Soil Moisture and Aeration

THE NATURE OF SOIL MOISTURE

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INTRODUCTION *Why is soil moisture important?*

In floriculture and other fields of agriculture, soil moisture probably limits plant growth more often than any other soil factor. Water is *the* most important nutrient needed by plants (see NYSFG Bulletin 269). Plants have a greater content and use of water than of any other nutrient required for their growth. Every plant function is directly or indirectly influenced by water. *Plants cannot live without water.* All the water used by plants comes from the soil. The status of soil water can therefore influence plant growth by influencing plant water absorption. Soil water can also influence plant growth by affecting the soil's physical, chemical, and biological character.

WHY IS SOIL MOISTURE IMPORTANT ?

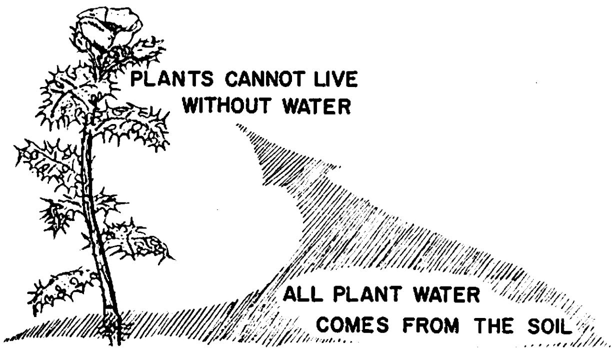

FIGURE 1. Water is quantitatively and qualitatively the most important nutrient required for plant growth and activity. All water used by plants comes from the soil. Soil moisture therefore plays an important part in plant growth.

Water is an essential plant nutrient and important soil environmental factor. Since the soil is the only source of this nutrient, it is essential for floriculturists to know the nature of soil moisture and how it can affect crop growth. The previous two articles in this series considered the basic concept of soil (NYSFG Bulletin 254) and the nature of plant water (NYSFG Bulletin 269). This article briefly considers the nature and behavior of soil moisture in relation to plant water use.

SOIL MOISTURE *What is soil moisture?*

The soil is a kind of reservoir which stores water and other nutrients for plant use. Water is stored in this reser-

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voir in three different forms; it is stored as solid, liquid, and gaseous water (Figure 2). The solid form, called *bound or hygroscopic water,* is a thin water layer held so strongly to soil particles that it behaves like ice. The gas form is the humidity in the soil air. The liquid form, called *soil moisture,* wets particle surfaces and fills soil pores.

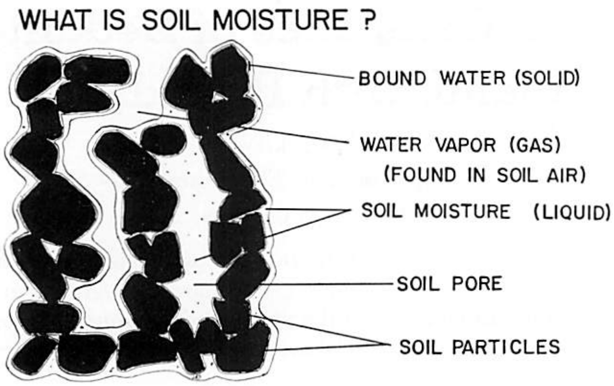

FIGURE 2. Three forms of water are found in the soil: solid, gaseous, and liquid water. Liquid water is the most important form in relation to plant growth and activity.

Soil moisture contains a small amount of dissolved minerals, gases, and organic matter and is therefore also called the *soil solution.* The amount of dissolved material in the soil solution varies with soil physical, chemical, and biological conditions and also with the addition of fertilizer and organic matter but is normally relatively small.

The amounts of solid, gaseous, and liquid water in the soil depends on soil type and conditions. The solid and gas forms of soil water normally constitutes much less than one percent of the total soil mass and are therefore not important sources of water for plants. Liquid water, however, often constitutes more than thirty percent of the total soil mass and is therefore the most important source of water for plant use. Liquid water is also the form which has the strongest influence on the soil physical, chemical, and biological character.

In summary, soil moisture is the soil liquid phase; it consists of liquid water and dissolved materials. Soil moisture is the most important form of water in the soil in relationship to plants.

