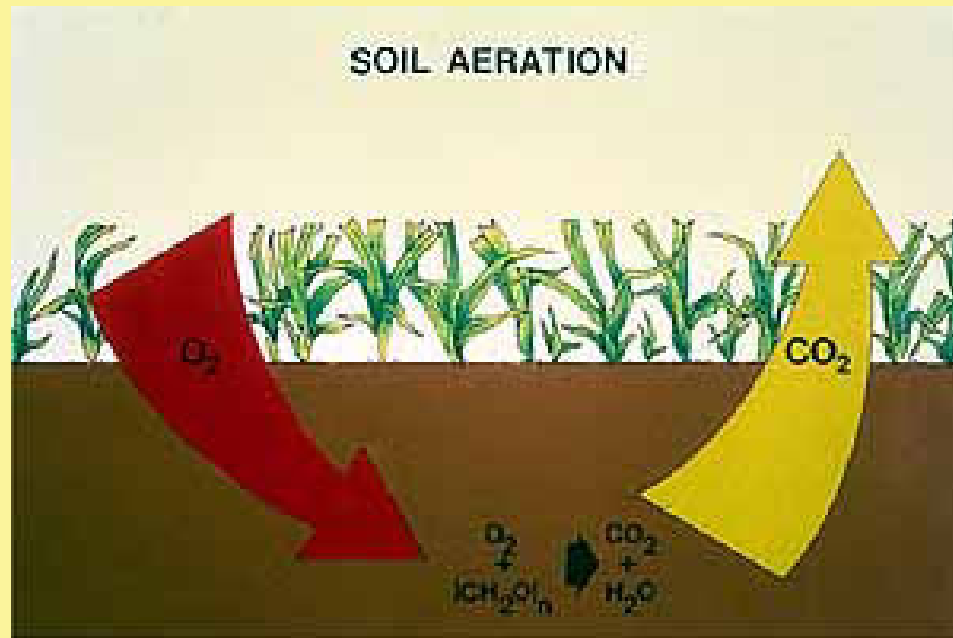
**M.S.SWAMINATHAN SCHOOL OF AGRICULTURE,CUTM,
PARLAKHEMUNDI**

Topic

Soil Air

Soil aeration

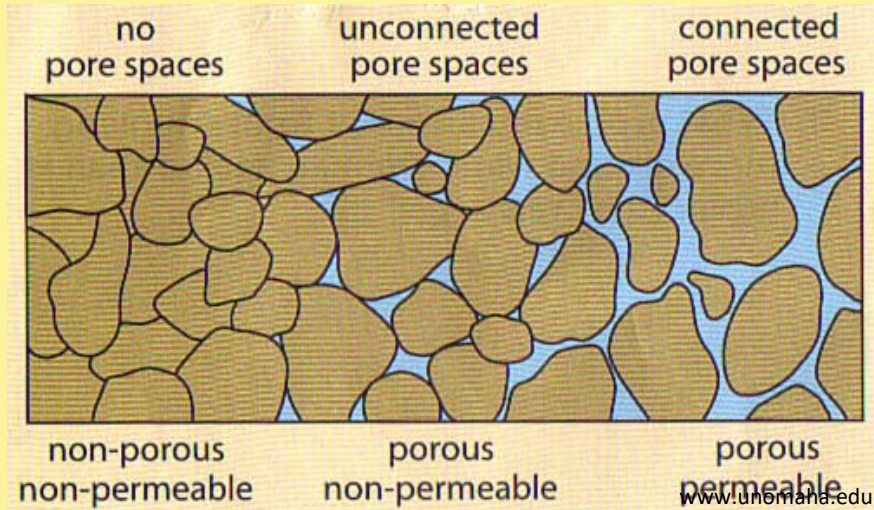
- ❑ Soil aeration facilitates exchange of gases between soil and atmosphere



