SOIL-PLANT WATER RELATIONS

Soil is a complex of varying proportions of four principal components–minerals, nonliving organic matter, air, and water. In addition, soil usually contains numerous living organisms, such as bacteria, fungi, algae, protozoa, insects, and small animals, which directly or indirectly affect soil structure and plant growth. Click here to access articles that discuss the soil microbiome and its importance in sustainable crop production.

Soil Texture

On a volumetric basis, the mineral particles are the chief components of soils. These particles are of various sizes, and the classification of a soil is based on its percentage of sand [largest particles], silt, and clay [smallest particles]. The mineral fractions, as defined by their diameter, are listed in Table 1, along with a representative percentage of each of these particle sizes in three common soil textural classifications.

Table 1. Classification of soil particles according to the International Society of Soil Science and the mechanical analysis of three representative soils.

		Soil texture		
Fraction	Particle diameter	Sandy loam	Silt loam	Clay
	millimeter	-----------%------------		
Sand	2.0–0.02	65	20	20
Silt	0.02–0.002	20	65	20
Clay	<0.002	15	15	60

Soil properties such as speed of internal drainage, water holding capacity, available water holding capacity, aeration, susceptibility to erosion, and cation exchange capacity [CEC] are influenced by texture. Soils that have a predominance of clay particles are called fine-textured soils, while those dominated by larger particles are called coarse-textured soils. Clay soils are often referred to as "heavy clay soils", which in fact is a misrepresentation since they are no heavier [or may weigh less] on a volumetric basis than sandy soils.

Sand. The least complex soil is a sand, which by definition contains less than 15% silt and clay and is relatively inert chemically. Sandy soils form relatively simple capillary systems, with a major portion of their volume made up of large pore spaces. This results in rapid gravitational drainage of water and maximum aeration. Because of these large pores and the subsequent rapid drainage following addition of water, sandy soils hold very little water that is available to plants.

Clay. Clay soils are the other textural extreme with reference to particle size and complexity. They contain a minimum of 40% clay. The clay particles usually are aggregated in complex granules and are plate-like in shape. Because of their shape and small size, these aggregates have a much greater surface area than coarser-textured soils.

The extensive surface area of the clay particles enables clay soils to hold more water and minerals than do sandy soils. For example, a cubic sand grain 1 mm in diameter on each edge has a surface area of only 6 mm^2, but if is broken into clay-size particles of 0.001 mm on each edge, the resulting total surface area is 6000 mm^2. Thus, the relatively small size of the particles in the clay fraction largely controls both the chemical and physical properties of soils.

Clay soils have the most total pore space, but the majority of the pores are micropores. This allows only slow air and water adjustment because of the large total surface area of the particles. This surface area holds water by surface tension, so it resists the force of gravity. This water is termed "adsorbed" water, or water that is held on the surface of the soil particles.

Loam. Loam soils contain a higher percentage of silt and sand [30-50% sand, 30-50% silt] and only 10-25% clay. Therefore, they have properties that are intermediate between those of sand and clay. Such soils are considered to be the most favorable for crop production because they hold more readily available water than sandy or clayey soils [**Table 2**], and can supply more nutrients to plants than can sand. They are also better aerated.

Cation exchange capacity refers to the quantity of negative charges that exist on the surfaces of clay particles and organic matter in soil. Sandy soils have the lowest CEC, whereas clay soils have the highest.

The negative charges of the soil particles attract positively charged ions or cations such as potassium [K^+], calcium [Ca^{++}], magnesium [Mg^{++}], and ammonium [NH_4^+], which are major plant nutrients. Hydrogen [H^+], sodium [Na^+], and aluminum [Al^{+++}] are the other predominant cations occupying the CEC in soils. High percentages of clay particles will impart a higher CEC, while a high percentage of sand particles will impart a low CEC. Small increases in organic matter will greatly increase soil CEC.

The CEC of a soil is important because it implies the size of the reservoir of nutrients that is available to replenish the nutrients removed by plant uptake. Also, the CEC of a soil can be an indicator of how much leaching of nitrogen [N] and K fertilizers will occur; i.e., higher CEC soils will experience less leaching of cationic elements.

Soil Porosity

Soil porosity refers to the amount of pore or open space between soil particles. Pores are created by the contact between soil particles. Fine-textured soils have more total pore space than coarse-textured soils; however, the pores are much smaller than those in soils with a high sand content. Thus, clay soils [more fine particles] hold more water than coarse-textured sandy soils, but because of the large surface area associated with the smaller clay particles, much of this water is adsorbed and is difficult for plants to extract.

For practical purposes, soil pore space may be divided into two major categories:

- Large pores [macropores], which 1) do not hold water against gravitational forces, 2) drain freely and quickly following rain and/or irrigation, and 3) are normally filled with air;
- Small pores [micropores], which hold water that will not drain due to gravity; part but not all of this water is available to plants.

