Soil Geography

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Soil as a component of Biosphere; Concept of land and soil; Plant-water-soil relationship

SOIL AS A MATERIAL

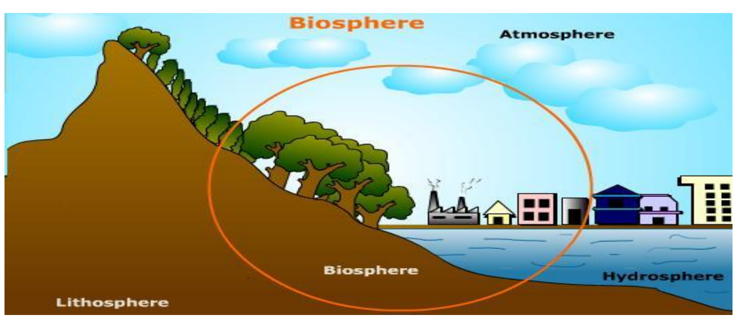
Soil is a material composed of minerals, gases, water, organic substances, and microorganisms.

SOIL AS A NATURAL BODY

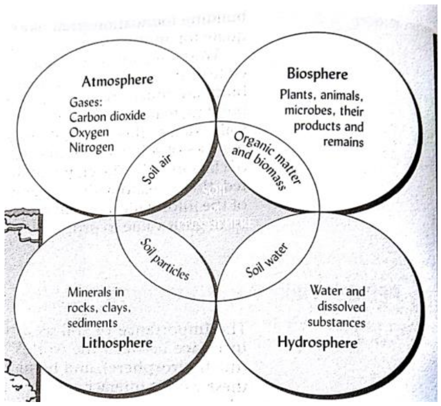
*It is a collection of individually different soil bodies, often said to cover the land as the peel c*overs an orange. However, while the peel is relatively uniform around the orange, the soil is highly variable from place to place on Earth. In most places, the rock exposed at the Earth's surface has crumbled and decayed to produce a layer of unconsolidated debris overlying the hard, un-weathered rock. This unconsolidated layer is called the *regolith.*

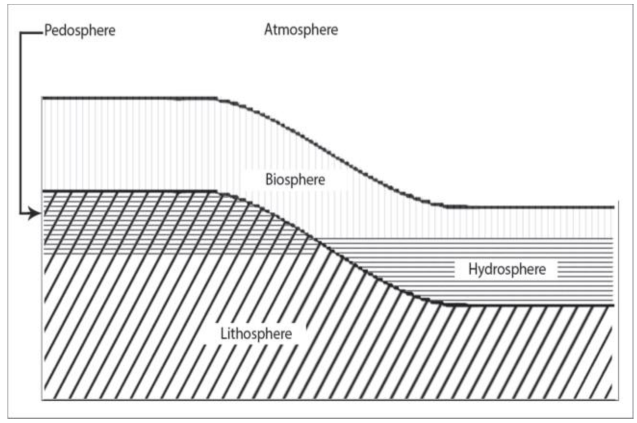
SOIL AS A COMPONENT OF BIOSPHERE

The biosphere is a relatively very thin layer (compared with the radius of the planet) forming the boundary between the atmosphere, hydrosphere and lithosphere. Here, living organisms live, develop and reproduce. The interaction of organisms and effect of the environment surrounding them results in communities of organisms or complex ecological systems. The upper biosphere zone is the atmosphere up to 12,000 to 14,000 m. In water, life can be found to a depth of approximately 10,000 m.



In soil, life has been recorded up to a depth of 20 to 30 m (including plant roots in dry deserts).The essential components of the biosphere, such as water, air, soil, plants, animals, raw materials and solar radiation provide resources for man and the whole of human society. Soil is important for its role as an interface between the worlds of rock (the lithosphere), air (the atmosphere), water (the hydrosphere), and living things (the biosphere). Environments where all four of these worlds interact are often the most complex and also productive. The soil, or pedosphere, is such an example. Soil is an integral part of the biosphere.





The pedosphere, in which lithosphere, atmosphere, hydrosphere and biosphere (living things) overlap and interact.

CONCEPT OF LAND AND SOIL

The part of Earth's surface that is not covered by water is land. The UN defines land as "a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes and swamps), the near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activities". Soil is an essential component of "Land" and "Eco-systems". Both are broader concepts encompassing soil, vegetation, water and climate. In addition to those three aspects, also social and economic considerations in the case of ecosystems(FAO).

