DEFINITION OF SOIL PHYSICS

Soil Physics is a branch of soil science that deals with physical properties of soil as well as measurement, prediction and control of physical processes taking place in and through the soil. Soil physical properties include soil texture, soil structure, soil colour, consistency, density thermal regime, soil water, porosity, infiltration, hydraulic conductivity etc.

Soil Physics could fundamentally be regarded as both basic and applied sciences. This is because, Soil Physics involves application of the principles of Physics to the characterization of soil properties and understanding of soil processes involving transport of matter or energy.

SOIL PRODUCTIVITY

Soil productivity is an economic concept and signifies the capability of the soil to produce specified plant or sequence of plants under well defined specified systems of management and environmental conditions. This suggests that productivity is not soil fertility alone but a function of several factors (e.g. climatic condition and soil factors). Soil productivity is measured in terms of output or harvest.

On the other hand, soil fertility refers to the inherent capacity of the soil to provide adequate amount and proper balance of nutrient for the growth of specified plant when other growth factors (e.g. light, water, temperature and favourable soil physical environment) are favourable.

In addition to chemical fertility i.e. presence of adequate nutrient in the soil and absence of toxic agents, the soil should also, be physically fertile. That is, the soil must be loose, soft and friable, possesses no mechanical impedance to root development, has pore volume and size distribution that allow entering, movement and retention of water and air to meet plant needs and has optimal thermal regime.

SOIL AS A DISPERSED SYSTEM

Soil is made up of 4 basic components: mineral matter; organic matter, soil water and soil air.

On the basis of these, there are three phases in the soil. These are solid phase, liquid phase and gaseous phase.

The dispersed nature of the soil and its constituent inter-phasal activities give rise to such phenomenon as:

adsorption of water and chemicals; ion exchange; adhesion and cohesion; dispersion and flocculation; swelling and shrinking and capillarity.

SOIL TEXTURE

Soil texture is the relative proportion of various soil separates in a soil. It is usually expressed on percentage basis.

The main textural classes are sand, silt and clay. These textural classes may be modified by addition of suitable adjective based on relative amount of each separate that make up the soil

Determination of Soil Texture

Soil texture may be determined on the field by textural feel and in the laboratory by soil mechanical analysis or soil particle size distribution. The mechanical analysis in the laboratory may be carried out either by Pipette or hydrometer method.

After the proportion of each of the soil separates are determination, the textural class of the soil is identified using a USDA Soil Textural Triangle.

Importance of soil texture

- It affects water and nutrient holding capacity of the soil

- It influences the type of crop to be grown

- It indicates type of management needed for crop growth and for engineering purposes.

- **Mechanical composition of soil**

- The mechanical composition of soil is a basic requirement in the soil physical investigation useful for land capability classification and in the study of soil morphology, genesis, classification and mapping.

- Soil mechanical analysis is the procedure for determining the particle size distribution of a soil sample.

Steps in soil mechanical analysis

- ❖ Sample collection
- ❖ Air dry the sample at room temperature
- ❖ Dispersion of the sample in an aqueous solution using Calgon solution (Sodium hexametaphosphate).
- ❖ If the sample contains high amount of organic matter remove the organic matter using H_2O_2.
- ❖ Carry out mechanical agitation by shaking or using ultrasonic vibration
- ❖ Determination/quantification of size fraction

(1) Sieving (for coarse fraction) – use net of sieve corresponding to the desired particle size

(2) Sedimentation (fine fraction)

The principles of sedimentation are that the velocity of fall of particle in a viscous medium is influenced by

(i) the viscosity of the medium

(ii) density difference between the medium and the falling particle

(iii) the size and shape of the material.

The law which govern sedimentation of particles is called Stoke's Law which states that resistance offered by liquid to the fall of a rigid spherical particles vary with the circumference of the sphere (and not its surface) **OR** the terminal velocity of a spherical particle settling under the influence of gravity in a fluid of a given density and viscosity is proportional to the square of the particle radius.

