**SOIL AIR AND AERATION**

Soil Air

Soil is a three-phase, porous media, composed of solids, liquids, and gases.

**Soil air** can be defined as the air that fills the soil pore spaces not occupied by water.

That is the gaseous phase of the soil not occupied by solid or liquid.

Soil Air Composition

| *Air Composition* | *Atmosphere* | *Soil* |
|---|---|---|
| Oxygen | 21% | < 20% (10.35 – 20.03) |
| Carbon Dioxide | 0.035% | > 0.035% (0.10 – 20.0) |
| Nitrogen | 78% | 78% |
| Argon | 0.94 | |
| Hydrogen | 0.01 | |

Gaseous Composition of Soil Air

**Oxygen**

- Soil air is consistently lower in oxygen
- The oxygen content may be only slightly below 20% in the upper layers of a soil
- Wet soils typically have low oxygen contents.
- Once the supply of oxygen is virtually exhausted, the soil environment becomes anaerobic

- Drastic reductions in the oxygen content of soil air may occur following a heavy rain.

**Carbon dioxide**

- Carbon dioxide typically increases in soil air.
- Carbon dioxide may become toxic to plants when it is as high as 10% in soil air.

**Other Gases**

- Soil air is usually higher in water vapour than in the atmosphere.
- Under waterlogged conditions, the concentrations of methane ($CH_4$), and hydrogen sulphide ($H_2S$) are particularly higher in soil air.
- Ethylene ($C_2H_4$) gas, a product of anaerobic microbial metabolism is toxic to plant roots, even in very small concentrations.

<u>Soil Aeration</u>

**Definition**: Soil aeration is the ability of soil to exchange gases with the atmosphere. This involves the rate of ventilation, composition of soil air, proportion of pore space filled with air, and redox reaction potential.

<u>Poor Soil Aeration</u>

1. This refers to a condition in which the availability of oxygen in the root zone is insufficient to support optimal growth of most plants and aerobic microorganisms.
2. Poor aeration becomes a serious impediment to plant growth when more than 80 to 90% of the soil pore space is filled with water, leaving less than 10 to 20 % of the pore space filled with air.

3. The high soil water content not only leaves little pore space for air storage but, more important the water blocks the pathways by which gases could exchange with the atmosphere.

<u>Water Saturated (Waterlogged) Conditions</u>

- The soil is said to be ***water saturated*** or ***waterlogged*** when all or nearly all of the soil pores are filled with water. Such conditions occur naturally in wetlands.
- Plants adapted to grow in waterlogged soils are known as ***hydrophytes*** (water-loving plants), e.g., grasses and rice. Respiration is via hollow structures in their stems and roots known as ***aerenchyma tissues.***
- When oxygen becomes depleted, soil conditions are said to be ***anaerobic***. Methane, hydrogen sulphide, and ethylene are often evolved under these conditions.

<u>Adverse Effects of Suboptimal Aeration on Plants and Soils</u>

1. Morphologic structure (e.g., Thin cell walls in root; Suppression of root hair formation)
2. Physiologic function (e.g., Decline in pH of plant sap; Reduction in transpiration rate)
3. Induced chemical/biochemical reactions (Denitrification; Manganese reduction; Iron reduction; Organic matter reduction).

<u>Factors Affecting Soil Aeration</u>

- Texture
- Bulk density
- Aggregate stability
- Organic matter content

- Biopore formation
- Soil heterogeneity –(tillage)
- Seasonal differences
- Vegetation

Mechanisms for soil aeration

**Mass flow:** This mechanism is dependent upon overall pressure gradients and is thus affected by soil water content, wind, and changes in barometric pressure.

**Diffusion:** Gases moves in the direction determined by its partial pressure. Consequently, the higher concentration of oxygen in the atmosphere will result in a net movement of this particular gas into the soil. Carbon dioxide and water vapour normally move in the opposite direction, since the partial pressure of these two gases are generally higher in the soil air than in the atmosphere.

**Soil Temperature and thermal properties**

Temperature is a measure of the thermal state of a body with respect to its ability to transfer heat.

Soil temperature affects:

- Soil (physical, biological and chemical processes occurring in the soil)
- Growing plants

Soil Processes Affected by Variation in Soil Temperature

a. In cold soil, rate of chemical and biological reactions are slow.

b. Microbial activities are slowed down at low temperatures, which bring biological decomposition to near standstill.

c. Absorption and transport of water and nutrients ions by higher plants are inhibited by low temperatures.

d. Plants and microbial processes are also inhibited by too high temperature.

e. Seed germination is most sensitive to soil temperature.

Solar Radiation

The primary source of energy to heat soils is the solar radiation from the sun.

Factors influencing the amount of solar radiation

- **Albedo –** This is the fraction of incident radiation that is reflected by the land surface.
- **Aspect –** The angle at which the sun's rays strike the soil
- **Rain/Irrigation water –** affect the soil temperature.
- **Soil Cover –** depends on whether the soil is bare, or is covered with vegetation or mulch.

