

Thermal properties of soils – Soil temperature – Soil air – Gaseous exchange – Influence of soil temperature and air on plant growth –

Thermal properties of soils

The thermal properties of soils are a component of soil physics that has found important uses in engineering, climatology and agriculture. These properties influence how energy is partitioned in the soil profile. While related to soil temperature, it is more accurately associated with the transfer of heat throughout the soil, by radiation, conduction and convection.

Main soil thermal properties:

Volumetric heat capacity, SI units: $\text{Jm}^{-3}\text{K}^{-1}$

Thermal conductivity, SI units: $\text{W.m}^{-1}\text{K}^{-1}$

Thermal diffusivity, SI units: $\text{m}^2.\text{s}^{-1}$

Soil temperature – Soil air – Gaseous exchange

Soil Temperature

Soil temperature is an important plant growth factor like air, water and nutrients. Soil temperature affects plant growth directly and also indirectly by influencing moisture, aeration, structure, microbial and enzyme activities, rate of organic matter decomposition, nutrient availability and other soil chemical reactions. Specific crops are adapted to specific soil temperatures. Apple grows well when the soil temperature is about 18°C, maize 25°C, potato 16 to 21°C, and so on.

Sources of soil heat

The sources of heat for soil are solar radiation (external), heat released during microbial decomposition of organic matter and respiration by soil organisms including plants and the internal source of heat is the interior of the

Earth - which is negligible. The rate of solar radiation reaching the earth's atmosphere is called as solar constant and has a value of $2 \text{ cal cm}^{-2} \text{ min}^{-1}$. Major part of this energy is absorbed in the atmosphere, absorbed by plants and also scattered. Only a small part of it reaches soil. Thermal energy is transmitted in the form of thermal infrared radiation from the sun across the space and through the atmosphere.

Factors affecting soil temperature

The average annual soil temperature is about 1°C higher than mean annual air temperature. Soil temperature is influenced by climatic conditions. The factors that affect the transfer of heat through the atmosphere from sun affect the soil temperature also.

Environmental factors

Solar radiation: The amount of heat received from sun on Earth's surface is $2 \text{ cal cm}^{-2} \text{ min}^{-1}$. But the amount of heat transmitted into soil is much lower. The heat transmission into soil depends on the angle on incident radiation, latitude, season, time of the day, steepness and direction of slope and altitude. The insulation by air, water vapour, clouds, dust, smog, snow, plant cover, mulch *etc.*, reduces the amount of heat transferred into soil.

Soil factors

a) Thermal (Heat) capacity of soil: The amount of energy required to raise the temperature by 1°C is called *heat capacity*. When it is expressed per unit mass (Calories per gram), then it is called as *specific heat*. The specific heat of water is 1.00 cal g^{-1} where the specific heat of a dry soil is 0.2 cal g^{-1} . Increasing water content in soil increases the specific heat of the soil and hence a dry soil heats up quickly than a moist soil.

b) Heat of vaporization: The evaporation of water from soil requires a large amount of energy, 540 kilocalories kg^{-1} soil. Soil water utilizes the energy from solar radiation to evaporate and thereby rendering it unavailable for heating up of soil. Also the thermal energy from soil is utilized for the evaporation of water, thereby reducing the soil temperature. This is the reason that surface soil temperatures will be sometimes 1 to 6°C lower than the sub-surface soil temperature. That is why the specific heat of a wet soil is higher than dry soil.

c) Thermal conductivity and diffusivity: This refers to the movement of heat in soils. In soil, heat is transmitted through conduction. Heat passes from soil to water about 150 times faster than soil to air. So the movement of heat will be more in wet soil than in dry soil where the pores will be occupied with air. Thermal conductivity of soil forming materials is 0.005 thermal conductivity units, and that of air is 0.00005 units, water 0.001 units. A dry and loosely packed soil will conduct heat slower than a compact soil and wet soil.

d) Biological activity: Respiration by soil animals, microbes and plant roots evolve heat. More the biological activity more will be the soil temperature.