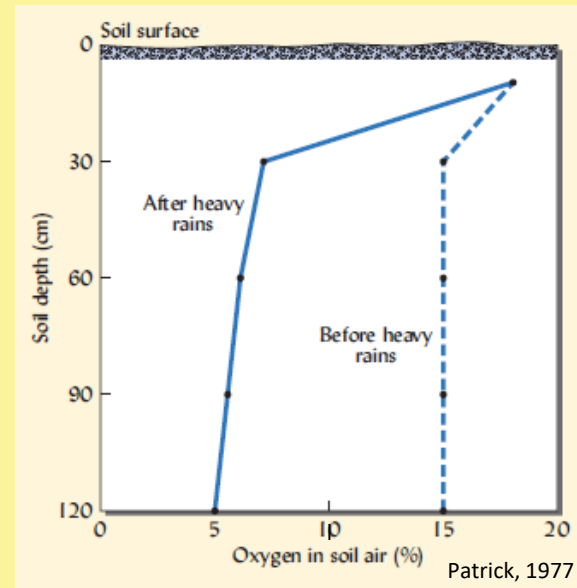
Soil aeration

- Oxygen availability in soil is determined by

1. Macro porosity



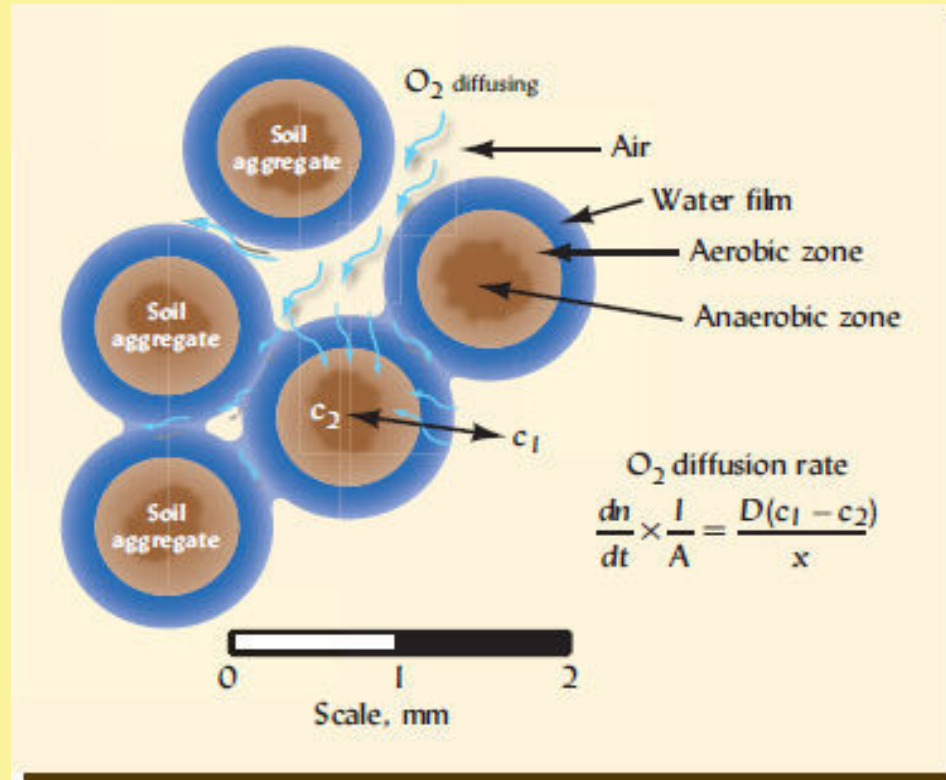
2. O₂ consumption by organisms



3. Soil water content

Soil aeration

- Oxygen availability in soil is determined by
 1. Soil structure
 2. Soil temperature
 3. **Soil water content**



