Soil Moisture Measurement Methodology

Soil Water Basics

Rainfall and snowmelt are natural sources of soil water and are normally greatly reduced during drought. Slope shape, gradient, and soil surface roughness will affect soil water content since surface or subsurface run-on from adjacent upslope sites can add to the soil moisture, while surface runoff can remove water from a site. Evaporation, plant transpiration, and deep percolation beyond rooting depth are other factors that deplete soil moisture.

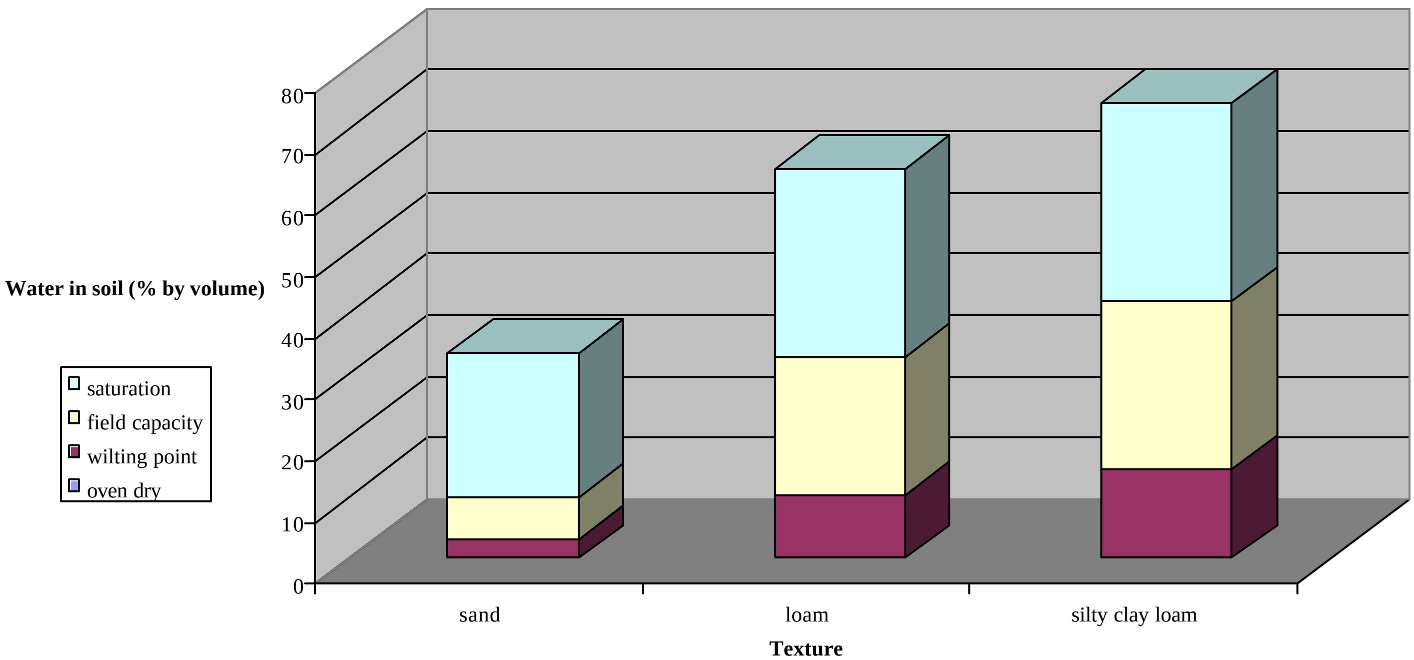
Soil water content must be defined in specific quantitative terms to accurately indicate the amount of water stored in the soil at any given time. At saturation, after heavy rainfall or snowmelt, some water is free to percolate down through the soil profile. This excess water is referred to as gravitational water and can percolate below the rooting depth of some plants. Field capacity is defined as the amount of water remaining in the soil after percolation has occurred. Wilting point is defined as the soil water content at which the potential of plant roots to absorb water is balanced by the water potential of the soil. The amount of water between field capacity and wilting point is generally considered plant-available water content (see Figure 1), although plants can also extract gravitational water while it is available.

The best plant growth occurs when the soil water content remains in the upper half of the plant-available soil moisture range. All plants are under stress when soil moisture is at wilting point or is drier. Rangeland plants utilize various methods to survive when soil moisture drops below the wilting point by going dormant or utilizing water stored in plant tissues. The amount of total soil water content at any soil water tension value varies by soil type depending on soil texture, organic matter content, and structure (see Table 1). Some soil moisture measurement techniques and instruments measure total soil water content and must be converted to plant-available water content to determine rangeland plant stress.