Soil Thermal Properties

- Specific heat (heat capacity) **:** This is the amount of energy required to raise the temperature of a substance by $1^{o}C$.

  Unit - (cal/g) or joules per gram (J/g)
- Thermal Conductivity: The amount of heat transferred through a unit cross-sectional area of unit thickness in unit time and unit temperature gradient.
- Thermal Diffusivity: Temperature change that takes place in a portion of a given soil as heat flows into it from adjacent layer.

Mode of Heat Transfer

- Conduction – Flow of heat through matter unaccompanied by any motion

- Convection – The transfer of heat by moving matter.
- Radiation – The transfer of heat through vacuum / space

Modification of soil thermal regime  Most of the methods are aimed at modifying the surface intake / loss of heat.

- Mulch
- Tillage
- Irrigation
- Drainage
- Weed control
- Plants/trees.

**Energy balance of soil**

Net radiation is the sum of all incoming minus all outgoing radiation on Earth's surface.

Steady state one-dimensional heat energy balance at the soil surface or crop canopy can be written as:

*Net heat energy arriving at surface − net heat energy leaving surface = 0*

The net radiation received by the soil surface is transformed into heat, which warms soil and air and vaporizes water.

Calculating the Specific Heat of Moist Soils

$$c_{moist\ soil} = \frac{c_1 m_1 + c_2 m_2}{m_1 + m_2} \quad c_{moist\ soil} = \frac{c_1 m_1 + c_2 m_2}{m_1 + m_2}$$

Where $c_1$ and $c_2$ are specific heat of the two substances and $m_1$ and $m_2$ are mass of the substances.

Specific heat: Water = 1.0 cal/g; dry mineral soil = 0.2 cal/g

## SOIL WATER

### Properties of Water Which Are Relevant to its Behavior in Porous Media

Water is the most common of all liquids, and it is indispensable for life. It accounts for 60-95% of the material in all organisms and it is a means of transporting nutrients dissolved or suspended in it to all parts of plants and other biological and porous bodies like soil. Water is thus a solvent to make solutions or suspension.

***In a solution,*** a chemical species (the solute) breaks up into its molecules or into portions of its molecules when it is added to a pure liquid (the solvent) and the result is a homogenous solution in which it is impossible to detect the physical presence of the solute**.** *In a suspension,* one substance made up of the very small particles is present in a pure liquid, but the particles are a size that makes them physically distinguishable from the liquid. As the size of the particles in a suspension is reduced, we reach a state referred to as *the colloidal state*, which is half way between the true solution and a true suspension.

### Soil Water Content and Potential

Quantity of water in soil is expressed by gravimetric or volumetric water content. However, water can also be characterized by describing its free energy per unit mass, which is termed potential. The tenacity with which water is held in soil solid is characterized by matric or pressure potential. When volumetric water content and matric potential are plotted graphically, the relationship is termed *Soil Moisture Characteristic Curve*.

When all soil pores are filled with water, the soil is at its maximum retentive capacity called saturation. In the field, the lowest wetness you can observe is called air-dryness and in the laboratory it is called oven-dry condition.

$w = M_w/M_s$

$\theta = V_w/V_t = V_w/(V_s + V_w + V_a)$

$\theta = w(\rho_b/\rho_w) = w\Gamma_b$

where Γ (capital letter of gamma) is the bulk specific gravity of the soil. The conversion of w to θ is easily done in son-swelling soil where soil bulk density does not change with wetness.

Application of soil water by irrigation or rainfall is reported as the depth of water if it were accumulated in a layer. This indicates the equivalent depth, $d_w$, soil water would have if it were ponded over the surface

$d_w = \theta d_t = w\Gamma_b d_t$

$d_t$ is depth of soil per unit area

Usually dw is given in mm, as rainfall and evaporation

To obtain the volume of water applied to a given area would require multiplication of the depth by the area, measured in the same length units.

**Water Potential**

The International Soil Science Society defines total potential of soil water as "the amount of work that must be done per unit quantity of pure water in order to transport reversibly and isothermally an infinitesimal quantity of water from a pool of pure water at a specified elevation at atmospheric pressure to the soil water(at the point under consideration". Soil water is subject to a number of force fields, which cause its potential to differ from that of pure, free water. Each of these forces is a component of the total soil water potential and they result from the attraction of the solid matrix for water, as well as from the presences of solutes and the action of external gas pressure and gravitation. Thus, the total potential $\Phi = \phi_g + \phi_w + \phi_o + \phi_a + \phi_e$

is the summation of the component potentials:

where - $\phi_g$ = gravitational potential

$\phi_w$ = is the soil water potential

$\phi_o$ = Osmotic potential owing to the difference in chemical composition of the soil solutiom related to free, pure, bulk water at the same elevation.