The six crucial ecological roles of soils are:

a. Medium for plant growth
b. Regulator of water supplies
c. Recycler of raw materials
d. Modifier of the atmosphere
e. Habitat for soil organism
f. Engineering medium

According to the FAO, “Soil is a natural body consisting of layers (soil horizons) that are composed of weathered minerals, organic matter, air and water; it is a natural medium for the growth of plants”.

SOIL AS A MEDIUM FOR PLANT GROWTH

There are plant-environment interactions below ground and above ground. A plant obtains the following from the soil:

a. Physical support
b. Air
c. Water
d. Temperature moderation
e. Protection from toxins
f. Nutrient elements

Soil provides water to plants. Soil pores absorb rainwater and hold it where it can be used by plant roots. As long as plant leaves are exposed to sunlight, the plant requires a continuous stream of water to use in cooling, nutrient transport, turgor maintenance, and photosynthesis. Since plants use water continuously, but in most places it rains occasionally, the water-holding capacity of soils is essential for plant survival. A deep soil may store enough water to allow plants to survive long periods without rain.

Soil supplies nutrient elements to plants mainly in the form of dissolved inorganic ions, or mineral nutrients. A fertile soil provides a continuing supply of dissolved mineral nutrients in amounts and relative proportions appropriate for optimal plant growth. The nutrients include metallic elements such as potassium, calcium, iron and copper and nonmetallic elements include nitrogen, sulphur, phosphorus and boron. The plant takes these elements out of the soil solution and incorporates most of them into thousands of different organic compounds that constitute plant tissue. Of 92 naturally-occurring chemical elements, 17 have been shown to be essential elements without which plants cannot grow and complete their life cycles. There are several additional elements that appear to be quasi-essential i.e. needed by some but not all plants. Essential elements used by plants in relatively large amounts are called macronutrients. Those used in smaller amounts are called micronutrients.

Macro nutrients used in relatively large amounts (>0.1% of dry plant tissue)		Micronutrients: Used in relatively small amounts (<0.1% of dry plant tissue)
Mostly from air and water	Mostly from soil solids	From soil solids
Carbon (CO_2)	Cations :	Cations :
Hydrogen (H_2O)	Calcium	Copper
Oxygen (O_2,H_2O)	Magnesium	*Cobalt
	Nitrogen	Iron
	Potassium	Manganese
	Anions :	Nickel
	Nitrogen	*Sodium
	Phosphorus	Zinc
	Sulphur	Anions:
	*Silicon	Boron
		Chlorine
		Molybdenum

* Quasi-essential elements

Plants also use minute quantities of organic compounds from soil. Plant's dry matter consists mainly of carbon, hydrogen and oxygen, which the plant obtains by photosynthesis from air and water.

SOIL MOISTURE CONDITIONS

Soil Moisture Content

The soil moisture content indicates the amount of water present in soil. It is commonly expressed as the amount of water (in mm of water depth) present in a depth of one metre of soil. For example: when an amount of water (in mm of water depth) of 150 mm is present in a depth of one metre of soil, the soil moisture content is 150 mm/m .

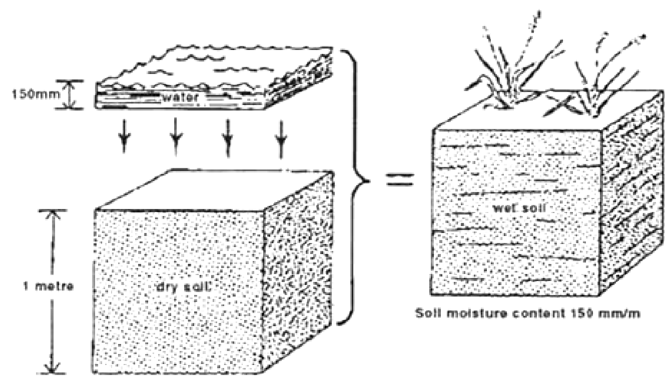


Fig:11. A Soil Moisture Content of 150 mm/m

The soil moisture content can also be expressed in per cent of volume. In the example above, 1 m^3 of soil (e.g., with a depth of 1 m and a surface area of 1 m^2) contains 0.150 m^3 of water (e.g., with a depth of 150 mm = 0.150 m and a surface 'area of 1 m^2). This results in a soil moisture content in volume per cent of:

$$\frac{0.150 m^3}{1 m^3} \times 100\% = 15\%$$

Thus, a moisture content of 100 mm/m corresponds to a moisture content of 10 volume per cent.