Recommended sample collection or measurement techniques

Soil moisture should be measured at a location most representative of a watershed when climatic data or vegetative conditions indicate a likelihood of drought conditions. A four-phased (early assessment, pre-season assessment, continuing assessment, and post-drought phase) approach to drought detection is recommended in IM No. 2003-074. Visual estimation of soil moisture can be used as a rough initial approximation of droughty soil conditions. Soil moisture measurements should be taken at a minimum of three sample locations at each monitoring site. Sample locations should have similar soil types, vegetation, aspect, slope, and elevation and should not be adjacent to a road or trail. Sampling or measurements should be taken on the same day within a watershed to be comparable. If a large difference in moisture content occurs between samples, it would be advisable to sample an extra location or two. Avoid sampling small areas of low spots or ridges that do not represent the majority of the area of concern. A soil map may be valuable in determining a major change in soil characteristics, such as texture, which will affect soil moisture measurements.

Figure 1. Typical Soil Water Content



Note: Oven dry soil is represented by 0% moisture. The top of the red bar represents wilting point. The top of the yellow bar represents field capacity. The top of the blue bar represents saturation. The yellow bar, from wilting point to field capacity, represents plant available water. Plants can also access gravitational water, represented by the blue bar, before it percolates down into the soil profile.

Table 1. Soil Moisture Relationships Based on Texture

Texture	**Bulk Density** *g/cm^3*	*Average Wilting Point % total soil water (volumetric)*	*Plant Available Water Inches/Foot*
Sandy loam	1.60	5.7	1.66
Silt loam	1.45	11.9	2.00
Loam	1.50	9.7	2.40
Sandy clay loam	1.45	13.7	1.66
Clay loam	1.45	15.7	1.90

Disclaimer: These are average values and can be different than actual field values. These differences can be due to variations in texture, organic matter and structure of the soil in the field, as well as average table values. The only true way to determine the wilting point for a soil is to use a pressure membrane chamber and an undisturbed soil sample. Contact your local NRCS office to obtain more accurate values for soils in your local area.

Measurements should be taken or samples collected at 10–12 inches depth below the soil surface. Use a soil auger to excavate down to the desired depth and collect the soil sample or insert the soil moisture probe into the soil at that depth. A second measurement can be taken at 2 feet and possibly even a third measurement at 3 feet if you desire to measure soil moisture at a deeper rooting depth. The majority of roots of most rangeland plant species are within the top 12 to 24 inches of the soil. Taproots of some rangeland plant species extend down more than 10 feet, but it is impractical to measure soil moisture below 3 feet on a widespread basis. Also, plants typically extract about 40% of their water needs from the top quarter of their root zone, 30% from the next quarter, 20% from the third quarter, and only 10% from the deepest quarter. Measurements to determine potential seeding success should be taken at 0–3 inches depth. Soil samples for the gravimetric method need to be placed immediately in resealable plastic bags or other sealed, waterproof containers to avoid changes in sample moisture.

When reporting your data it is important to note the approximate percentage of rock fragments in the layer you collected your sample or moisture reading from. This makes a large difference in the amount of water available to plants.

Quantitative Methods

Gravimetric (oven dry and weigh)

Basic Principle: The gravimetric method is a direct, absolute technique for estimating the total (both plant-available and plant-unavailable) water content of soils. The method involves drying a soil sample in an oven (105^{o}C [221^{o}F] for 24 hours) to determine the soil moisture content. Water content (grams of water per grams of soil) equals the initial field soil weight minus the oven-dry weight. The best method is to take a soil sample of known volume (usually 60 cm^{3}) so that the soil moisture content can be expressed in terms of percent water by volume or inches of water per foot of soil.

Advantages: This technique is relatively inexpensive, simple, and highly accurate.

Disadvantages: This technique is time-consuming, labor-intensive, and difficult in rocky soils. A lab oven or microwave oven, soil sampling equipment, and lab scale are required.

Readily Available Instruments: Lab ovens and lab scales are available from many scientific instrument companies. Soil sampling equipment is available from many vendors.

Di-electric constant soil moisture probe and meter (TDR and FDR)

Basic Principle: TDR (Time Domain Reflectometers) and FDR (Capacitance) probes or sensors both measure the difference in capacity of a non-conductor (soil) to transmit high-frequency electromagnetic waves or pulses, which is related through calibration to soil moisture content. The difference is that the TDR measures the time it takes for an electromagnetic wave to travel through the soil between the probes. The FDR uses radio frequency waves to measure soil capacitance.

Advantages: The advantages of the TDR and FDR equipment is they are relatively accurate (±1–2%); can provide direct readouts of volumetric, plant-available soil moisture percentages or continuous readings if used with a data logger; don't need calibration; and are relatively unaffected by salts in soil. The TDR is more accurate and less affected by salts while the FDR can detect "bound" water in fine particle soils, which is still available to plants. Thus, if you have extensive acreages salt-affected soils, the TDR instrument would be preferable, while if you are dealing with primarily fine-textured, non-saline soils, the FDR instrument would be preferable. In general, these instruments are accurate, reasonably affordable, easy to use, and very suitable for Bureau needs.