SOIL MOISTURE RETENTION *How is water held in soils? How strongly?*

Water is held in the soil reservoir because it can "stick to" soil particles and "to itself". The soil solution wets or *adheres to* soil particle surfaces and is also "trapped" or held in soil pores by a combination of *adhesion* to soil particles and *cohesion* to other water molecules. These cohesive and adhesive forces result in *surface tension* which forms a tightly-stretched "skin" of water across pore openings. This surface tension "skin" tends to either hold water in or out of the pores. This combination of adhesion and cohesion of soil moisture, commonly called *capillary activity,* can also pull water into pores. Most water is held in soils by capillary activity.

The strength of soil water retention can vary tremendously between soils or within a given soil as conditions change. A measure of the strength of soil water retention is called *soil water suction* (see Glossary). The greater the soil water suction, the stronger that water is held in soils, and the harder it is for plants to absorb it.

Glossary A
Soil Moisture Retention Terms

suction—the pressure (force per unit area) required to remove water from the soil (expressed in energy, work, or pressure units). Atmospheric pressure is set equal to zero suction as a reference point. (Soil moisture tension, soil moisture stress, and water potential are analogous terms often used).

centimeter water (or *centimeter mercury*)—a unit of pressure or suction equal to the pressure exerted at the bottom of a layer of water (or mercury) one centimeter deep (1 cm water equals the weight of 1 gm/cm^2 and 1 cm mercury equals the weight of 13.6 gm/cm^2).

atmosphere—another unit of pressure or suction equal to about 14.7 pounds per square inch. One atmosphere equals about 1033 cm water or about 76 cm mercury.

bar—another unit of pressure or suction equal to about one atmosphere (actually about 0.985 atmospheres).

water table—a soil condition where the suction equals zero (the soil is usually saturated).

moisture equivalent—a soil condition where the matric suction equals approximately ½ atmosphere or 500 centimeters water suction (laboratory approximation of field capacity).

wilting coefficient—a soil condition where the matric suction equals approximately 31 atmospheres (31,000 centimeters of water suction) (laboratory approximation of the permanent wilting point).

suction gradient—a soil condition where one part of the soil has a lower suction than another part (water flows along a suction gradient from lower to higher suctions).

Soil suction is therefore a measure of the ease of water absorption by plants, called *soil moisture availability.*

Soil water suction actually is the combined result of different factors. *Matric suction,* the attraction of water to soil particles, and *osmotic suction,* the effect of solutes, are usually the most important suction components in relation to plants. Matric suction normally controls the physical status of soil water (movement, retention, and content) and is therefore probably the most commonly measured component (measured with tensiometers). Osmotic suction occasionally becomes dominant as demonstrated by the wilting of plants immediately following excessive soluble

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fertilizer applications or under high salt conditions. When this happens plants cannot absorb water from the soil and water may even be drawn out of the plant back into the soil (high salts may also have a toxic effect on plant growth not related to the osmotic effect).

HOW IS WATER HELD IN SOILS ?

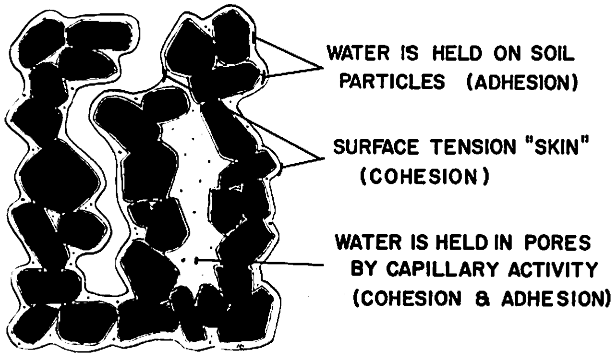

FIGURE 3. Water is held in soils by a combination of adhesion and cohesion of the water called capillary activity. Most soil moisture is held in water-filled soil pores.