Saturation

During a rain shower or irrigation application, soil pores will fill with water. If all soil pores are filled with water the soil is said to be saturated. There is no air left in soil. Plants need air and water in soil.At saturation, no air is present and the plant will suffer. The period of saturation of the topsoil usually does not last long. After the rain or the irrigation has stopped, part of the water present in the larger pores will move downward. This process is called drainage or percolation. The water drained from the pores is replaced by air. In coarse textured (sandy) soils, drainage is completed within a period of a few hours. In fine textured (clayey) soils, drainage may take some (2-3) days.

Field Capacity

After the drainage has stopped, the large soil pores are filled with both air and water while the smaller pores are still full of water. At this stage, soil is said to be at field capacity. At field capacity, the water and air contents of soil are considered to be ideal for crop growth.

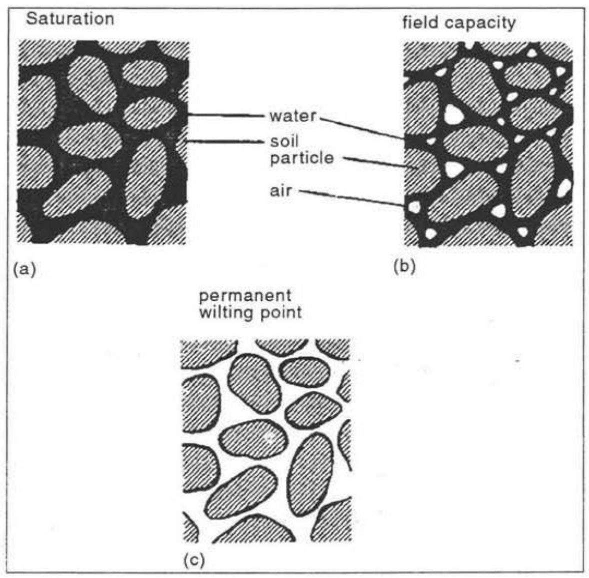


Fig:12. Some Soil Moisture Characteristics

Permanent Wilting Point

Little by little, the water stored in the soil is taken up by the plant roots or evaporated from the topsoil into the atmosphere. If no additional water is supplied to soil, it gradually dries out. The drier the soil becomes, the more tightly the remaining water is retained and the more difficult it is for the plant roots to extract it. At a certain stage, the uptake of water is not sufficient to meet the plant's needs. The plant looses freshness and wilts; the leaves change colour from green to yellow. Finally the plant dies. The soil water content at the stage where the plant dies, is called permanent wilting point. Soil still contains some water, but it is too difficult for the roots to suck it from soil.

Plant Available Water Content

Soil can be compared to a water reservoir for the plants. When soil is saturated, the reservoir is full. However, some water drains rapidly below the root zone before the plant can use it. When this water has drained away, soil is at field capacity. The plant roots draw water from what remains in the reservoir.

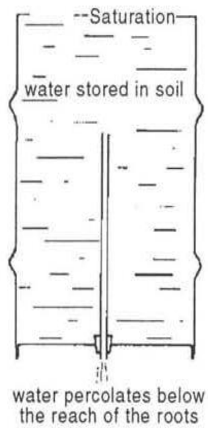


Fig. Saturation

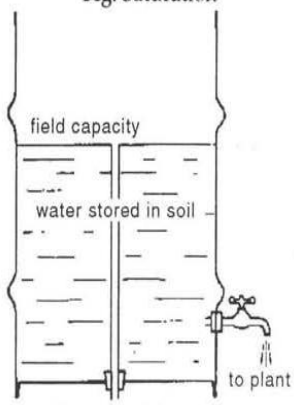


Fig:13. Field Capacity

When soil reaches permanent wilting point, the remaining water is no longer available to the plant. The amount of water actually available to the plant is, the amount of water stored in soil at field capacity minus the water that will remain in soil at permanent wilting point.

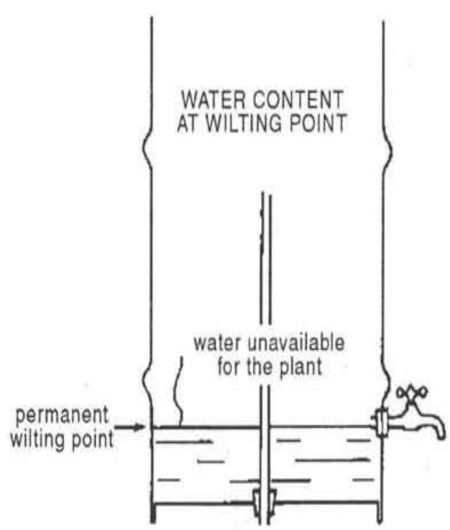


Fig:14A. Permanent Wilting Point

Available water content = water content at field capacity minus water content at permanent wilting point. The field capacity, permanent wilting point (PWP) and available water content are called soil moisture characteristics. They are constant for a given soil, but vary widely from one type of soil to another.