Disadvantages: These instruments are more expensive than some methods, readings can be affected if good contact is not made with soil, and prongs can be damaged in hard or rocky soils. The TDR has complex electronics and is the most expensive, whereas the FDR is more susceptible to soil salinity errors. Data logger readings are in the form of graphs, which must be interpreted.

Readily Available Instruments: TDR instruments range in price from approximately $500 to $4,400 for one pair sensors and hand-held display unit or data logger. Manufacturers include Campbell Scientific, Stevens Vitel, Spectrum Technologies, Environmental Sensors Inc., and Imko. The hand-held display units are very portable and quite easy to use and interpret. Field offices desiring continuous monitoring of soil moisture will need to use a data logger. FDR instruments range in price from approximately $475 to $895 for one pair sensors and hand-held display unit. Manufacturers include Aquaterr Instruments, Delta T Devices, and Decagon Devices.

Neutron Probe

Basic Principle: This instrument measures the slowdown of fast neutrons emitted into the soil resulting from collision with soil water molecular hydrogen. Thus, it measures the amount of total water in a volume of soil (6- to 12-inch sphere) based on the rate of neutron slowdown.

Advantages: The neutron probe allows a rapid, accurate, repeatable measurement of soil moisture content to be made at several depths and locations.

Disadvantages: The major disadvantages are the use of radioactive material requiring a licensed and extensively trained operator, the very high equipment cost ($3,500–$4,500), and extensive calibration required for each site.

Readily Available Instruments: Neutron probes manufacturers include Campbell Pacific Nuclear International, Troxler Electronics, and Geoquip.

Qualitative Methods

Gypsum-porous blocks/electrical resistance

Basic Principle: Soil moisture blocks operate on the principle that the electrical resistance of a porous block is proportional to its water content. Ceramic thermal dissipation blocks are available which measure the rate of heat dissipation in the soil, which correlates to soil moisture content.

Advantages: The method is quick, repeatable, and relatively inexpensive.

Disadvantages: The blocks don't work well in coarse-textured, high shrink-swell, or saline soils. Accuracy is rather poor unless blocks are individually calibrated for the soil being monitored using a pressure plate extractor or gravimetric method. Blocks should be replaced every 1 to 3 years. A major consideration is that the sensitivity of the blocks is poor in dry soil conditions. The blocks need to be soaked in water for several hours before installing them in the field.

Readily available instruments: The blocks generally cost between $5 and $15 with meters costing approximately $200. Thermal dissipation blocks are more expensive, $35 to $50 per block and $150 to $600 for the meter. Manufacturers include Soil Moisture Equipment Corp., Delmhorst, Watermark, Measurement Engineering Australia, and many vendors sell these products.

<u>Calcium carbide gas pressure meter (Speedy Moisture Tester)</u>

Basic principle: Calcium carbide reagent reacts with the free moisture in the weighed soil sample to produce acetylene gas, resulting in an increase in pressure within a sealed vessel. The percentage of moisture content based on the wet weight of soil is then read directly from the calibrated pressure gauge. This meter is widely used for civil engineering projects and non-soil material. Readings need to be converted to the percentage of moisture content based on the dry weight of soil using the following formula:

$$\%\ \text{Moisture}_{\text{(Dry Wt.)}} = \frac{\%\ \text{Moisture}_{\text{(Wet Wt.)}} \times 100}{100 - \%\ \text{Moisture}_{\text{(Wet Wt.)}}}$$

Advantages: This equipment is easy to use, reliable, accurate ($\pm$1–2%), fairly fast, and does not need to be calibrated for different soils.

Disadvantages: The test kit is somewhat bulky if carrying for long distances, fairly expensive ($1,100–$2,085), conversion of reading is required, and it is not widely used for soil moisture measurement. Two common problems, which may require factory repair, are 1) the pressure gauge may lose its calibration, and 2) the tiny passage between the main chamber and the pressure gauge may become plugged. The calcium carbide reagent forms explosive or flammable acetylene gas when wet so it must be kept dry. This is not a significant danger as long as the reagent storage container is kept well sealed and dry. In conclusion, there are cheaper, easier to use instruments available that are equally accurate.

Readily available instruments: Ashworth Instrumentation manufactures The Speedy Moisture Tester and many vendors sell this product.

Tensiometers

Basic principle: A tensiometer is an airtight, hollow tube filled with water. A porous ceramic cup is attached to the end of the tube inserted into the soil and a vacuum gauge is attached to the upper end. The tensiometer measures soil moisture tension, an index of how tightly water is held in the soil. A soil moisture retension curve is developed for each horizon of the soil to determine soil water content.