Excess moisture



Ray R. Weil

Adaption for poor aeration in waterlogging conditions

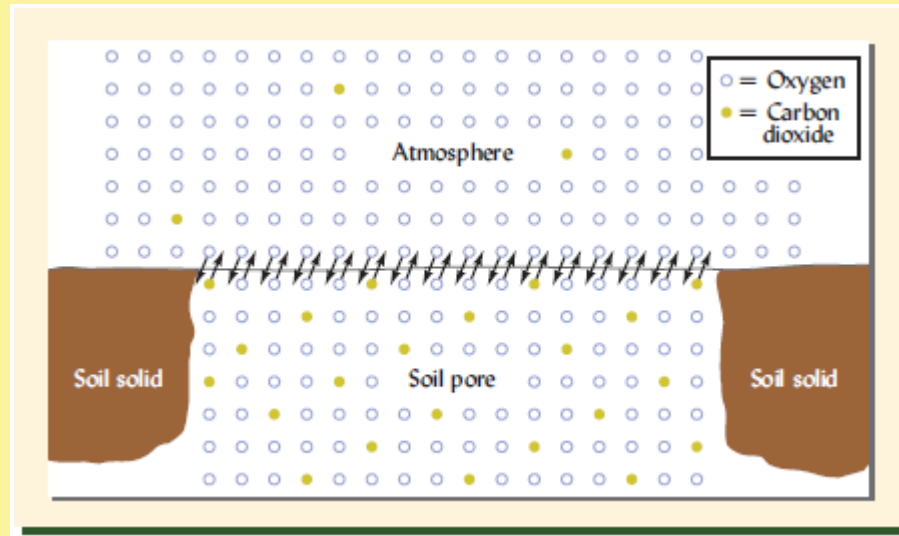
Aerenchyma cells supply oxygen to roots from atmosphere



- Hydrophytes** are adapted to grow in waterlogged conditions
- Have above water roots to supply oxygen

Process of gaseous exchange

- ❑ Gaseous exchange occurs by **mass flow** and **diffusion**
- ❑ Mass flow caused by fluctuations in soil moisture content that force air in and out
- ❑ In diffusion, movement of a gas and its direction is governed by partial pressure of the gas
- ❑ **Partial pressure is the pressure exerted by an individual gas in a mixture of gases**
- ❑ Partial pressure gradient causes movement of gases from high to low concentration



Calculation of partial pressure

What is the partial pressure of oxygen?

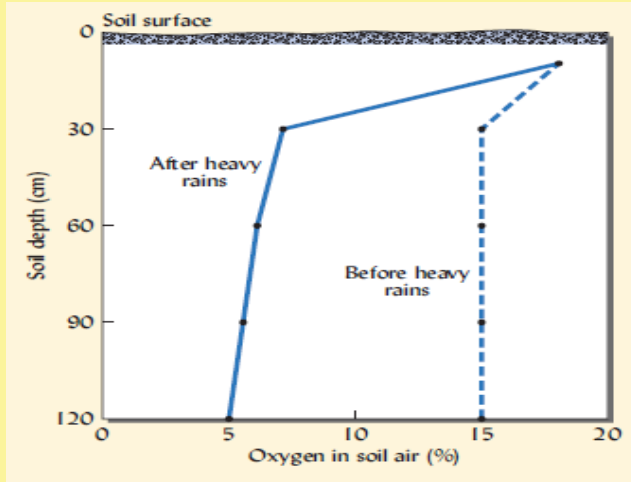
- ❑ Air pressure = 100 kPa (~1 atm)
- ❑ Concentration of oxygen in air = 21% = (0.21 L/L) by vol
- ❑ Hence, **partial pressure of oxygen = 21 kPa**