The Stokes' law consists of the factors contributing to the cause of settling and resistance to settling.

SURFACE RELATIONSHIP

The extent of the surface of dispersed soil system is described in terms of the soil specific surface.

The soil specific surface is defined as the sum of the surfaces of constituent dispersed soil particles referred to unit mass or unit volume.

$$\text{Specific surface of soil } (A_m) \text{ or } (A_v) = \frac{\text{Total surface area of soil } (A_s)}{\text{Mass or volume of soil } (M_s \text{ or } V_s)}$$

That is, $A_m \text{ or } A_v = \dfrac{A_s}{M_s \text{ or } V_s}$

Therefore, on mass basis $A_m = \dfrac{A_s}{M_s}$ $\dfrac{cm^2}{g}$ or $\dfrac{m^2}{g}$ or $\dfrac{m^2}{kg}$

On volume basis, $A_v = \dfrac{A_s}{V_s}$ $\dfrac{cm^2}{cm^3}$ or $\dfrac{m^2}{cm^3}$

Soil specific surface depends on: i. Particle size ii. Particle shape iii. Mineralogy of the materials

cle size ii. Particle shape iii. Mineralogy of the materials

Based on the diagram above, a quantitative representation of the 3 phases can be expressed in terms: Particle density, Bulk density, Total porosity, Void ratio, Degree of saturation and Air filled porosity. Others are soil wetness: This can be expressed relative to total mass or total volume.

In term of mass: mass wetness, called gravimetric water content

SOIL STRUCTURE

Soil structure is the arrangement of soil particles to form peds. Or, the arrangement of primary particles into secondary particles (aggregate).

Soil structure is strongly affected by changes in climate, biological activities and soil management practices.

Measurement of soil structure

There are direct and indirect methods of measuring soil structure.

The direct method involves measuring the size and shape of aggregate and pores of the soil. That is, three dimensional study of soil. This is done by thin section analysis with aid of powerful microscope e.g. scanning electron microscope, transmission microscope, petrographic microscope etc.

The indirect methods involve measuring soil properties that depend on soil structure. These properties include: aggregate size distribution, aggregate stability, bulk density, porosity, pore size distribution, permeability, infiltration etc.

Importance of soil structure

- It affects water and nutrient holding capacity of the soil
- It affects germination and root growth and development
- It affects water retention and transmission of fluid in soil
- It affects soil aeration
- It influences soil thermal properties

Measurement of soil structural stability

There are various methods: the two common methods that will be considered are sieving method and water drop impact technique

1. Sieving method: there are wet and dry sieving techniques. What is measured here is the Mean weight diameter (MWD). For wet soil it is called MWDW and for dry soil it is called MWDD

The formula is given as

$$MWD = \sum_{i=1}^{n} X_i W_i$$

Where X = mean of diameter of particles size range separated by sieve

W*i* = weight (proportional) of the aggregates in each size range

2. **Water drop technique:** this is done by studying the impact of rain drop on soil aggregate stability. This is done in the laboratory by using a rainfall simulator.

SOIL WATER

Soil water is the amount of water present in the soil available to crop. Water can enter into the soil by precipitation or by irrigation.

Forms in which water exist in the soil

Water exists in 3 forms in the soil

(i.) Hygroscopic water (ii.) Capillary water (iii.) Gravitational water.

Importance of water to crop

i. It is important in the absorption of mineral salts from the soil by plant.

ii. It helps in the transportation of plant nutrients from the root to other parts of the plant.

iii. Water is an essential raw material needed during photosynthesis.

Some terminologies in soil water include

The hydrologic cycle: Hydrologic cycle is the set of processes by which water moves through different reservoirs on earth. The hydrologic cycle can be thought of as a series of reservoirs, or storage areas, and a set of processes that cause water to move between those reservoirs. The largest reservoir by far is the oceans (Anne, 2003).

Water balance is an accounting of all water volumes that enters and leave a 3-dimensional space over a period of time (Burt, 1999).