$\phi_a$ = pneumatic potential which accounts for air pressure inside the soil pores being different from the outside atmospheric air pressure acting upon the reference water

$\phi_e$ =envelope potential. When an external mechanical pressure such as the overburden pressure of the topsoil layers acts upon the soil, the magnitude of change of the total potential is expressed by the envelope potential, which is usuall negligible for sandy soils and becomes more important for soils having greater clay contents.

In the majority of situations, the simplest definition of the total potentasl is

$\Phi = \phi_w + \phi_g$

and with the potential expressed as energy per unit weight of water

$H = h + z$

Thus, the total potential head of soil water (H) is the sum of the pressure potential head (h) and gravitational potential head (z). H is commonly called hydraulic head.

**Hysteresis**

The relationship between soil water content and potential, determined as soil dries out, will differ somewhat from the relationship measured as the soil is rewetted. This phenomenon describing the dependence of the equilibrium content and state of soil water upon the direction of the process leading up to it is called hysteresis.

**Available soil water**

Soil Water is classified according to how "tightly" it is being held in the Soil.

Free water or gravitational water will drain from a soil until the soil water potential reaches **-1/3 bar**. This is called **field capacity**. Gravitational water is not considered available to plants because it is in the soil only a short time and reduces oxygen levels to the point where the plant will not be absorbing water anyway.

As the soil continues to dry--or water is used by plants--more and more energy is needed by the plants to remove the water. Eventually a point is reached where the plant can no longer remove water. This is called the **wilt point** and occurs at -15 bars water potential for most plants. From **-1/3 to -15** bars is the zone of **available water.**

If the soil dries to an **air dry** state, the potential is **-31** bars. (This assumes that the air has 100% relative humidity.) Plants cannot exert enough tension to pull water away from the soil. Tension is used to express water potential with positive numbers. So a tension of +15 bars equals a potential of -15 bars.

Additional drying requires putting the soil in an oven to drive off the tightly held water. Water is held in the soil like a series of beads, the farther the beads are from the soil particle, the weaker they are held by cohesion

**Water flow in saturated soil**

Soil pores are highly irregular, tortuous and intricate with the consequence that the geometry of the pores restrict flow of water compared to what it would have been in straight tubes. However, the detailed flow pattern of water in soil is ignored, and it is treated as if it were a uniform medium, with flow spread over the entire cross section. The movement of water through a porous system occurs whenever there is a difference in potential energy of water within the porous matrix. The water content in a saturated soil system does not change during flow and only positive potentials are the driving force during the water transport.

**Water flow in unsaturated soil**

Unsaturated flow of water is a more commonly prevailing condition in the field than saturated flow. An unsaturated soil zone, or vadose zone, provides a continuum of water unsaturated subsurface porous media connecting the soil/atmospheric interface and underlying saturated groundwater zone. It has several functions including:

(i) storage of water and nutrients, and

(ii) transmission of water and other substances.

The storage of water and nutrients is vital to the biosphere, and the water transmission is important for replenishing the aquifers. Unsaturated flow conditions are more complex and very often do not have direct solutions. Instead indirect methods, approximations, and numerical methods are more commonly used in the solution of unsaturated flow problems.

The fundamental driving forces in both saturated and unsaturated flow are the potential gradient and hydraulic conductivity. As a stream of water is passed through the unsaturated soil matrix, the incoming water replaces the air present in the soil pores; it increases the total volume of water inside the soil, thus increasing the moisture content *($\vartheta$)* of soil. This agrees with the fundamentals of continuity equation, which states that the difference in the inflow and outflow rate is equal to the change of water storage in soil. The gradient causing flow in unsaturated soils is of negative pressure potential. The flow paths in unsaturated flow are more tortuous as several pores are filled with air

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Table 1. Some differences between saturated and unsaturated flow

| Parameter | Saturated flow | Unsaturated flow |
|---|---|---|
| Water content | Constant | Variable over space and time |
| Air content | Zero (close to zero) | Variable over space and time |
| Potential gradient | Positive and constant | Negative and variable |
| Hydraulic conductivity | Maximum, constant | Low and variable |
| Water flow | Steady | Steady as well as unsteady |
| Flow paths | Continuous | Tortuous |

Source – Lal and Shukla, 2004

**Solute transport and water quality**

When water flows on soil surface as overland flow and/or through the soil matrix, it also dissolves solutes (e.g., salts, fertilizers, pesticides). These solutes not only move with soil water but also within the soil matrix mainly due to the concentration gradients. Sometimes, solutes react among themselves and/or with soil material according to a range of physical and chemical processes. In agricultural ecosystems, solutes may be categorized on the basis of their function (e.g., nutrients, pesticides, waste compounds, salts, organic chemicals, and heavy metals). Understanding transport of solutes in soil is important to many management problems in agriculture. It can help when developing procedures for maximizing the effective use of fertilizers or pesticides and other chemicals within the root zone while minimizing their movement into groundwater, so as to safeguard water quality. Knowledge of these processes is important to understanding the problems of contamination of natural water through leaching or redistribution within a vadose zone to groundwater.