Soils of the different textural classes differ in their ability to supply water to plants. Ideal agricultural soils have about equal volumes of small and large pores. Such soils have enough large pores to permit adequate and reasonably rapid water infiltration, drainage, and aeration, and enough small pores to provide adequate water-holding capacity to support crop growth.

Soil Water

A supplement to the above information is the definition of some basic soil water terms.

- As per the above discussion, **soil texture** is the major soil component governing the amount of water available to plants during the growing season because it controls pore size distribution and particle surface area that will adsorb water.

- **Infiltration** is the movement of water into soil, and is affected by both surface compaction [crusting] and subsurface compaction. Soils low in organic matter [OM] are more prone to crusting than are soils with >2% organic matter.
- **Saturation** is the soil water content when all pores are filled with water. This usually lasts for only a short period following rain or irrigation. Saturation may or may not involve the entire soil profile, depending on the rapidity of infiltration.
- **Percolation** is the downward movement of water within the soil due to gravity. The speed of percolation is dependent on soil texture and subsequent pore size distribution.
- **Soil water holding capacity** is the amount of water that is held in a soil after gravitational water loss has ceased.
- **Field capacity [FC]** is the volume of water in soil after gravitational water flow has ceased. This point of soil water content is generally accepted as about 0.3 bar tension.
- **Permanent wilting point [PWP]** is the volume of water remaining in soil when plants can no longer extract water, and the point at which a plant will not recover from wilt until water is added to soil. This point of soil water content is generally accepted as about 15 bars tension.
- **Available soil water holding capacity** is the amount of soil water that is available for plant use, or the amount of water volume between field capacity and permanent wilting point. The data in **Table 2** provide a general categorization of plant-available water related to soil texture. Available water ranges from an average 0.7 in./ft. of soil in coarse sand to an average 2.25 in./ft. of soil in very fine sandy loam and silt loam.

Table 2. Available water holding capacity of soil categorized by textural class.

Soil textural class	In. available water per ft. (avg.)
Coarse sand	0.6–0.8 (0.7)
Fine sand	0.8–1.0 (0.9)
Loamy sand	1.1–1.2 (1.15)
Sandy loam	1.3–1.4 (1.35)
Fine sandy loam	1.5–2.0 (1.75)
Very fine sandy loam, silt loam	2.0–2.5 (2.25)
Silty clay loam	1.8–2.0 (1.9)
Silty clay	1.5–1.7 (1.6)
Clay	1.3–1.5 (1.4)

The water content at 15 bars may be subtracted from the water content at field capacity [Table 3] to determine the amount of water available to plants between field capacity and the permanent wilting point. Thus, Sharkey clay has about 11%, Dubbs silt loam about 20%, and Bosket very fine sandy loam about 17% plant-available water in their profiles. Interestingly, a Sharkey clay still has about 25% water content when it is at the permanent wilting point.

A more practical term might be **readily available soil water**, or the water available between field capacity [~0.3 bar] and ~1.0 bar. The soil moisture available between 1.0 and 15.0 bars tension apparently requires the plant to be under tensions high enough to cause water-deficit stress, and some level of plant injury will occur depending on the point of soil water tension in the range between 1.0 and 15 bars. Therefore, the soil water held between 0.3 and 1.0 bar tension is more readily available to plants.

Using the above process, the amount of water that is readily available to plants is about 4% for Sharkey clay, about 9% for Dubbs silt loam, and about 10.5% for Bosket very fine sandy loam.

Thus, a clay soil has a higher total water content than a silt loam/very fine sandy loam soil in the plant-available range, but a lower readily available water content in that range.

The difference in the ability of soils of different textures to supply water to plants will result in a differing pattern of canopy development in soybean. For example, when the same soybean varieties are planted on the same date at the same location on both a silt loam and a clay soil, plants of varieties growing on the loam soil will grow taller and have more leaf area than plants of the same varieties growing on the clay soil [Heatherly and Russell FCR 1979]. In a year when soil moisture is adequate or above adequate for optimum growth, this can lead to excessively tall plants on the loam soil, which increases their potential for lodging.

Table 3. Volumetric water content of soils equilibrated at different pressures.

	Soil series		
Soil water tension*	Sharkey clay	Dubbs silt loam	Bosket very fine sandy loam
bars	---------------------%---------------------		
0.3	36.8	27.5	24.2
0.7	34.1	21.0	16.1
1.0	32.8	18.4	13.6
3.0	30.0	13.0	8.9
5.0	28.4	11.2	8.0
10.0	27.0	9.0	7.3
15.0	26.0	8.0	6.9

*0.3 bar ~ field capacity; 0.7 bar ~ tensiometer limit; 1.0 bar ~upper tension limit of readily available water; 15 bars ~ permanent wilting point.

A detailed discussion of the above soil texture/soil water/soil-plant water relations topic is available in MAFES Bulletin 919.

Composed by Larry G. Heatherly, Revised/Updated Mar. 2025, larryh91746@gmail.com