Various terms commonly used to describe soil moisture retention are listed in part A of the Glossary. Since container soils are shallow, the term *moisture equivalent* usually has no practical application for these soils (explained in section on soil moisture distribution). Water retained in soils between zero suction (wet) and wilting coefficient (dry) can be absorbed by plants and is therefore *available soil moisture.*

In summary, water is retained in soils by a combination of adhesion and cohesion (capillary activity). *Soil suction is a measure of the strength of soil water retention which is one measure of soil moisture availability to plants.*

SOIL MOISTURE CONTENT *How much water is held in soils?*

Soil moisture content is the amount of water held in the soil reservoir. Water is held primarily in the soil pores so the total amount and size distribution of soil pores, which is determined by soil texture and structure, affects the amount of water retained. Soils with smaller pores usually contain more water following irrigation and drainage than soils with larger pores. Finer-textured, less-compacted soils usually have greater surface area, greater total porosity, and small pores and therefore greater water content than coarser-textured, more compacted soils. Porosity is also usually greater in soils of one particle size (clay *or* silt *or* sand) than in a *well-graded soil* (mixture of clay *and* silt *and* sand). (Figure 4)

Soil texture and structure are not the only factors controlling soil water content. Matric suction is the primary factor influencing the water content within a *particular soil.* Two identical soils having different matric suction levels will contain different amounts of water. The relationship between matric suction and soil water content is called the *soil moisture characteristic* (Figure 5). As soil

HOW MUCH WATER IS HELD IN SOILS ?

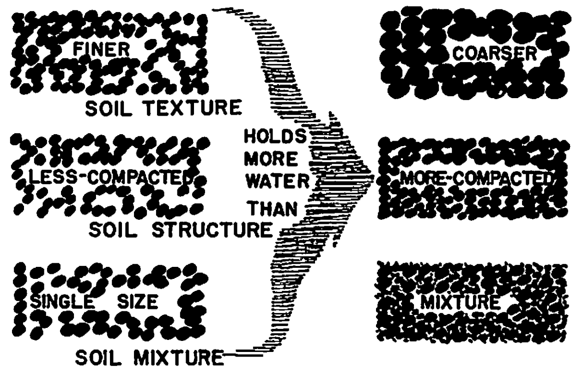

FIGURE 4. Soil texture, structure, and mixture are factors which determine pore size and total porosity and therefore determine the total amount of water that a soil can potentially hold.

SOIL WATER CONTENT AND SOIL SUCTION

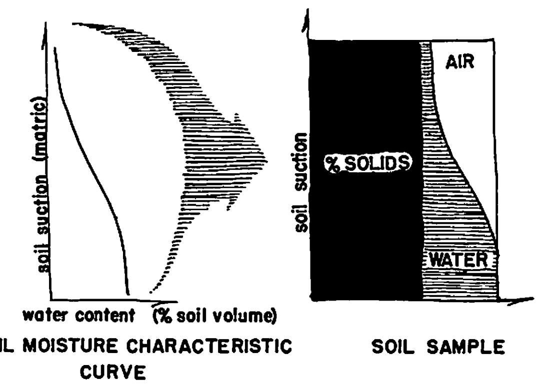

FIGURE 5. The soil moisture characteristic curve shows the relationship between soil matric suction and soil moisture content. The figure on the right illustrates how the relative proportions of air and water change as soil suction changes. The amount of soil solids (black part) does not change with soil suction.

water content decreases, matric suction increases; as the soil dries, water becomes more strongly held. Each soil has its own specific moisture characteristic (Figure 6);

SOIL POROSITY AND SOIL WATER CONTENT

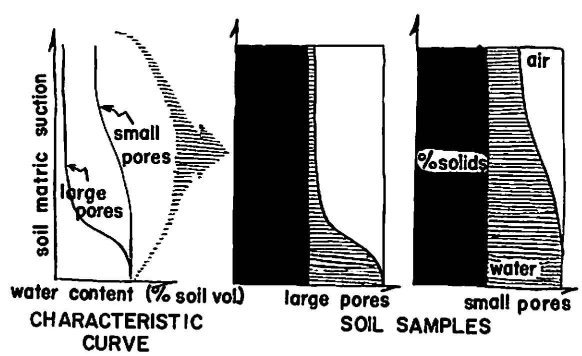

FIGURE 6. Illustration showing the soil moisture characteristic curves for two different soils (left) and how the proportions of air and water in each change with solution (right).