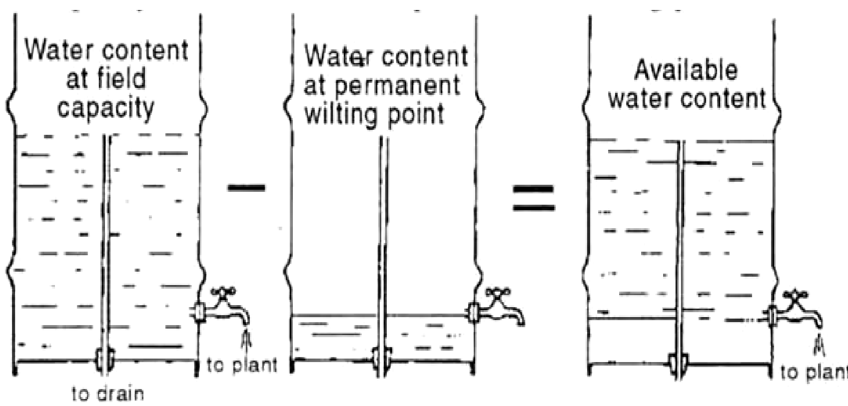


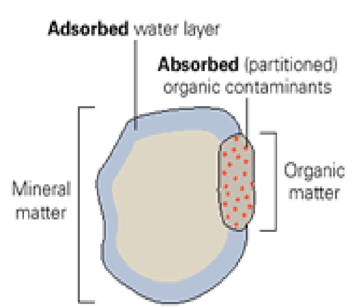
Fig:14B. The Available Soil Moisture or Water Content

Water Potential

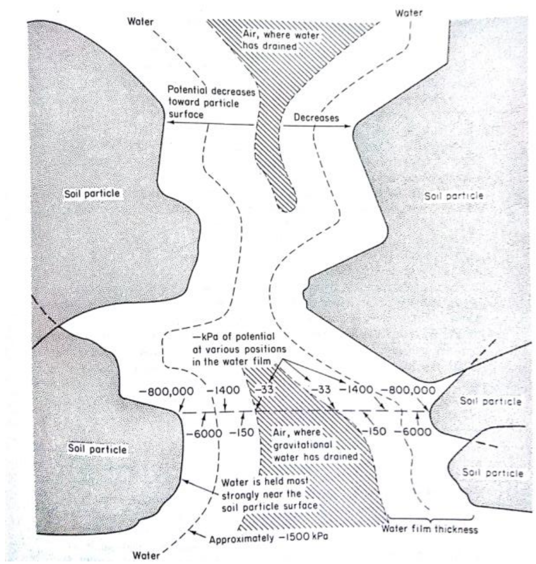
Plants use large quantities of water and are able to satisfy their water needs by absorbing water from the soil. Most of the concerns about soil water involve movement:

a. water movement into the soil surface,
b. water movement from the soil surface downward through soil,
c. and movement of water from the soil to, and into, roots, microorganisms, and seeds.

The soil water potential affects nutrient uptake and plant growth The water potential is the potential energy per unit mass (or volume) of water in a system, compared to that of pure, free water. Adsorbed water in soil is less free to move than is water in a pool of water (which has zero potential by definition). The free-energy value of less than zero is therefore indicated by a negative sign (-).



Negative free energy means that work must be done on the water to remove it from the soil to a pool of water. The more tightly the water is held, the more negative is the number. The pressure of soil water, which is an indication of tendency for soil water to move, is used to express soil water potential. The unit used is (kPa). The difference in energy level of water from one site or one condition to another (e.g. between wet soil and dry soil) determines the direction and rate of water movement in soils and in plants. In a wet soil, most of the water is retained in large pores or thick water films around particles. Therefore most of the water molecules in a wet soil are not very close to a particle surface and so are not held very tightly by the soil solids (the matrix). In this condition, the water molecules have considerable freedom of movement, so their energy level is near that of water molecules in a pool of pure water outside the soil.