e) Radiation from soil: Radiation from high temperature bodies (Sun) is in short waves (0.3 to 2.2 μ) and that from low temperature bodies (soil) is in long waves (6.8 to 100 μ) Longer wavelengths have little ability to penetrate water vapour, air and glass and hence soil remains warm during night hours, cloudy days and in glass houses.

f) Soil colour: Colour is produced due to reflection of radiation of specific wavelengths. Dark coloured soils radiate less heat than bright coloured soils. The ratio between the incoming (incident energy) and outgoing (reflected energy) radiation is called *albedo*. The larger the albedo, the cooler is the soil. Rough surfaced soil absorbs more solar radiation than smooth surface soils.

$$\text{Albedo} = \frac{\text{Reflected energy}}{\text{Incident energy}}$$

g) Soil structure, texture and moisture: Compact soils have higher thermal conductivity than loose soils. Natural structures have high conductivity than disturbed soil structures. Mineral soils have higher conductivity than organic soils. Moist soil will have uniform temperature over depth because of its good conductivity than dry soils.

h) Soluble salts: Indirectly affects soil temperature by influencing the biological activities, evaporation *etc.*

Soil Air

Soil air is a continuation of the atmospheric air. Unlike the other components, it is constant state of motion from the soil pores into the atmosphere and from the atmosphere into the pore space. This constant movement or circulation of air in the soil mass resulting in the renewal of its component gases is known as soil aeration. .

Composition of Soil Air: The soil air contains a number of gases of which nitrogen, oxygen, carbon dioxide and water vapour are the most important. Soil air constantly moves from the soil pores into the atmosphere and from the atmosphere into the pore space. Soil air and atmospheric air differ in the compositions. Soil air contains a much greater proportion of carbon dioxide and a lesser amount of oxygen than atmospheric air. At the same time, soil air contains a far great amount of water vapour than atmospheric air. The amount of nitrogen in soil air is almost the same as in the atmosphere.

Composition of soil and atmospheric air

Percentage by volume

Nitrogen	Oxygen	Carbon
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dioxide			
Soil air	79.2	20.60	0.30
Atmospheric air	79.9	20.97	0.03

Factors Affecting the Composition of Soil Air:

1. Nature and condition of soil: The quantity of oxygen in soil air is less than that in atmospheric air.

The amount of oxygen also depends upon the soil depth.

The oxygen content of the air in lower layer is usually less than that of the surface soil. This is possibly due to more readily diffusion of the oxygen from the atmosphere into the surface soil than in the subsoil.

Light texture soil or sandy soil contains much higher percentage than heavy soil.

The concentration of CO_2 is usually greater in subsoil probably due to more sluggish aeration in lower layer than in the surface soil.

2. Type of crop: Plant roots require oxygen, which they take from the soil air and deplete the concentration of oxygen in the soil air. Soils on which crops are grown contain more CO_2 than fallow lands. The amount of CO_2 is usually much greater near the roots of plants than further away. It may be due to respiration by roots.

3. Microbial activity: The microorganisms in soil require oxygen for respiration and they take it from the soil air and thus deplete its concentration in the soil air. Decomposition of organic matter produces CO_2 because of increased microbial activity. Hence, soils rich in organic matter contain higher percentage of CO_2 .

4. Seasonal variation: The quantity of oxygen is usually higher in dry season than during the monsoon. Because soils are normally drier during the summer months, opportunity for gaseous exchange is greater during this period. This results in relatively high O_2 and low CO_2 levels. Temperature also influences the CO_2 content in the soil air. High temperature during summer season encourages microorganism activity which results in higher production of CO_2 .

Exchange of Gases between Soil and Atmosphere

The exchange of gases between the soil and the atmosphere is facilitated by two mechanisms

1. Mass flow: With every rain or irrigation, a part of the soil air moves out into the atmosphere as it is displaced by the incoming water. As and when moisture is lost by evaporation and transpiration, the atmospheric air enters the soil pores. The variations in soil temperature cause changes in the temperature of soil air. As the soil air gets heated during the day, it expands and the expanded air moves out into the atmosphere. On the other hand, when the soil begins to cool, the soil air contracts and the atmospheric air is drawn in.