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this is probably the most important soil physical character a horticulturist can know.

Various terms commonly used to describe soil moisture content are listed in part B of the Glossary. All of these terms can be correctly used to describe container soil conditions *except field capacity.* Shallow field or container soils normally never reach field capacity during drainage (see section on soil moisture distribution). The soil water content between field capacity or container capacity and permanent wilting percentage can be absorbed by plants and is therefore *available soil moisture.*

In summary, the amount of water held in soils, soil moisture content, depends on soil texture, structure, and suction. The relationship between soil moisture content and soil suction is called the soil moisture characteristic. Soil moisture content is one measure of soil moisture availability.

Glossary B
Soil Moisture Content Terms

water content—the amount of water in a soil (usually a percentage based on soil dry weight, soil wet weight, or soil volume).

saturation—a soil condition where the pores are filled with water (the suction usually equals zero).

percent pore saturation—the percentage of the soil pore volume which is water-filled.

field capacity—the water content of a deep (field) soil after 48 hours drainage without any other loss of water (a characteristic of each soil).

container capacity—the water content of a container soil following complete draining without any other water loss (an analog of field capacity except it is a characteristic of *both* the soil and the container).

permanent wilting percentage—the soil water content at which a plant can not absorb sufficient water to keep from wilting even in a water-saturated atmosphere.

water-depth ratio—the volume of water contained per volume of soil.

SOIL MOISTURE MOVEMENT *How does water move through soils?*

Only part of the water applied during irrigation stays in any single part of the soil, the rest moves or drains downward (called *saturated* or *gravitational water movement*). The gravitational force on water, its weight, pulls it downward, mostly through the larger soil pores. The rate of gravitational water movement depends on the size and total amount of soil pores; *drainage* is more rapid and complete in coarser-textured and less-compacted soils (ie. sand). Movement of the liquid water retained in the soil reservoir is called *unsaturated or capillary water movement.* Capillary or suction forces can pull water in *any direction* through adhered water films and water-filled pores, always *from* areas of *lower* to areas of *higher suction.* The size of the water film, the amount of water-filled pores, the water path length (all depend on texture, structure, and suction) and the *suction gradient* (Part A Glossary) all influence the rate of capillary water movement. Capillary water movement is generally greater in wetter, finer-textured, more-compacted soils. Water movement through the soil as vapor is insignificant in relation to plant water use.

HOW DOES WATER MOVE THROUGH SOILS ?

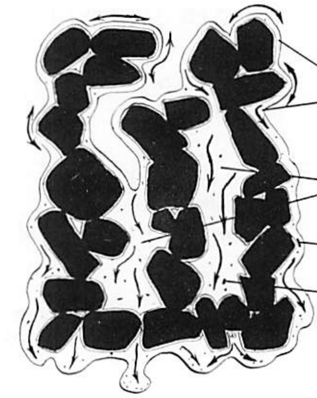

FIGURE 7. Saturated water movement occurs downward mainly through the larger soil pores. Capillary water movement occurs in any direction through water-filled pores or water films on partill surfalbs.

The initial distribution of water throughout the soil reservoir is by gravitational water movement during irrigation. Secondary or horizontal distribution of water throughout the soil occurs by capillary water movement; this is how water absorbed by plants moves to the roots.

Soil aeration, which also influences poor water absorption, depends on the completeness of drainage; a well-drained soil will have better aeration than a poorly-drained soil. In all of these ways, soil moisture movement influences soil moisture availability.

In summary, two main kinds of water movement occur in soils, gravitational water movement and capillary water movement. Soil texture, structure, and suction all influence soil water movement. Soil moisture availability also depends on soil moisture movement.

SOIL MOISTURE DISTRIBUTION *Where is water located in soils?*

Water is not always distributed uniformly throughout a soil following irrigation. When a deep (field) soil is irrigated, it usually does drain to a relatively uniform water content throughout most of its wetted depth (*field capacity*). Shallow container soils also drain to a certain water content following each irrigation, called *container* or *depth capacity;* however in shallow containers the water content is different at different soil levels. When drainage from a shallow soil ceases, the bottom of the soil is *saturated* (at zero suction) and the *matric suction* increases with height above the bottom (ie. at 10 cm height, matric suction equals approximately 15 cm water, etc.) (Figure 9). In other words immediately following drainage, the

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top of a shallow container soil is usually drier than the bottom. The actual distribution of water depends on the soil depth and the soil moisture characteristic.

