TECHNICAL NOTES

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCES CONSERVATION SERVICE
PORTLAND, OREGON FEBRUARY 2013

SOIL TECHNICAL NOTE 1

PROCEDURE FOR MAKING KNOWN MOISTURE SOIL SAMPLES FOR IRRIGATION WATER MANAGEMENT PURPOSES

Irrigation water management (IWM) requires an understanding of soils and soil physical characteristics. Soil texture, structure, bulk density, organic matter content, salt levels, and rocks in soils are variables that influence water-holding characteristics.

The purpose of this document is to supplement the "Estimating Soil Moisture by Feel" method of soil moisture monitoring. The ability to feel a soil and estimate the water content requires experience best developed by practice. Known moisture samples can provide NRCS employees and irrigators with a calibration to how local soils feel over a range of known water contents. Estimating soil moisture by feel provides irrigators with a straight forward and quick means of moisture monitoring, and it also provides a quick check on any instrumentation used. Instrumented soil moisture monitoring is sometimes not attractive to irrigators for various reasons and this may provide a less expensive alternative.

The following link is to the color brochure, Estimating Soil Moisture by Feel and Appearance:
http://www.mt.nrcs.usda.gov/technical/ecs/agronomy/soilmoisture/index.html

Soil water retention curves can be developed for soils using laboratory procedures. These soil specific plots of soil water tension over the entire range of water contents require careful field sampling, and are costly and time consuming. Soil bulk density measurements are dependent on management, are time consuming and require repetitions for accuracy. The highly variable nature of soils and the complexity of accurately measuring soil water content are reasons for a scarcity of soil water data. Even when data are available they are often under utilized.

CONCEPTS OF SOIL WATER-HOLDING CHARACTERISTICS

Soil is a collection of mineral and organic particles of varying sizes. Voids between individual particles provide spaces for air, water, microorganisms, and plant roots. Each soil is unique in combinations of varying sizes of particles (soil texture), organic matter

content, rock fragments, and salt levels. These are factors that influence how a soil holds and releases water**.** Appendix 1 contains a glossary of definitions of the bold terms used in this section.

Soil texture is the principal physical property in soils that determines water holding characteristics. Soil texture, structure and compaction determine the percent porosity of a soil. Fine texture (clayey) soils contain the highest proportion of pore spaces. Sandy soils contain larger individual pores, but less total pore space. The large pore spaces in sandy soils allow rapid water movement and little water retention. While small pores in fine textured soils relate to slow **soil permeability** and high water retention. Soil water is held tightly by capillary tension in small pore spaces. Plants must overcome this tension to extract water. Sandy soils hold most of their water at low tensions, making soil water readily available for plant use. Conversely, fine textured or clayey soils hold water tightly with a substantial portion of water held at tensions too great for plants to extract. **Permanent wilting point** describes water held at tensions too great for plants to utilize.

Field capacity is the amount of water held in a soil after gravitational water drainage stops. This is water contained in a soil a few hours to a day after a soaking rain or irrigation. Field capacity includes plant unavailable water held at or below the permanent wilting point. Plant **available water holding capacity** is the amount of water held between wilting point and field capacity.

Soil **bulk density** is related to soil porosity and soil texture. Because finer textured soils have more total pore space the bulk density is lower, while sandy soils have less total pore spaces and higher bulk density. Soil compaction results in the loss of pore space and so in the loss of water holding capacity. Bulk density relates percent water by weight to percent water by volume. Percent water by volume is useful for irrigation management. It is easily converted to a depth of soil water per depth of soil (inches of water per inch of soil depth).