In a drier soil however, the water that remains is located in small pores and thin water films and is therefore held tightly by the soil solids. Thus the water molecules in a drier soil have little freedom of movement, and their energy level is much lower than that of the water in wet soil. If wet and dry soil samples are brought in touch with each other, water will move from wet soil (higher energy state) to the drier soil (lower energy). Total water potential(ψ_t) is made up of several components, the first two of which are closely related to water content:

a. matric potential, the work required to remove water against surface tension and particle surface forces, a negative value;
b. osmotic potential, the work necessary to remove water from ions in the solution, also a negative value;

c. gravity potential, the work involved in moving water from soil at a particular elevation to a reference elevation – this may be either positive or negative, depending on the choice of reference elevation;
d. pneumatic potential (or gas pressure potential), involved where a gas pressure gradient exists; and
e. overburden potential, involving the weight of those soil particles that are somewhat free to move and to exert a pressure on water below (somewhat comparable to the contribution of suspended materials to total pressure of a liquid column).

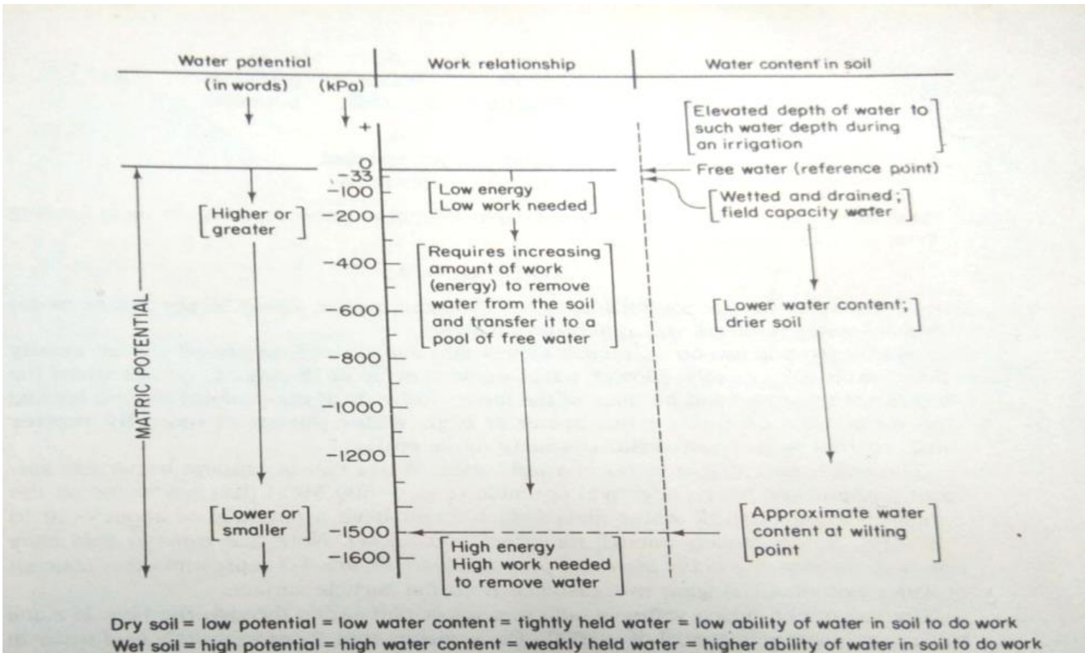


FIGURE 4-2 Schematic representation of the terminology for matric potential and for water potential in general. Water with a high potential has more mobility in a soil than has water with lower potential. The *matric potential* is zero at soil saturation and does not ever become a positive number. Notice that as the water potential becomes lower or smaller, the kilopascals (kPa) are negative (and larger negative numbers). (Courtesy of Raymond W. Miller, Utah State University.)