WHERE IS WATER LOCATED IN SOILS ?

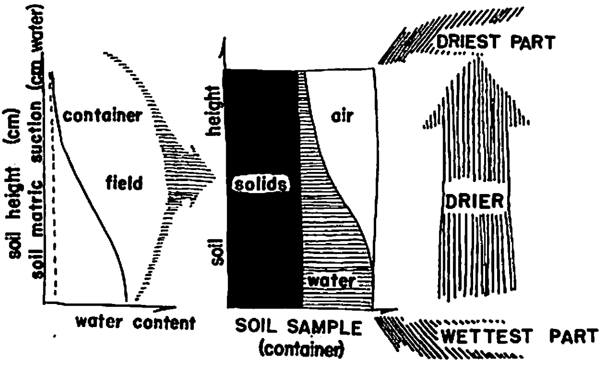

FIGURE 8. Water is not uniformly distributed throughout the depth of a container soil. The figure also illustrates the relationship of this distribution to the soil moisture characteristic.

SOIL DEPTH AND WATER DISTRIBUTION

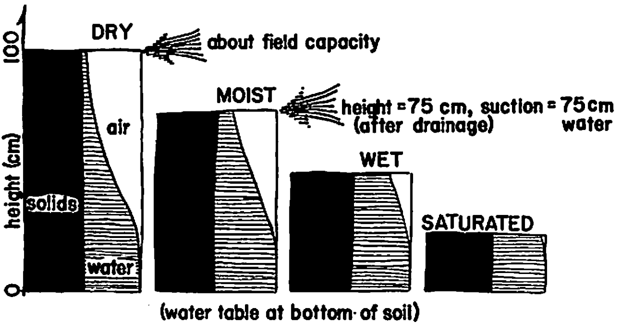

FIGURE 9. The average water content of a soil increases as the soil becomes shallower. The bottom of a drained container soil is always saturated and the water content decreases with height above the bottom of the water content at the top of a soil decreases with increasing soil depth.

Following irrigation, a coarser soil (sand) will probably be much drier at the top of a container than a finer soil (silt) and the coarser soil may not provide a good water supply for shallow-rooted plants whereas a finer soil probably will (Figure 10). A fine soil, however, might contain *too much* water resulting in *poor aeration;* this, of course, depends on the soil moisture characteristic and soil depth.

In summary, water is generally uniformly distributed throughout deep soils but not uniformly distributed throughout shallow (container) soils following irrigation and drainage. The distribution of soil moisture in a container depends on the soil moisture characteristic and the soil depth.

SUMMARY

Water is a very important requirement for plant growth. All the water used by plants is absorbed from the soil. The most important aspect of soil moisture in relation to plant growth is its availability for plant use. The

SOIL MOISTURE DISTRIBUTION AND AVAILABILITY

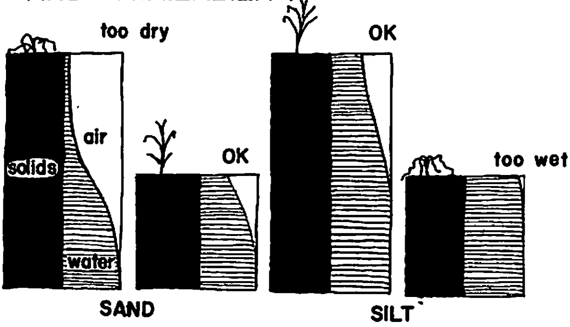

FIGURE 10. Soil moisture distribution in a container affects the availability of soil moisture for plant use.

availability of soil moisture depends on soil moisture retention, content, movement, and distribution. Availability also depends on plant factors and on other soil physical, chemical, and biological factors such as aeration, nutrition, temperature, pH, and micro-organisms which are often directly or indirectly influenced by soil moisture. Soil aeration, soil moisture, availability, and soil measurement will be discussed in greater detail in future articles in this series.