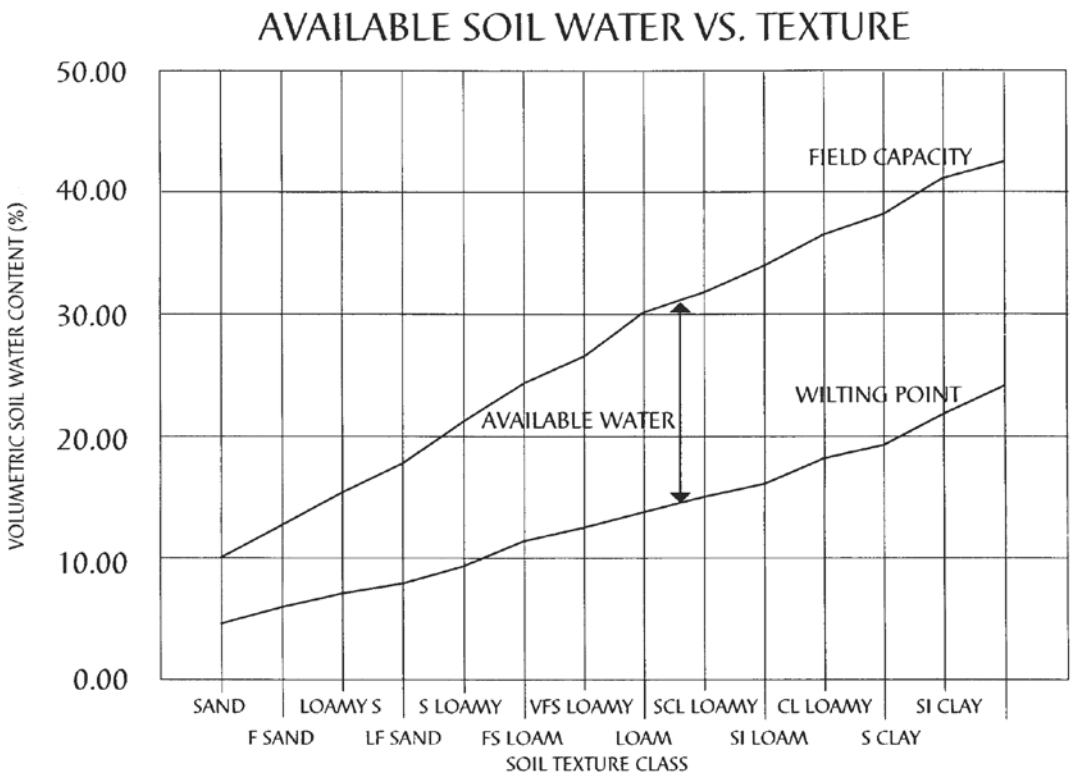


Figure 2. Available soil water vs. soil texture showing estimates of field capacity, permanent wilting point.
S-SAND, SI-SILT, CL-CLAY, F-FINE, VF-VERY FINE, L-LOAMY

From Pacific Northwest Extension Publications, PNW 475, "Soil Water Monitoring & Measurement"

The plot in Figure 2, illustrates many of the concepts in this section. The trend of the field capacity line shows increasing water holding capacity as clay content increases with associated increasing total pore space. Consequently, the wilting point increases as average pore space becomes smaller. Available water, or area in the graph between wilting point and field capacity, increases from sand to loam textures and then increases very little from silt loam to clay textures.

SOIL WATER CHARACTERISTICS MODEL

An interactive soil textural triangle is available through the National Water and Climate Center, on their Irrigation – Water Management Models web page. The page link is http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/irrigation/?cid=stelprdb1044890 under the SPAW and Soil Water download button.

This model allows the user to determine soil water characteristics based on soil texture. Based on inputs of percent sand and clay, the model provides values for field capacity, wilting point, saturation, available water, bulk density, and saturated hydraulic conductivity, as shown in Example 1.

This tool provides good estimates of the soil characteristics that influence water holding capacity based on field estimated percent sand and clay. The model is based on research that developed statistical correlations between soil texture and selected soil potentials using a large data base.

PROCEDURE FOR MAKING KNOWN MOISTURE SAMPLES

Items needed to complete this process are a gram scale, a graduated cylinder, a soil drying oven, and someone to accurately hand texture soil samples. The following procedure uses the *Soil Water Characteristics from Texture* program described above. An experienced soil scientist can provide a good estimate of the percent sand and clay needed to run the model.

Careful selection of a sampling site is important to collect soils that represent as broad an area as possible. Irrigated soils that are extensive in an area and soil horizons that are representative throughout the root zone of common crops should be collected.

Field capacity moisture can be determined by collecting soil samples from intact soil profiles a few hours after a thorough wetting from rainfall or irrigation. If the soil is clayey or the weather is cool and overcast, collect the sample the following day after wetting. See Appendix 1 and the discussion above for a definition of field capacity. Alternately, or as a check, the field capacity moisture percent by volume can be derived from the Soil Water Characteristics program with a field estimate of percent sand and clay. A precision instrument such as a neutron probe or time domain reflectometer (TDR) can also be used to determine soil moisture. If the field sampled water level and modeled field capacity by volume do not agree, compaction of the soil layer or incomplete wetting is a possibility.