PLANT-WATER-SOIL RELATIONSHIP

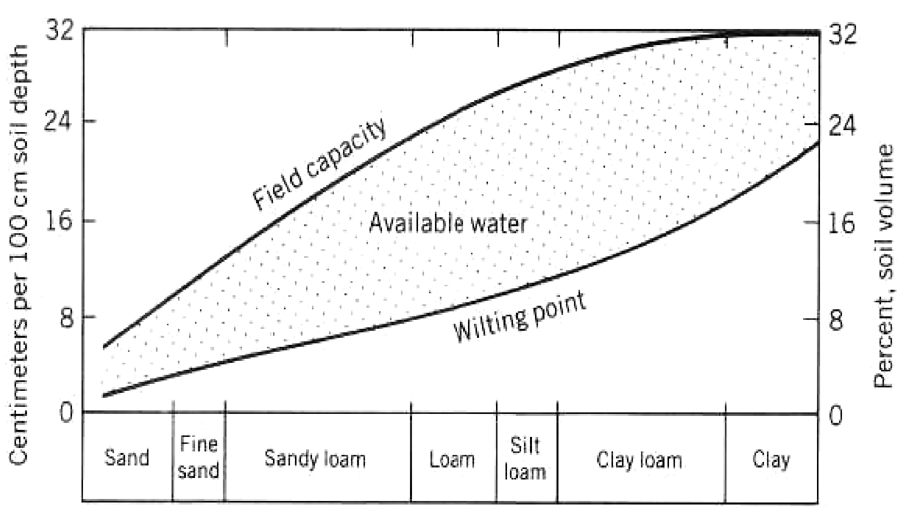
1. Available Water-Supplying Power of Soils
2. Water Uptake from Soils by Roots
3. Diurnal Pattern of Water Uptake
4. Pattern of Water Removal from Soil
5. Soil Water Potential Versus Plant Growth
6. Role of Water Uptake for Nutrient Uptake

1. Available Water-Supplying Power of Soils

The water-supplying power of soils is related to the amount of available water a soil can hold. The available water is the difference in the amount of water at field capacity (-30 kPa or -0.3 bar) and the amount of water at the permanent wilting point (-1,500 kPa or -15 bars). In most conditions, soil water content or soil water potential appears to be of particular importance since it directly affects both root growth and functions and indirectly influences other significant factors, such as aeration, mechanical resistance, and soil temperature. The interrelationships between soil water and other physical factors are expressed by the indicator called a non-limiting water range or least limiting water range at which soil aeration and mechanical resistance do not restrict root growth or is minimal. Thus, the non-limiting water range (NLWR) represents the range of water content in the soil where limitations to plant growth (such as water potential, air-filled porosity, or soil strength) are minimal.

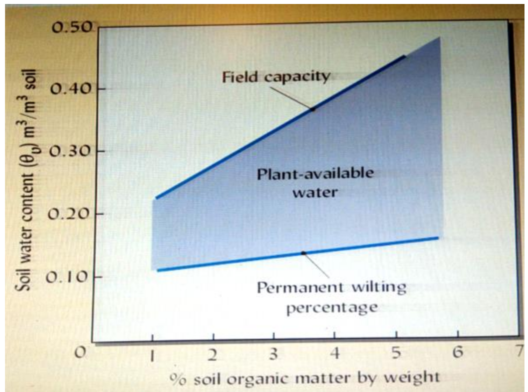
Water Content–Potential Relationship

The amount of available water is related to both texture and structure, because it is dependent on the nature of the surfaces and pores, or soil matrix. Soils high in silt (silt loams) tend to have the most optimum combination of surfaces and pores. They have the largest available water holding capacity.



Relationship of soil texture to available water-holding capacity of soils. The difference between the water content at field capacity and the water content at the permanent wilting point is the available water content.

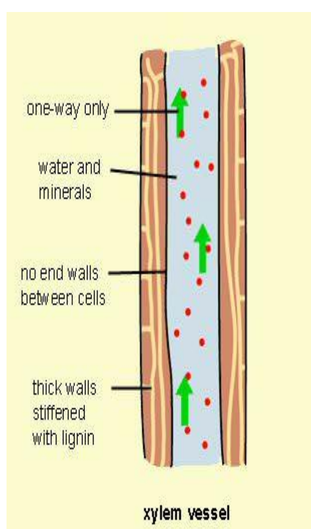
As fineness of texture increases, there is a general increase in available moisture storage from sands to loams and silt loams. Plants growing on sandy soils are more apt to suffer from drought than are those growing on a silt loam in the same area. However, clay soils frequently provide less available water than do well-granulated silt loams since the clays tend to have a high wilting coefficient. Organic matter indirectly affects the amount of water available to plants mainly by enhancing soil structure, which in turn increases both water infiltration and water-holding capacity.



The effects of organic matter content on the field capacity and permanent wilting percentage of a large number of silt loam soils. The difference between the two lines shown is the available soil moisture content, which was obviously greater in the soils with higher organic matter levels

2. *Water uptake from soils by roots*

Plants play a rather passive role in their use of water. Water loss from leaves by transpiration is mainly dependent on the surrounding environment. Water in the atmosphere has a much lower water potential than the water in a leaf, causing the atmosphere to be a sink for the loss of water from the plant via transpiration.