2. Diffusion: Most of the gaseous interchange in soils occurs by diffusion. Atmospheric and soil air contains a number of gases such as nitrogen, oxygen, carbon dioxide etc., each of which exerts its own partial pressure in proportion to its concentration.

The movement of each gas is regulated by the partial pressure under which it exists. If the partial pressure on one of the gases (i.e. carbon dioxide) is greater in the soil air than in the atmospheric air, it (CO_2) moves out into the atmosphere. Hence, the concentration of CO_2 is more in soil air.

On the other hand, partial pressure of oxygen is low in the soil air, as oxygen present in soil air is consumed as a result of biological activities. The oxygen present in the atmospheric air (partial pressure of O_2 is greater) therefore, diffuses into the soil air till equilibrium is established. Thus, diffusion allows extensive movement and continual change of gases between the soil air and the atmospheric air. Oxygen and carbon dioxide are the two important gases that take in diffusion

Importance of Soil Aeration:

1. Plant and root growth: Soil aeration is an important factor in the normal growth of plants. The supply of oxygen to roots in adequate quantities and the

removal of CO_2 from the soil atmosphere are very essential for healthy plant growth.

When the supply of oxygen is inadequate, the plant growth either retards or ceases completely as the accumulated CO_2 hampers the growth of plant roots. The abnormal effect of insufficient aeration on root development is most noticeable on the root crops. Abnormally shaped roots of these plants are common on the compact and poorly aerated soils. The penetration and development of root are poor. Such undeveloped root system cannot absorb sufficient moisture and nutrients from the soil

2. Microorganism population and activity: The microorganisms living in the soil also require oxygen for respiration and metabolism. Some of the important microbial activities such as the decomposition of organic matter, nitrification, Sulphur oxidation etc depend upon oxygen present in the soil air. The deficiency of air (oxygen) in soil slows down the rate of microbial activity.

For example, the decomposition of organic matter is retarded and nitrification arrested. The microorganism population is also drastically affected by poor aeration.

3. Formation of toxic material: Poor aeration results in the development of toxin and other injurious substances such as ferrous oxide, H_2S gas, CO_2 gas etc in the soil.

4. Water and nutrient absorption: A deficiency of oxygen has been found to check the nutrient and water absorption by plants. The energy of respiration is utilized in absorption of water and nutrients. Under poor aeration condition (this condition may arise when soil is water logged), plants exhibit water and nutrient deficiency

5. Development of plant diseases: Insufficient aeration of the soil also lead to the development of diseases. For example, wilt of gram and dieback of citrus and peach.

Influence of soil temperature and air on plant growth

4. Effect of soil temperature on plant growth

a) Soil temperature requirements of plants: The soil temperature requirements of plants vary with the species. The temperature at which a plant thrives and produces best growth is called *optimum range (temperature)*. The entire range of temperature under which a plant can grow including the optimum range is called *growth range*. The maximum and minimum temperatures beyond which the plant will die are called *survival limits*.

Range	Maize (°C)	Wheat (°C)
Optimum range	25 - 35	15 - 27
Growth range	10 - 39	5 - 35
Survival limits	0 - 43	0 - 43

b) Availability of soil water and plant nutrients: The free energy of water increases with temperature. Up to wilting point limit, warming of soil increases water availability beyond which it decreases. Low temperatures reduce the nutrient availability, microbial activities and root growth and branching. The ability to absorb nutrients and water by plants reduces at low temperatures.

Soil temperature management

Use of organic and synthetic mulches: Mulches keep soil cooler in hot summer and warm in cool winter.

Soil water management: High moisture content in humid temperate region lowers soil temperature.

Tillage management: Tilling soil to break the natural structure reduces the heat conductance and heat loss. A highly compact soil loses heat faster than loose friable soil.

Methods of measuring soil temperature: Mercury soil thermometers of different lengths, shapes and sizes with protective cover are buried at different depths to measure the temperature. Thermo couple and thermister based devices are also available. Infra-red thermo meters measure the surface soil temperature. Automatic continuous soil thermographs record the soil temperatures on a time scale. The International Meteorological Organization recommends standard depths to measure soil temperatures at 10, 20, 50 and 100 cm.