Collect at least 500 cm_3 (1/2 gallon) of soil in an air tight container. Double bagging is recommended to preserve the moisture content at time of sampling. Oven drying of soil samples should be at 220º Fahrenheit (105º C) for a 24 hour period. Oven dry soil is needed to make known samples as well as to determine percent moisture from the field. Soil drying ovens are available in some NRCS offices. Drying should continue until weight of sample is stable on subsequent weighing.

After the percent clay and percent sand are determined for the sample, enter those numbers in the Soil Water Characteristics textural triangle program and use data in metric units to complete worksheet 1 (Excel sheet attached). Section A of Worksheet 1 should always be completed with data from the Soil Water Characteristics program. Section A may also be used to calculate water in a sample if the interest is scheduling irrigation or determining moisture depletion based on the textural triangle model data.

Section B of worksheet 1 is used to calculate the water holding capacity of a soil collected. When using this section of the worksheet, first complete data entry to section A. Wilting point water and bulk density from the model are used in Section B. Field

capacity and other calculated data are based on the field collected data. If field capacity by volume calculated in this section is drastically different from field capacity by volume in Section A check calculations.

After oven drying the soil and completing Worksheet 1, rewet the soil to make known moisture samples. Weigh 100 grams of oven dry soil and place in a zip lock plastic bag. **Water should be added to the sample according to the percent weight column from Worksheet 1**. To make a wilting point water content sample, if Worksheet 1 wilting point by weight is 10 percent, add 10 milliliters or 10 grams of water to 100 grams of oven dry soil. The use of 100 gram samples of oven dry soil allows the percent weight calculations to directly complete a set of known moisture samples for a given soil.

Double and triple bag the samples to assure water content is retained until needed. After extensive use samples should be dried and rewet.