Characterizing soil aeration

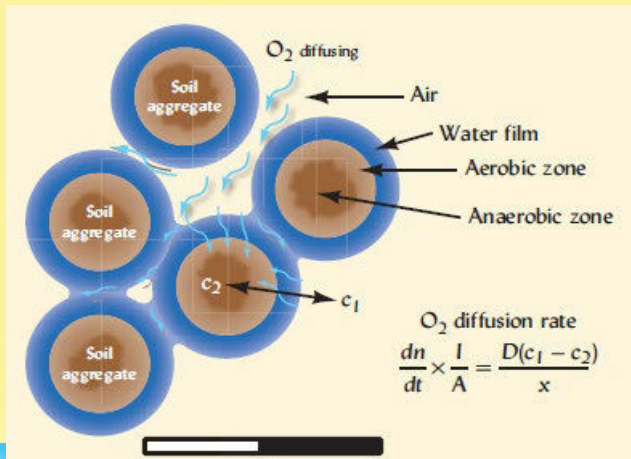
1. Gaseous composition of soil air

- Soil air composed of various gases
- Soil air has same amount of N_2 as atmosphere (**78%**)
- O_2 is less (**~20%**) in soil than atmosphere and decreases further with depth
- CO_2 is more in soil (**0.35%**) (10 times more concentrated than atmosphere)
- Lack of oxygen causes anaerobic conditions
- Under such conditions, concentration of CH_4 , H_2S and C_2H_4 increases

Characterizing soil aeration



Ray R. Weil



1. Gaseous composition of soil air
2. Air filled porosity

More the air filled porosity,
better the aeration

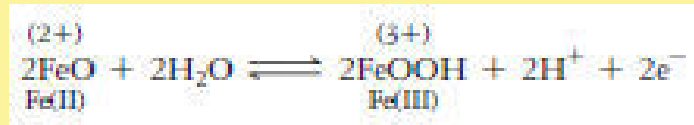
oxygen diffuses 10,000
slower through water filled
pores than in air filled pores

Characterizing soil aeration

1. Gaseous composition of soil air
2. Air filled porosity
3. Oxidation-reduction (redox) potential
 - ❑ Redox potential – tendency or potential for electrons to be transferred from one substance to another (E_h)
 - ❑ Reference for E_h : Hydrogen, $E_h = 1$
 - ❑ Redox potential determines which compound is present in the soil at a particular time, its concentration and oxidation state

Redox potential

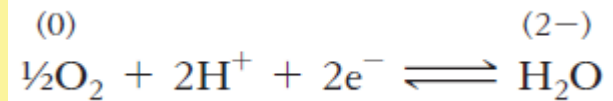
- ❑ Living organisms release electrons while oxidizing carbon for energy
- ❑ O_2 acts as an acceptor of these electrons (**oxidizing agent**)
- ❑ Once all O_2 is depleted by this process, anaerobic zone created



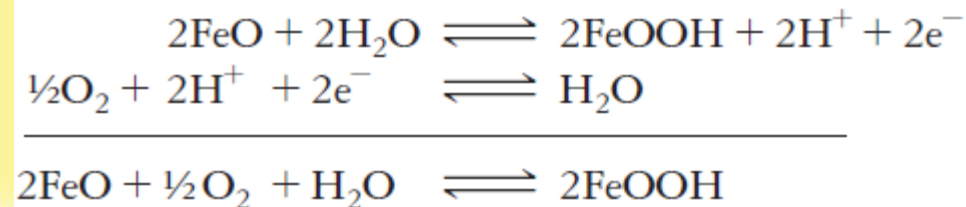
- As reaction proceeds to the right, each Fe(II) loses an electron (e^-) to become Fe(III) and forms H^+ ions by hydrolyzing H_2O . These H^+ ions lower the pH.
- When the reaction proceeds to the left, FeOOH acts as an electron acceptor and the pH rises as H^+ ions are consumed.
- The tendency or potential for electrons to be transferred from one substance to another in such reactions is termed the redox potential (Eh)
- Eh measured by platinum electrode attached to a millivolt meter

Redox potential: influence of O₂

- Living organisms release electrons while oxidizing carbon for energy
- O₂ acts as an acceptor of these electrons (**oxidizing agent**)
- O₂ is in turn reduced
- Once all O₂ is depleted by this process, anaerobic zone created