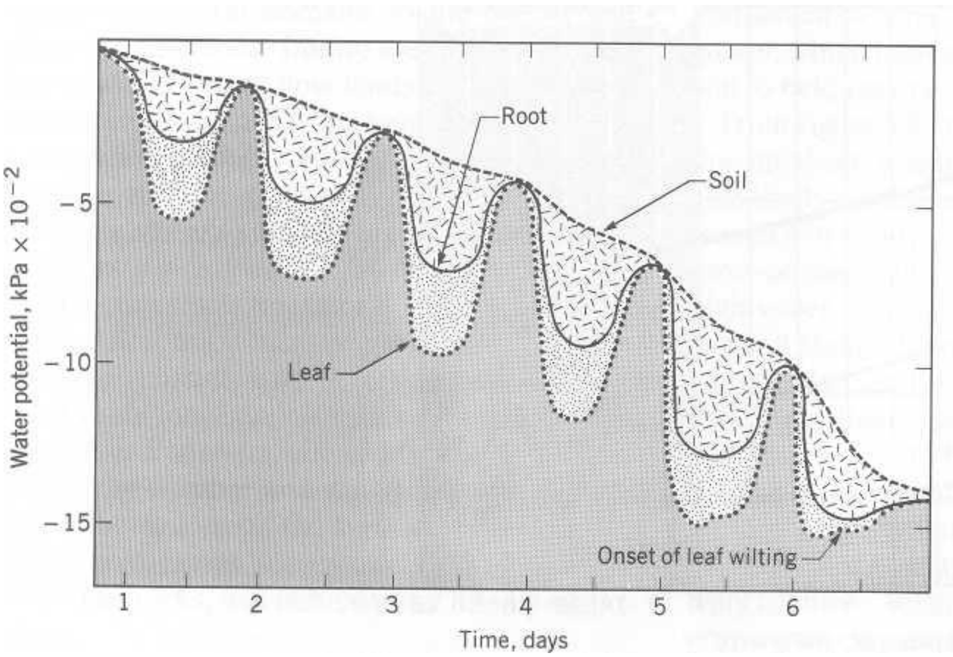
The water conducting tissue of the leaves (xylem) is connected to the xylem of the stem, and a water potential gradient develops between leaves and stems due to water loss by transpiration. The xylem of the stem is connected to the xylem of the roots and a water potential gradient is established between the stem and roots. This water potential gradient, or continuum, is called the soil-plant-atmosphere-continuum, or SPAC. The water potential gradients established between roots of transpiring plants and soil causes water to move from the soil into roots.

Water Potential	
In the atmosphere	-50,000 kPa (-500 bars)
In the leaf	-2500 kPa (-25 bars)
In the root	-800 kPa (-8 bars)
In the soil	-700 kPa (-7 bars)

Some realistic water potentials in the continuum during midday when plants are actively absorbing water

3. *Diurnal pattern of water uptake*

Suppose that it is a hot summer morning, and there has been a soaking rain or irrigation during the night. The soil is about at field capacity and water availability is high. The demand for water is nil, because the water-potential differences in the leaves, roots, and soil are small. There is no significant water gradient and no water uptake. After the sun rises and the temperature increases, thus decreasing relative humidity, the water potential gradient increases between the atmosphere and the leaves. The leaves begin to transpire. A water potential gradient is established between the leaves, roots, and soil. Roots begin water uptake. The low water conductivity in the plant causes the water potential difference between leaves and roots, and between roots and soil, to increase to a maximum at about 2 P.M. This is a period of greater water loss than water uptake, which creates a water deficit in the leaves.



It is normal for these leaves to be less than fully turgid and appear slightly wilted. After 2 P.M., decreasing temperature and increasing relative humidity tend to reduce water loss from leaves. With continued water uptake, the plant absorbs water faster it is lost, and the water potential gradient between leaves and soil decreases. The water deficit in the plant is decreased, and any symptoms of wilting disappear. By the next morning, the water potential gradient between the leaves and soil is eliminated. As this pattern is repeated, the soil dries and the hydraulic conductivity decreases rapidly and the distance water must move to roots increases. In essence, the availability of soil water decreases over time. As a consequence, each day the potential for water uptake decreases and the plant increasingly develops more internal water deficit, or water stress, during the afternoon. The accumulated effects of these diurnal changes, in the absence of rain or irrigation or the elongation of roots into underlying moist soil will continue. Eventually, leaves may wilt in midday and not recover their turgidity at night. Permanent wilting occurs, the soil is at the permanent wilting point, and the soil has a water potential of about -1,500 kPa (-15 bars).