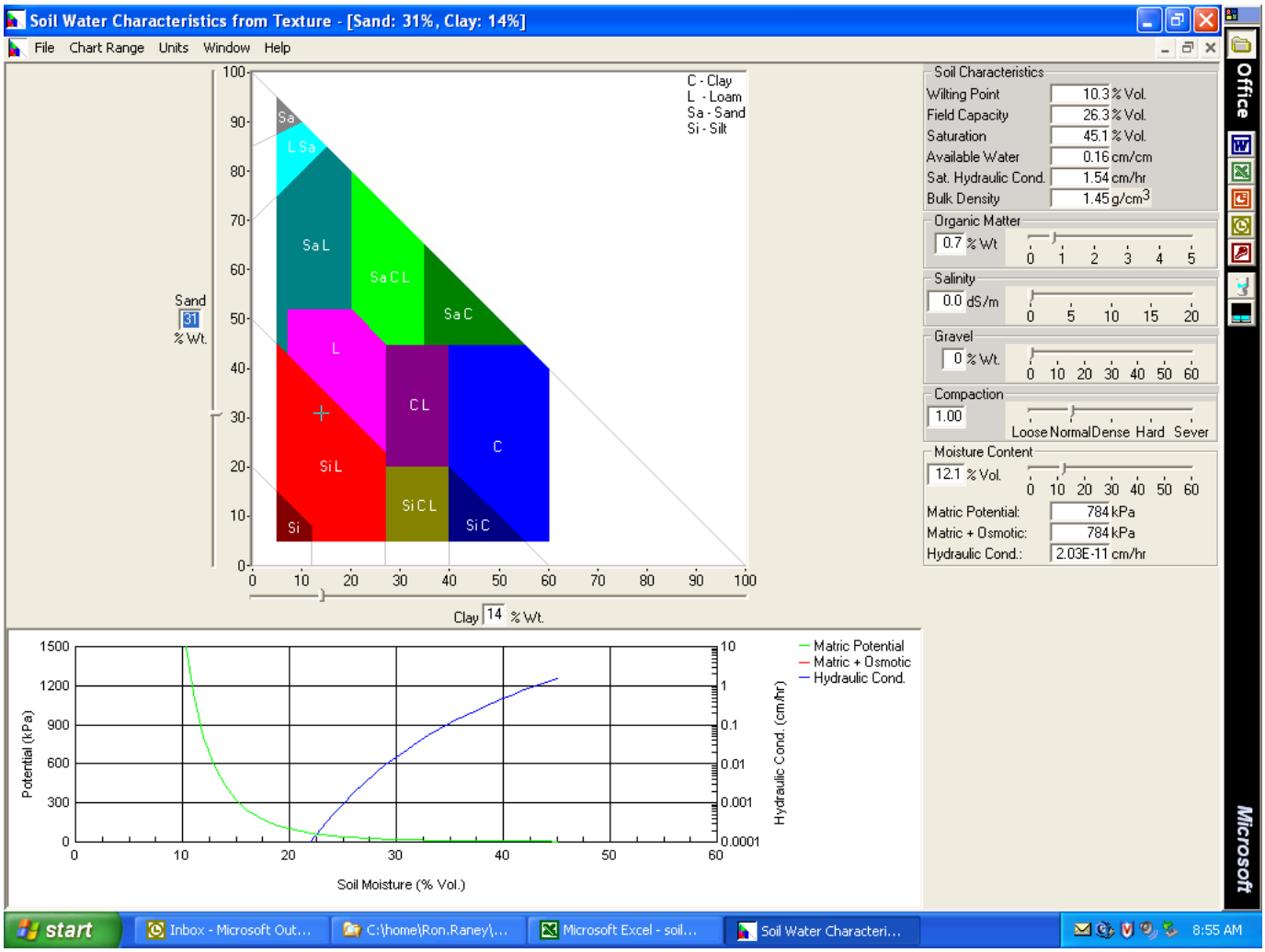
Summary Procedure

1. Determine purpose of sampling
   a. Known soil moisture samples using Soil Water Characteristics model. Soil texture only needed from field (Example 2).
   b. Known moisture samples and field moisture determination. Soil is collected at moisture level of interest (Example 3).
   c. Known moisture samples from field sampled soils at field capacity. Take soil after a soaking irrigation or rain event (Example 4).
2. Collect 500cm^3 (1/2 gallon) of moist soil in air-tight container at appropriate soil moisture level.
3. Obtain estimate of percent sand and clay to use Soil Water Characteristics model (Example 1).
4. Transfer data from Soil Water model to Soil Moisture Calculation Worksheet Part A (blue cells).
5. Weigh approximately half of wet soil collected. Carefully weigh and record wet weight. Dry at about 220º Fahrenheit for 24 hours or until weight is stable on reweighing. Reseal and save remainder of wet soil.
6. When weight is stable on reweighing, record dry weight.
7. If interest is only known soil moisture samples using model, weigh 100 grams of oven dry soil and place in zip lock bag. Add water in amounts shown in percent water by weight cells from Section A of Worksheet 1 (Example 2).
8. If interest is field moisture determination, enter weights of wet and dry soil in Section A cells. Worksheet will calculate AWC and percent water of sample (Example 3).
9. If interest is determination of soil field capacity, use Section B of Worksheet 1. Enter weights of wet and dry soil in Section B of worksheet.
10. Using worksheet calculated percent water by weights from Section B, rewet oven dry soils to make known moisture samples (Example 4).

11. A set of samples at field capacity, 75 percent of FC, 50%, 25%, and WP can provide a reference for estimating when to irrigate and provide calibration for soil moisture instrumentation.

An example of Soil Water Characteristics interactive textural triangle is shown below.

EXAMPLE 1



Click within the textural triangle or directly enter percent sand and clay to calculate soil-water characteristics. Units can be changed from metric to English. For excel worksheet entries use metric units. Entries to the organic matter, salinity, gravel, or compaction areas trigger adjustments to soil characteristics data. Soil characteristics data is to be copied to excel worksheet for known moisture sample projects. Link to download this tool is http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/irrigation/?cid=stelprdb1044890

EXAMPLE 2

WORKSHEET 1 -- SOIL MOISTURE CALCUATIONS
(manual entries in blue)

Soil Series/Map Unit	Powval MU 126A			Date	8/25/2004
Texture	silt loam	% clay	31	% sand	14
Location-ownership	Smith Baker Co. T6S, R29E, Section 26				