Advantages: They are not affected by the amount of salts dissolved in the soil water. They measure soil moisture tension with reasonable accuracy in the wet range.

Disadvantages: They only operate between saturation and about –70kPa. Thus they're not suited for measurements in dry soils or for Bureau use.

Observable soil characteristics

Basic principle: A set of observable soil characteristics can be used to estimate the percentage of plant-available moisture in the soil profile or within the root zone of desirable vegetation. Photo and descriptive guides are available (see Table 2).

Advantages: This method is fast and simple so many locations can be sampled quickly. It can be used to make preliminary estimates of soil moisture and for making quick comparisons within a sample site.

Disadvantages: The estimation of soil moisture is subjective and describes broad ranges of soil moisture. Estimations can vary considerably between individuals applying the method, especially if they are inexperienced in using it. This method is not adequate for estimating soil water content for management decision making.

Summary

In summary, a variety of methods are available for measuring soil moisture to help determine drought conditions. The method and equipment selected will depend on ease of use, cost of equipment, applicability to drier rangeland conditions, and desire to monitor continuous changes in soil moisture. Additional sources of information on soil moisture can be found on the Web. The Natural Resources Conservation Service National Water and Climate Center has a Soil Climate Analysis Network (SCAN) with real-time soil moisture and temperature at www.wcc.nrcs.usda.gov/scan/. NOAA and the National Weather Service Climate Prediction Center have U.S. soil moisture monitoring and soil moisture outlook information at www.cpc.ncep.noaa.gov/soilmst.

Table 2. A Field Guide for Estimating Plant Available Moisture by Feel and Appearance

This table contains a set of observable soil characteristics that can be used to estimate the percentage of plant- available moisture in the soil profile or within the root zone of desirable vegetation.

To use this table, determine the textural category (Coarse, Light, Medium, Heavy) of the soil sample and with a palm-full of soil, form a ball of soil and, making a fist, squeeze with the pressure of a strong hand shake. Open hand and compare your observation of the soil condition against the descriptions in the column for the textural category you have chosen. Also try forming a ribbon of the soil material between your thumb and forefinger. Consider taking separate samples from various depths or zone(s) of interest in the soil profile, keeping in mind that textural categories may vary with depth.

Plant-Available Soil Moisture as a Percentage	General Textural Categories			
	Coarse (fine sand, loamy fine sand and coarser)	**Light (sandy loam and fine sandy loam)**	**Medium (sandy clay loam, loam, and silt loam)**	**Heavy (clay, clay loam, or silty clay loam)**
0 to 25%	Dry, loose, single grained, flows through fingers.	Dry, loose, flows through fingers.	Dry, powdery, or aggregates easily break down into a powdery condition.	Hard, baked, cracked, sometimes has loose crumbs on surface
25 to 50%	Appears to be dry, will not form a ball with pressure.	Appears to be dry, will not form a ball.	Somewhat crumbly but will hold together from pressure,	Somewhat pliable, will ball under pressure, no water stains, clods flatten with applied pressure
50 to 75%	Moist, tends to stick together slightly but crumbles easily, will not form a ball, will not ribbon	Moist, tends to ball under pressure but seldom holds together,	Moist, forms a ball, somewhat plastic; will sometimes slick slightly with pressure, forms a weak ribbon between the thumb and forefinger	Moist, forms a smooth ball with define finger marks, will ribbon out between thumb and forefinger.
75 to near Field Capacity (<100%)	Wet, tends to stick together slightly, may form a very weak ball under pressure, darkened color, will not ribbon	Wet, forms a weak ball, breaks easily, will not slick, forms slight wet outline on hand, makes a weak ribbon between the thumb and forefinger	Wet, forms a ball and is very pliable; slicks readily if relatively high in clay, light to heavy soil/water coating on fingers, ribbons between thumb and forefinger	Wet, easily ribbons out between fingers; slick feeling, uneven medium to heavy soil/water coating on fingers
At Field Capacity (100%)	Wet, forms a weak ball, loose and aggregated sand grains remain on fingers, darkened color, wet outline of the ball is left on the hand.	Wet, forms a soft ball, medium to heavy soil/water coating on fingers	Wet, forms a soft ball, medium to heavy soil/water coating on fingers	Wet, forms a soft ball that resists deformation, slick, sticky, thick soil/water coating on fingers
Above Field Capacity (>100%)	Free water appears when soil is shaken or bounced in the hand.	Free water will be released with kneading	Can squeeze out free water.	Puddles and free water comes to the surface when shaken or bounced in the hand.

Adapted from: Pacific Region Pocket Handbook, USDA - SCS - E–15 and Water Management Note-Estimating soil moisture by feel and appearance, High Plains Underground Water Conservation District No. 1.

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