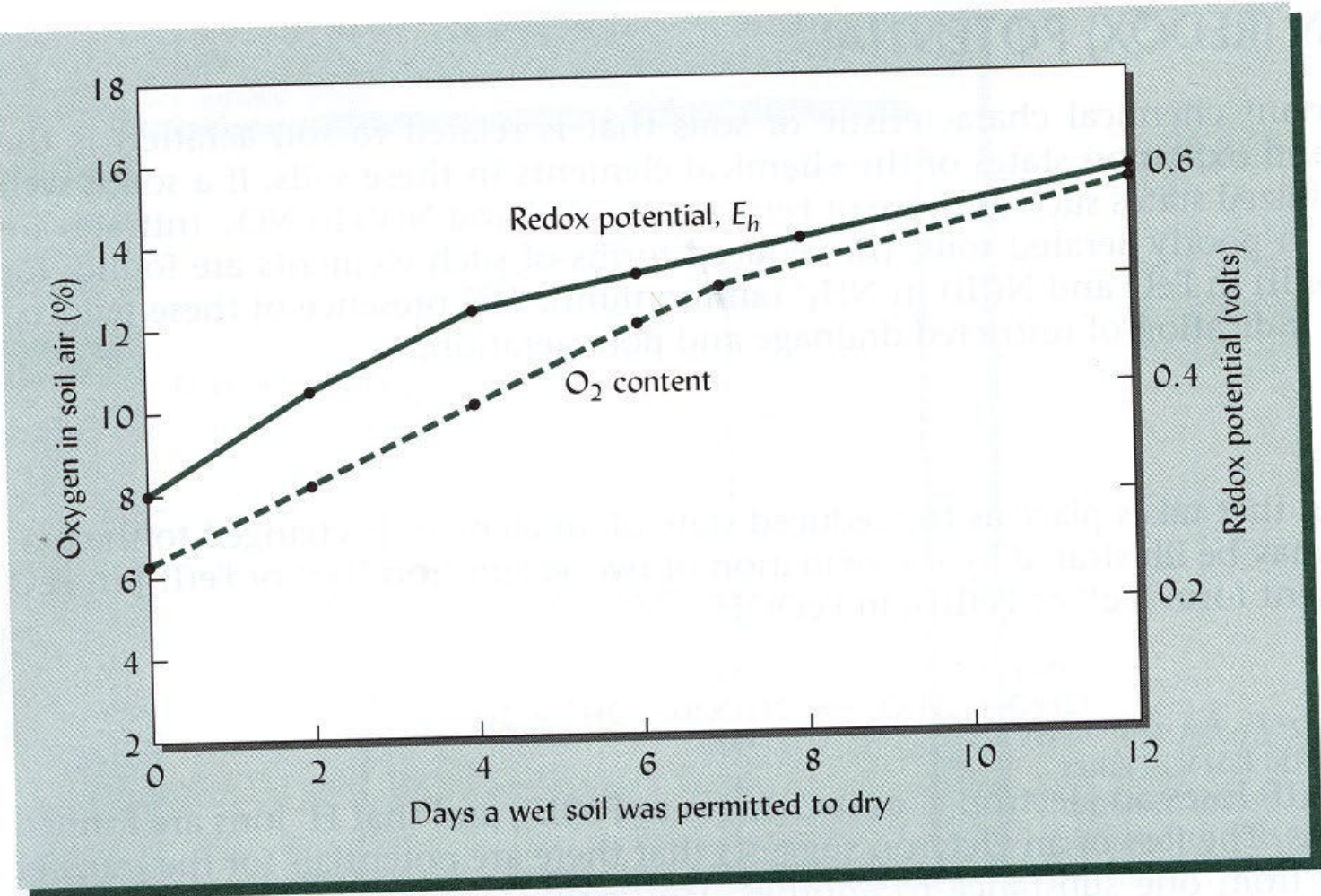


overall effect of oxidation and reduction

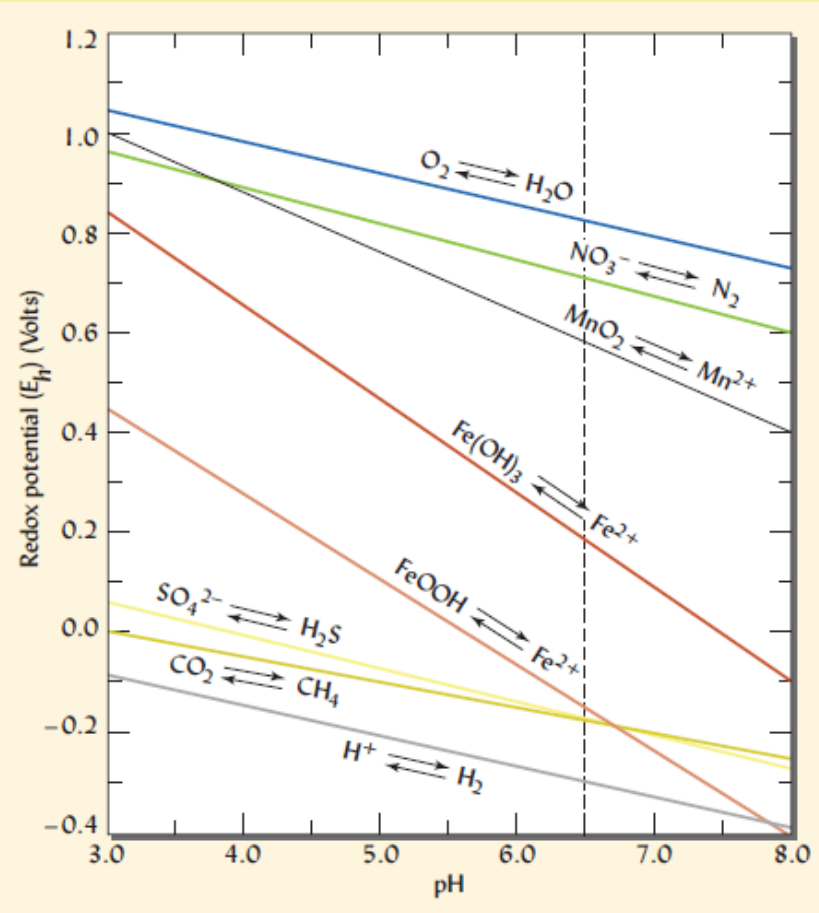


Redox potential: influence of O₂

- ❑ In a well-aerated soil with plenty of gaseous O₂, the Eh is in the range of **0.4–0.7 volt (V)**.
- ❑ As aeration is reduced and gaseous O₂ is depleted, the Eh declines to about **0.3–0.35 V**.
- ❑ If organic matter–rich soils are flooded under warm conditions, Eh values as low as **-0.3 V** can be found.



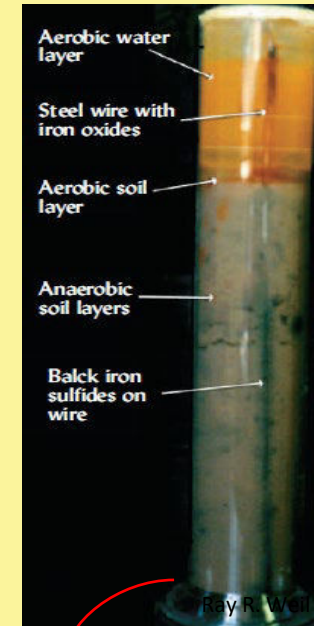
Relative order of reduction in redox reactions



Modified from McBride (1994);
used with permission of Oxford University Press

Element	Oxidized form	Charge on oxidized element	Reduced form	Charge on reduced element	E_h at which change of form occurs, V
Oxygen	O_2	0	H_2O	-2	0.38 to 0.32
Nitrogen	NO_3^-	+5	N_2	0	0.28 to 0.22
Manganese	Mn^{4+}	+4	Mn^{2+}	+2	0.22 to 0.18
Iron	Fe^{3+}	+3	Fe^{2+}	+2	0.11 to 0.08
Sulfur	SO_4^{2-}	+6	H_2S	-2	-0.14 to -0.17
Carbon	CO_2	+4	CH_4	-4	-0.20 to -0.28

E_h values from Patrick and Jugsujinda (1992).