A. SOIL MOISTURE CHARACTERISTICS FROM TEXTURE ENTRIES (from texture triangle tool) Blue cells are data entry.

Wilting point H2O percent volume	10.3	Bulk Density (g/cm3)	1.45	Crop Allowable Depletion % (MAD)	
Field capacity H2O percent volume	26.3	Organic mater % wt.	0.7	Percent of AWC at sampling	
Saturation H2O percent volume	45.1	Salinity (dS/m)	0		
Available H2O (cm/cm)	0.16	Gravel % wt.	0		
Saturated hydraulic conductivity (cm/hr)	1.54	Compaction	0.00		
Field capacity H2O percent Weight	18.1	Weight of wet soil and container (grams)			
Percent H2O by weight at 75% AWC	15.4	Weight of container (tare wt. grams)			
Percent H2O by weight at 50% AWC	12.6	Weight of field wet soil (grams)			
Percent H2O by weight at 25% AWC	9.9	Oven dry wt. soil (grams)			
Percent H2O by weight at WP	7.1	Percent H2O by weight (field)			

If AWC at sampling above is less than crop allowable depletion, irrigation is needed.

B. Field determination of soil field capacity (FC) (manual entries in blue)

enter following blue cells only if soil collected and oven dried to determine field capacity water		bulk density and wilting point H2O must be entered in section A	
Weight of wet soil and container (grams)		Bulk Density (g/cm3)	1.45
Weight of container (tare wt. grams)		Wilting point H2O percent volume	10.3
Weight of field wet soil (grams)			
Oven dry wt. soil (grams)		AWC (inch/inch)	
Percent H2O by wt = **FC** field measured		Percent H2O by volume at FC	
Percent H2O by weight at 75% AWC		Percent H2O by volume at 75% AWC	
Percent H2O by weight at 50% AWC		Percent H2O by volume at 50% AWC	
Percent H20 by weight at 25% AWC		Percent H2O by volume at 25% AWC	
Percent H2O by weight at WP		Percent H2O by volume at WP	

To make known moisture samples use percent weight column above. Weigh 100 grams of oven dry soil and add water (1 gram H2O = 1 milliliter H2O) in amounts shown in cells B19 through B23 or B11 through B15.

This example illustrates use of Soil Characteristics textural triangle to calculate soil water using field soil sample percent clay and sand only. To make known soil moisture samples, weigh 100 grams of oven dry soil and add water (milliliters or grams) in amounts shown in Section A. For example, 100 grams of oven dry soil and 12.6 milliliters of water equal a 50% of available water soil sample. Blue cell entries were copied from previous page after field determined texture was entered.

EXAMPLE 3

WORKSHEET 1 -- SOIL MOISTURE CALCUATIONS
(manual entries in blue)

Soil Series/Map Unit	Powval MU 126A			Date	8/25/2004
Texture	silt loam	% clay	31	% sand	14
Location-ownership	Smith Baker Co. T6S, R29E, Section 26				

A. SOIL MOISTURE CHARACTERISTICS FROM TEXTURE ENTRIES (from texture triangle tool) — Blue cells are data entry.

Wilting point H2O percent volume	10.3	Bulk Density (g/cm3)	1.45	Crop Allowable Depletion % (MAD)	50
Field capacity H2O percent volume	26.3	Organic mater % wt.	0.7	Percent of AWC at sampling	29
Saturation H2O percent volume	45.1	Salinity (dS/m)	0		
Available H2O (cm/cm)	0.16	Gravel % wt.	0		
Saturated hydraulic conductivity (cm/hr)	1.54	Compaction	0.00		
Field capacity H2O percent Weight	18.1	Weight of wet soil and container (grams)	80.00		
Percent H2O by weight at 75% AWC	15.4	Weight of container (tare wt. grams)	5.00		
Percent H2O by weight at 50% AWC	12.6	Weight of field wet soil (grams)	75.00		
Percent H2O by weight at 25% AWC	9.9	Oven dry wt. soil (grams)	68.00		
Percent H2O by weight at WP	7.1	Percent H2O by weight (field)	10.3		

If AWC at sampling above is less than crop allowable depletion, irrigation is needed.