The water balance equation is given as:

$\Delta W = P - (O + U + E_t)$. Where ΔW is change in water content between sampling; P is precipitation; O is the runoff; U is deep drainage and E_t is evapotranspiration.

Water content is the amount of water present in the soil. This is usually expressed as a percentage of oven dried weight of soil volume.

Water retention: The spaces that exist between soil particles, called pores, provide for the passage and/or retention of gasses and moisture within the soil profile. The soil's ability to retain water is strongly related to particle size; water molecules hold more tightly to the fine particles of a clay soil than to coarser particles of a sandy soil, so clays generally retain more water (Leeper and Uren, 1993).

Field capacity is the water content after the force of gravity has drained or removed all the water it can. FC is considered the upper limit of plant-available water (PAW).

Permanent wilting point (PWP): is the water content at which healthy plants can no longer extract water from the soil fast enough to recover from wilting. The PWP is considered the lower limit of PAW (Evans et al., 1996)

Ways by which soil loss water

i.) evaporation from the soil surface ii.) Transpiration from plant leaves, stem and fruit surface.

iii. drainage iv.) erosion

Sources of water in the soil

i.) Precipitation ii.) Irrigation iii.) High humidity

Methods of determining soil water content

1. Gravimetric method 2. Volumetric method 3. Neutron scattering technique

4. Gamma ray attenuation technique 5. Electric resistant method

6. Time domain reflectomery 7. Tensiometry method

Method of expressing soil water content

1. On mass basis 2. On volume basis 3. On depth basis

Forces acting on soil water

1. Matric force 2. Osmotic force 3. Body force

Water flow in soil

Flow of water in soil may take the following forms:

1. Saturated flow: this is when soil pores are filled with water. This normally occur immediately after rainfall or irrigation. The flow of water in this state is influenced by factors such as soil, fluid and moving forces. The soil factor is termed permeability, the fluid factor is termed fluidity while the moving force is known as the hydraulic gradient.

2. Unsaturated flow: Unsaturated flow is expectedly slower than the saturated flow and it takes place under normal field condition. The driving force under this flow is the suction gradient where water moves from the zone of lower suction (high water content) to a zone of high suction (low water content).

3. Vapour movement: Vapour pressure in soil varies with temperature. Therefore, under considerable temperature gradient, water vapour may move from warmer zone of the soil and condense at the cooler zone.

Energy balance

Net radiation is the sum of all incoming minus all outgoing radiation on the earth surface. According to Lal and Shukla (2004) 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. The total surface energy balance can therefore be given as:

$(1-\alpha)Rs + R_{nt} - (H_c + J_H + L_*E) = 0$

Where α is albedo, Rs is global solar radiation, R_{nt} is net long-wave thermal radiation, H_c convective heat flux, J_H is the vertical transport of heat into the soil, L_*E is the evaporation and subsequent transport of water from the soil surface.

Conservation tillage

Tillage practices that leave a high percentage of the residues from previous crops on the soil surface is referred to as conservation tillage. Examples include, stubble mulching, zero or no tillage system.

<u>Soil Air and Aeration</u>

- **Soil air -** is the air that fills the soil pore spaces not occupied by water. The gaseous phase of the soil not occupied by solid or liquid.

- **Soil aeration -** is the process of exchange of oxygen and carbon dioxide of soil air with the atmosphere.

Soil Air Composition

Soil Air Composition

Gas	Atmosphere (%)	Soil air (%)
Oxygen	21	10 to 20
Carbon dioxide	0.03	0.10 to 5
Nitrogen	78	78.8 to 80
Argon	0.94	
Hydrogen	0.01	

Factors Influencing Soil air Composition

i. Organic matter content ii. Microbial activity iii. Plant root respiration

iv. Texture v. Structure vi. Water content vii Crops

viii Drainage ix. Tillage x. Season

Soil Air Capacity

Definition:

– Is the fractional volume of air in the soil at field capacity.

– That is the quantity of air in the soil after soil has been saturated and allowed to drain for about twenty-four (24) hours.