Oxidized zone

Reduced zone

- Reactions occur from top to bottom order
- Anaerobic organisms must use electron acceptor other than O_2
- Example : iron is used here which is reduced to iron sulfide (black color)

Factors affecting soil aeration

1. Drainage of excess water

- Drainage of gravitational water out of the profile and concomitant diffusion of air into the soil takes place most readily in macropores
- Dependent on soil texture, bulk density, organic matter content etc

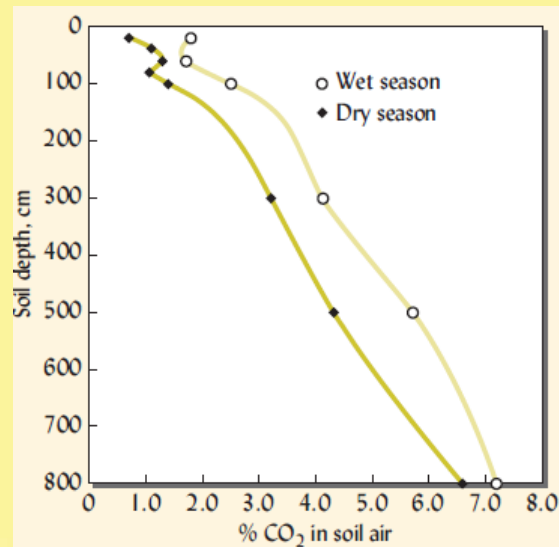
2. Rates of respiration in soil

- Depends on organic matter content
- More the organic matter, more the microbes use them and release gases into the soil

Factors affecting soil aeration

3. Soil profile

- O_2 tends to decrease with depth
- CO_2 increases with depth



4. Soil heterogeneity

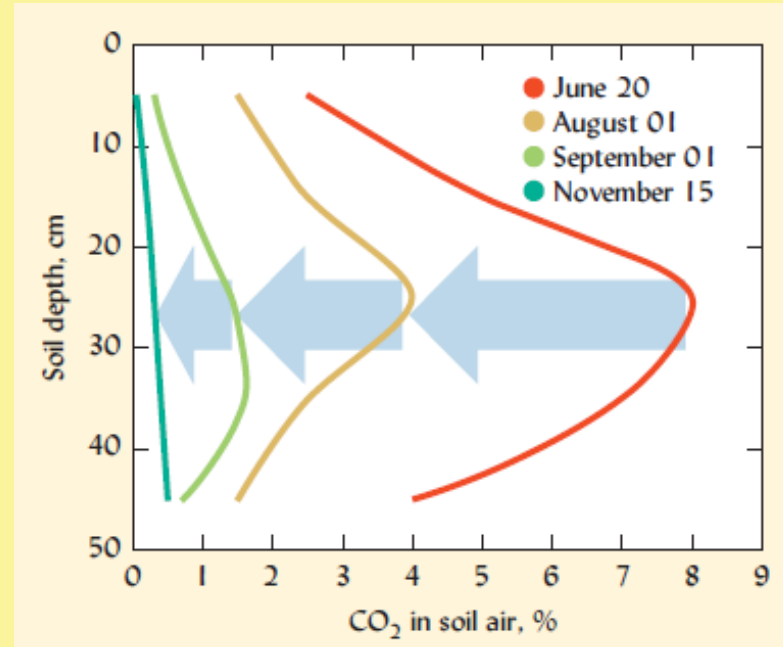
- Long term tillage reduces aeration
- Clay soil has less aeration
- Interped zones have more aeration than within peds