B. Field determination of soil field capacity (FC) (manual entries in blue)

enter following blue cells only if soil collected and oven dried to determine field capacity water		bulk density and wilting point H2O must be entered in section A	
Weight of wet soil and container (grams)		Bulk Density (g/cm3)	1.45
Weight of container (tare wt. grams)		Wilting point H2O percent volume	10.3
Weight of field wet soil (grams)			
Oven dry wt. soil (grams)		AWC (inch/inch)	
Percent H2O by wt = **FC** field measured		Percent H2O by volume at FC	
Percent H2O by weight at 75% AWC		Percent H2O by volume at 75% AWC	
Percent H2O by weight at 50% AWC		Percent H2O by volume at 50% AWC	
Percent H20 by weight at 25% AWC		Percent H2O by volume at 25% AWC	
Percent H2O by weight at WP		Percent H2O by volume at WP	

To make known moisture samples use percent weight column above. Weigh 100 grams of oven dry soil and add water (1 gram H2O = 1 milliliter H2O) in amounts shown in cells B19 through B23 or B11 through B15.

This example illustrates use to determine field soil water. This procedure can be used to calibrate moisture sensors or to schedule irrigation. Soil sample is taken and oven dried. After drying and weighing, enter blue cell data in Section A to calculate percent water by weight and percent AWC of field moist soil. Maximum allowable depletion (MAD) is a crop dependent number and indicates when irrigation should begin. In this example, crop is being stressed and irrigation should begin immediately.

EXAMPLE 4

WORKSHEET 1 -- SOIL MOISTURE CALCUATIONS

(manual entries in blue)

Soil Series/Map Unit	Powval MU 126A			Date	8/25/2004
Texture	silt loam	% clay	31	% sand	14
Location-ownership	Smith Baker Co. T6S, R29E, Section 26				

A. SOIL MOISTURE CHARACTERISTICS FROM TEXTURE ENTRIES (from texture triangle tool) Blue cells are data entry.

Wilting point H2O percent volume	10.3	Bulk Density (g/cm3)	1.45	Crop Allowable Depletion % (MAD)	50
Field capacity H2O percent volume	26.3	Organic mater % wt.	0.7	Percent of AWC at sampling	29
Saturation H2O percent volume	45.1	Salinity (dS/m)	0		
Available H2O (cm/cm)	0.16	Gravel % wt.	0		
Saturated hydraulic conductivity (cm/hr)	1.54	Compaction	0.00		
Field capacity H2O percent Weight	18.1	Weight of wet soil and container (grams)	80.00		
Percent H2O by weight at 75% AWC	15.4	Weight of container (tare wt. grams)	5.00		
Percent H2O by weight at 50% AWC	12.6	Weight of field wet soil (grams)	75.00		
Percent H2O by weight at 25% AWC	9.9	Oven dry wt. soil (grams)	68.00		
Percent H2O by weight at WP	7.1	Percent H2O by weight (field)	10.3		

If AWC at sampling above is less than crop allowable depletion, irrigation is needed.

B. Field determination of soil field capacity (FC) (manual entries in blue)

enter following blue cells only if soil collected and oven dried to determine field capacity water		bulk density and wilting point H2O must be entered in section A	
Weight of wet soil and container (grams)	84.00	Bulk Density (g/cm3)	1.45
Weight of container (tare wt. grams)	5.00	Wilting point H2O percent volume	10.3
Weight of field wet soil (grams)	79.00		
Oven dry wt. soil (grams)	66.00	AWC (inch/inch)	0.18
Percent H2O by wt = **FC** field measured	19.7	Percent H2O by volume at FC	28.6
Percent H2O by weight at 75% AWC	16.5	Percent H2O by volume at 75% AWC	24.0
Percent H2O by weight at 50% AWC	13.4	Percent H2O by volume at 50% AWC	19.4
Percent H20 by weight at 25% AWC	10.3	Percent H2O by volume at 25% AWC	14.9
Percent H2O by weight at WP	7.1	Percent H2O by volume at WP	10.3

To make known moisture samples use percent weight column above. Weigh 100 grams of oven dry soil and add water (1 gram H2O = 1 milliliter H2O) in amounts shown in cells B19 through B23 or B11 through B15.

This example illustrates use to determine field capacity and available water holding capacity from field sample. Wilting point water is from Soil Water Characteristics tool. Soil samples are taken after a soaking rain or irrigation. Known moisture samples are made using percent water by weight cells from Section B. For example, 100 grams of oven dry soil and 16.5 grams of water equal a 75% of available water sample. If large discrepancies exist between Section A and B percent water by weight check work. Field wet soil samples taken should be saved and should be large enough to weigh and dry a second soil sample.

Appendix 1

IRRIGATION WATER MANAGEMENT DEFINITIONS—SOILS

Soil texture is percent sand, silt, and clay sized particles. All soils described in county soil survey have textural names and percent clay ranges attached to them.