Poor Soil Aeration

Poor soil aeration has adverse effects which could result in certain changes that are –

1. Morphological 2. Physiologic

3. Anaerobic conditions in soil induce series of reduction reactions

Soil Thermal Properties

Soil thermal regime determines:

1. The rates and directions of some physical processes.

2. The rates of energy and mass exchange with the atmosphere.

3. Governs the type and rates of chemical reactions taking place in the soil e.g. weathering.

4. Influences biological processes such as:

i) Microbial activity ii) Soil germination iii) Plant growth

Major Aspects Of Soil Thermal Regime

The major aspects which characterize the soil thermal regime are:

1. Soil heat intensity: This describes mainly the soil temperature (˚C, degree Celsius; K, Kelvin).

2. Soil heat capacity (gravimetric): The amount of heat required to raise the temperature of a given mass by one degree Celsius (1˚C)

Mode of Heat Energy Transfer in Soil

Mode of heat energy transfer in soil include:

i) Conduction – This is the primary mode of heat transfer in soil.

ii) Convection iii) Radiation

Factors Influencing soil Temperature Variation

1. Factors that influence the amount of heat available at the soil surface are:

i) Soil colour ii) Soil mulch

2. Factors that influence dissipitation of available heat (i) Water content of the soil

Types of Soil Temperature Variation

1. Diurnal 2. Seasonal 3. Variation due to soil depth

Solar Radiation

Solar Radiation is the major source of soil heat. Only a portion of the emitted solar radiation reaches the earth's surface. Part of the solar radiation may be:

1. Reflected by the clouds
2. Scattered into the atmosphere by atmospheric gases.
3. Absorbed by the ozone and water vapour.

Management of Soil Heat

These methods includes:

1. Covers 2. Mechanical manipulation of soil surface

3. Others (indirect effects) i) Irrigation – reduces temperature ii) Drainage – increases temperature iii) Weed control iv) Plants/trees

SOIL EROSION

Definition

Soil erosion can be simply defined as the wearing away of soil materials from place to place by the agents of erosion such as water, wind and ice.

In general soil erosion is broadly divided into

1. Geological Erosion

Soil erosion that occurs naturally, without the influence of human activities.

2. Accelerated Erosion

Soil erosion resulting from human interference with the natural environment.

Mechanics of Soil Erosion

a. **Detachment** of soil aggregates into particles

b. **Transportation** of the detached particle by floating, rolling, and dragging.

c. **Deposition** of the transported materials where the energy of force dissipates.

Soil erosion by water and wind erosion involves the three processes listed above. However, the method of soil movement in wind erosion defers.

Factors causing soil erosion

1. Climatic factor 2. Soil factors 3. Topography 4. Vegetation cover

5. Human activities e.g., *Tillage, Overgrazing, Fires, Lowering of the water table (water use in excess of replenishment rate)* - these accentuates wind erosion

Types of Soil Erosion by water

- **Sheet Erosion:** The removal of a fairly uniform layer of soil from the land surface by runoff water.

- **Rill Erosion:** As sheet flow is concentrated into tiny channels (*called rills*), rill erosion occurs.

- **Gully Erosion:** When the volume of runoff is concentrated, the rushing water cuts deeper into the soil, deepening and fusing the rills into larger channels called gullies.

Measurement of Soil Erosion by Water

The **Universal Soil Loss Equation** (USLE), was designed by Wischmeier and Mannering, (1969), to predict annual soil loss by water in the USA but has been adapted and modified in some cases for prediction around the world. The USLE equation is as follows:

$$A = R\ K\ L\ S\ C\ P$$

A - predicted soil loss (kg m^2 s^{-1}); R - rainfall erosivity

K - soil erodibility; L - slope length; S - slope gradient or steepness C - cover and management P - erosion control practices

Wind Erosion

Types of soil movement

1. Saltation 2. Soil Creep 3. Suspension

Factors affecting Wind Erosion

1. Wind velocity 2. Soil characteristics / properties 3. Vegetation / mulch

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