5. Seasonal differences

❑ Poor aeration in wet seasons

6. Effects of vegetation

❑ Vegetation transpires, lowers the ground water table, improves aeration



Buyanovsky and Wagner (1983); used with permission of the Soil Science Society of America

Ecological effects of soil aeration

1. Effects on organic residue degradation

- ❑ More O₂, more the decay of organic matter
- ❑ Entire soil property depends on soil aeration

2. Oxidation reduction of elements

Element	Normal form in well-oxidized soils	Reduced form found in waterlogged soils
Carbon	CO ₂ , C ₆ H ₁₂ O ₆	CH ₄ , C ₂ H ₄ , CH ₃ CH ₂ OH
Nitrogen	NO ₃ ⁻	N ₂ , NH ₄ ⁺
Sulfur	SO ₄ ²⁻	H ₂ S, S ²⁻
Iron	Fe ³⁺ [Fe(III) oxides]	Fe ²⁺ [Fe(II) oxides]
Manganese	Mn ⁴⁺ [Mn(IV) oxides]	Mn ²⁺ [Mn(II) oxides]

Ecological effects of soil aeration

- ❑ Oxidized zones have red colors while reduced zones have grey, blue colors
- ❑ Anaerobic conditions causes emission of green house gases CH_4 and N_2O

3. Effects on activities of higher plants

- ❑ Poor aeration affects shoot growth more than root growth
- ❑ Different plants have different degree of tolerance to waterlogging
- ❑ Low aeration also affects the nutrient uptake by plants

Fick's law

The diffusion process can be described by Fick's law

$$q_d = -D \frac{dc}{dx}$$

q_d = diffusive flux (mass diffusing across a unit area per unit per unit time)

D = diffusion coefficient (area per time)

c = concentration (mass of diffusing substance per volume)

x = distance, and

$\frac{dc}{dx}$ = the concentration gradient

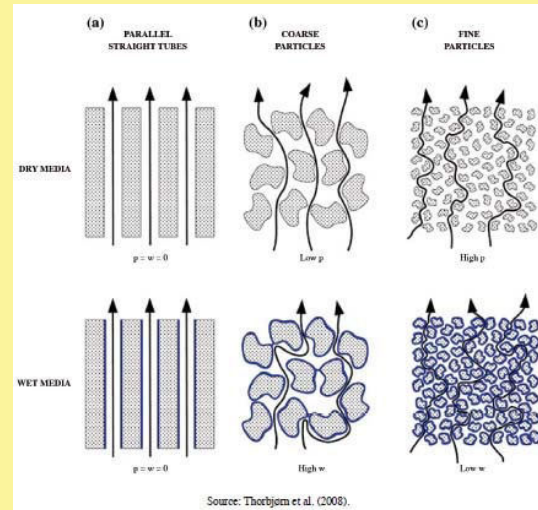
If partial pressure p is used instead of concentration of the diffusing component, we get $q_d = -(D/\beta)(dp/dx)$

β = ratio of the partial pressure to the concentration

Fick's law

Considering first the diffusive path in the air phase,

- the diffusion coefficient in the soil D_s must be smaller than that in bulk air D_0 owing to the limited fraction of the total volume occupied by continuous air-filled pores and also to the tortuous nature of these pores
- D_s to be some function of the air-filled porosity, f_a .



Fick's law

- Different workers have over the years found different relations between D_s and f_a for various soils. For instance, Buckingham (1904) reported the following nonlinear relation: $D_s / D_0 = K f_a^2$
- Penman (1940) found a linear relation : $D_s / D_0 = 0.66 f_a$

0.66= tortuosity coefficient, suggesting that the apparent path is about 2/3 the length of the real average path of diffusion in the soil

Reference:

- ❑ **The Nature and Properties of Soils by Nyle C. Brady and Ray R. Weil**