Soil permeability or **saturated hydraulic conductivity** relates to the rate that water moves through a soil layer. Soil surveys include estimates of permeability for all soils described. Values are in inches/hour or metric equivalents.

Infiltration is the rate that water enters the surface soil. This property varies depending on moisture content of the surface soil, slope of the soil, surface crusting, vegetation on the surface, and recent management activities such as tillage. NRCS offices have engineering guides that estimate infiltration rates on agricultural soils.

Soil bulk density (BD) is the weight per unit volume of soil. This property is estimated for all soils in soil survey publications. BD is related to the size of soil particles (texture) and the total pore space in a soil. BD is commonly measured in grams per cubic centimeter or pounds per cubic foot.

Field capacity (FC) is the total amount of water that a soil can hold after gravitational water or internal drainage loss stops. FC is the amount of water present at about 0.33 to 0.1 bars or 10 to 33 KPa of tension. Saturation is the point where water is free or at zero tension.

Permanent wilting point (PWP) is the water content where plants can no longer extract water from the soil. The remaining water in the soil is held at a higher tension than the plant can exert. PWP depends upon both plant and soil characteristics. Value of PWP has been experimentally determined to be about 15 bar or 1500 KPa of tension.

Available water holding capacity (AWC) is the difference between field capacity and wilting point. Soil surveys include AWC data for all soils described. Units are inches of water per inch of soil or metric equivalent.

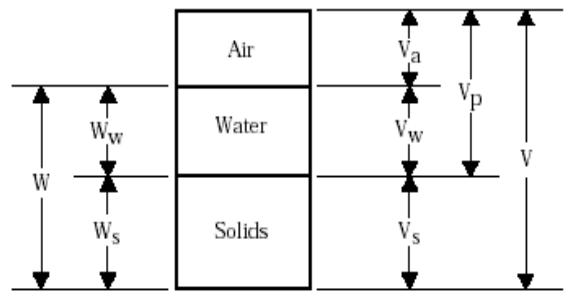
Management allowable depletion (MAD) is a percentage of available water that can be safely depleted from a soil root zone before moisture stress in crop occurs. This value varies by crop and by the stage of crop growth. For example, most orchard crops have a MAD of 50-65% of AWC, alfalfa is in the area of 65%, and potatoes are about 35% of AWC.

Appendix 2

Exhibit 2–2 Process to determine total volume of water held in a soil

Let:
D_b = bulk density
D_p = particle density (specific gravity)
W_s = weight of soil solids (oven dry)
W_w = weight of soil water
V_s = volume of solids
V_p = volume of pores (both air & water)
V_w = volume of water
$V_s + V_p$ = total soil volume

Schematic:



$$D_b = \frac{W_s}{V_s + V_p} \qquad D_p = \frac{W_s}{V_s} \qquad D_b \times V_s = D_b(V_s + V_p)$$

$$\frac{V_s}{V_s + V_p} = \frac{D_b}{D_p} \qquad \%\ \text{Solids} = \frac{V_s}{V_s + V_p} \times 100 = \frac{D_b}{D_p} \times 100$$

$$\%\ \text{pore space} = 100 - \left(\frac{D_b}{D_p} \times 100\right) \qquad \%\ \text{water} = \frac{W_w}{W_s} \times 100$$

$$\%\ \text{volume of water} = \frac{V_w}{V_s + V_p} \times 100 = \frac{W_w}{W_s} \times D_b \times 100$$

$$\text{Volume of water (in/ft)} = \frac{\%\ \text{volume of water} \times 12\ \text{in/ft}}{100}$$

From NRCS National Engineering Handbook 210-Vi, Part 652, Irrigation Guide

Percent H_2O Weight = ((wet sample wt - dry sample wt.) /dry sample wt.) x 100
Bulk Density (BD) = wt. oven dry soil /unit volume of soil (soil survey displays BD Volume at FC; 0.33 or 0.1 bar)
Percent Volume H_2O = % H_2O wt. x BD
Percent H_2O Weight = % H_2O volume / BD
Soil moisture inch H_2O / inch soil = % volume H_2O / 100
Soil moisture inch H_2O / foot soil = (% volume H_2O x 12) / 100
1 gram H_2O = 1cm^3 H_2O = 1 milliliter H_2O