4. Pattern of Water Removal from Soil

With each passing summer day, water moves more slowly from soil to roots as soils dry, and the availability of the remaining water decreases. This encourages root extension into soil devoid of roots where the water potential is higher and water uptake is more rapid. For young plants with a small root system, there is a continual increase in rooting depth to contact additional supplies of available water in the absence of rain or irrigation during the summer. In this way the root zone is progressively depleted of water. When the upper soil layers are rewetted by rain or irrigation, water absorption shifts back toward the surface soil layer near the base of the plant. This pattern of water removal results in:

1. more deeply penetrating roots in dry years than in wet years, and
2. greater absorption of water from the uppermost soil layers, as compared to the subsoil layers, during the growing season.

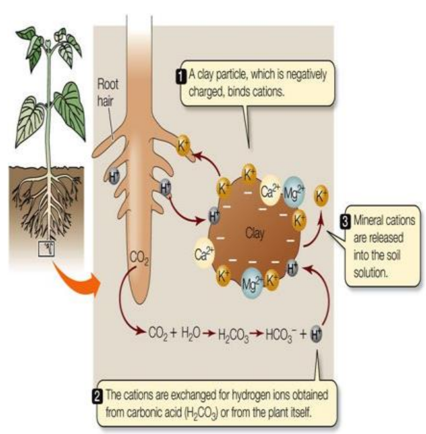
Crops that have a long growing season and a deep root system, like alfalfa, absorb a greater proportion of their water below 30 centimeters.

5. Soil Water Potential versus Plant Growth

Most plants cannot tolerate the low oxygen levels of water-saturated soils. In fact, water saturation of soil kills many kinds of plants. These plants experience an increase in plant growth from saturation to near field capacity. As soils dry beyond field capacity, increased temporary wilting during the daytime causes a reduction in photosynthesis. Thus, plant growth tends to be at a maximum when growing in soil near field capacity, where the integrated supply of both oxygen and water are the most favorable. During periods of water stress, the damage to plants is related to the stage of development.

6. Role of Water Uptake for Nutrient Uptake

To be taken up by a plant, the nutrient element must be in a soluble form and must be located *at the root surface. Often, parts of a root are in such intimate contact with soil particles* that a direct exchange may take place between nutrient ions adsorbed on the surface of soil colloids and H^+ ions from the surface of root cell walls.

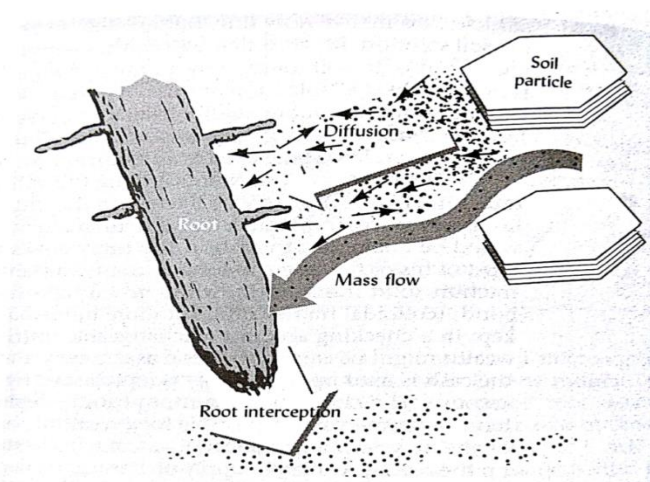


As nutrients deplete, additional supplies are to be obtained. Three basic mechanisms by which the concentration of nutrient ions at the root surface is maintained are :

a. Root interception - Root exploration in search of nutrients by thin root cell extensions called root hairs, into water-filled soil pores where nutrients may be dissolved.

b. Mass flow - nutrient ions must still travel some distance in the soil solution to reach the root surface. Mass flow carries dissolved nutrients along with the flowing soil water toward a root that is actively drawing water from the soil.

c. Diffusion - nutrient ions continually move by diffusion from areas of greater concentration toward the nutrient-depleted areas of lower concentration around the root surface.



Mass flow carries ions to the root surfaces, where they are in a position to be absorbed by roots. An increased flow of water increases the movement of nutrient ions to roots, where they are available for uptake. This results in a positive interaction between water uptake and nutrient uptake. Droughts reduce both water and nutrient uptake.

Probable Questions:

1. Describe with the help of diagrams the relationship between plant, water and soil. 10
2. What is soil water? Define field capacity and permanent wilting point with the help of diagrams. 5
3. Define available water in soil for plant with the help of a diagram. 5
4. What is water potential? Describe how matrix potential determines availability of soil water to plants. 1+4