SOIL MOISTURE MEASUREMENT TECHNOLOGY

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Achieving maximum vine performance requires an irrigation management program that determines when to irrigate and how much to apply. A key component in making irrigation scheduling decisions is the moisture content of the soil. The soil rootzone serves as a reservoir for moisture. Early in the season, moisture content can be high as a result of winter rainfall. When near harvest, the soil is commonly depleted of soil moisture. Soil moisture can be evaluated to prevent over-irrigation, resulting in the waste of water and fertilizers through leaching, or under-irrigation, causing excessive vine water deficits.

<u>Soil Water</u>

Water in the soil resides within soil pores in close association with soil particles. The largest pores transport water to fill smaller pores. After irrigation, the large pores drain due to gravity and water is held by the attraction of small pores and soil particles. Soils with small pores (clayey soils) will hold more water per unit volume than soils with large pores (sandy soils). After a complete wetting and time is allowed for the soil to de-water the large pores, a typical soil will have about 50% of the pore space as water and 50% air. This is a condition generally called field capacity or the full point.

<u>Measurement of Soil Water</u>

Unlike the measurement of rainfall or irrigation application, water in the soil is measured as a function of a volume of the bulk soil. Soil moisture can be expressed as:

1) Percent of the water on a weight basis (grams/gram)
2) Percent water on a volume basis (in/in)
3) Inches of water per foot of soil (in/ft)

Water in the soil can also be calculated on a weight basis; however, it is not very useful without converting it to a volume measurement by multiplying water by weight by the soil bulk density [weight (gms) or volume (ml)/cm^3].

Since 1 gm of water = 1 cc volume

$$\frac{\text{water weight or volume}}{\text{soil weight}} \text{ x bulk density} = \frac{\text{volume water}}{\text{volume soil}} \text{ or } \frac{\text{water(in)}}{\text{soil(in)}}$$

The best method of measuring the volume of water in a volume of soil (in/in) is to take a soil sample of known volume (usually 60 cc), dry the soil to determine the water content and dry soil weight.

$$\frac{\text{inches water}}{\text{inches soil}} \text{ x 12 inches = inches water/ft soil}$$

The most useful expression is the inches of water contained per foot of soil. This measurement can be repeated throughout the extent of the rootzone and totaled as the rootzone water content.

This volumetric measurement of soil water can be valuable when:

1) Determining irrigation volume requirement to fill rootzone
2) Measuring the volume of water extracted from one date to another
3) Establishing a rootzone “full point”
4) Establishing a rootzone “dry point”
5) Determining the available soil water (wet point—dry point)

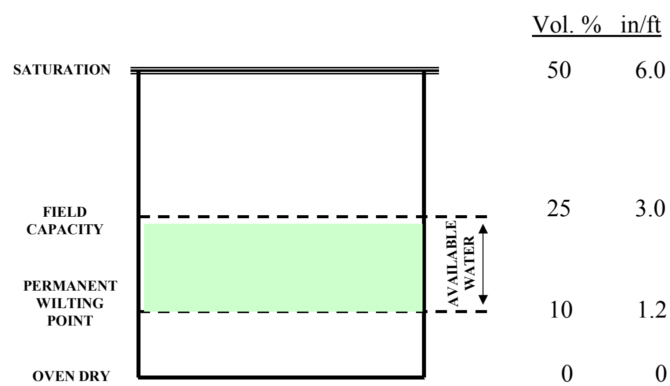
As a general rule when 50 percent of the available water's depleted, it is necessary to irrigate to prevent vine water stress. When salts in the rootzone are excessive, a lesser depletion is used to prevent excessive plant stress.

Plant Available Soil Water

The soil moisture content of the soil varies from a low point where extraction by the vine stops (permanent wilting point, PWP) and a high point when the pores are full of water (soil saturation). After a significant irrigation or rainfall event and the soil has drain time to usually about 48-72 hours, the soil is said to have reached field capacity (FC). This is the point where most of the large pores have de-watered. The moisture between field capacity and the permanent wilting point is known as the plant available water (Figure 1).

FC – PWP = Plant Available Water

Figure 1. Soil Water Content

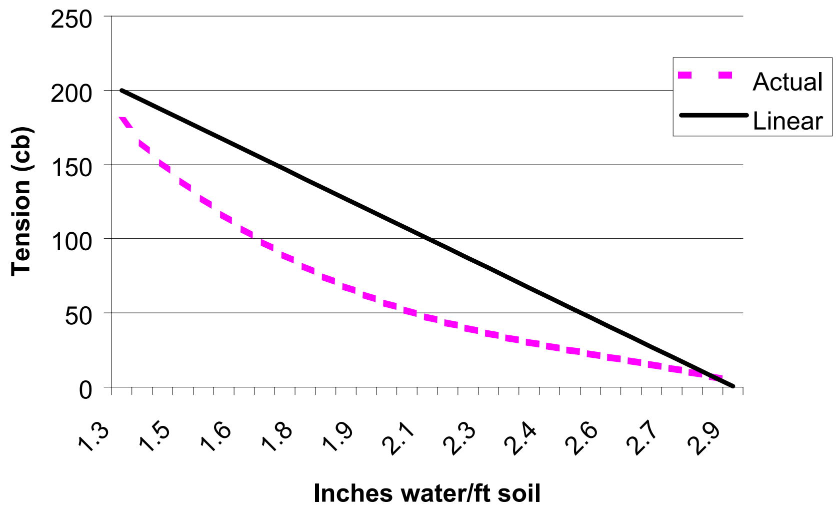


The terms, field capacity and permanent wilting point, are conceptual, as the actual soil moisture values will vary in each soil due to differences in soil texture and structure. Soil water can be measured throughout the unavailable through saturated levels; however, the most useful is between the lower point near the permanent wilting point and field capacity.

The availability of soil moisture is not linear when relating soil tension to water content between field capacity and the permanent wilting point (Figure 2).

Available soil moisture is measured in units of tension. Other terms for tension often used are soil suction, matric potential or water potential. All are an indication of how tightly water is held by the soil. Units of tension in soils vary from 0-1500 cb at saturation and PWP, respectively. Tension in a medium textured soil will typically vary from 2 cb (after irrigation) to as much as 70 cb, before the next irrigation.

Figure 2. Water Content and Soil Tension (with linear line for comparison)



DEVICES TO MEASURE SOIL WATER CONTENT AND WATER AVAILABILITY

Soil moisture is measured in two very distinctly different methods—quantitatively, which means by amount, and qualitatively, which is an indication of how tightly the water is held by the soil particles.

<u>QUANTITATIVE METHODS</u>

- gravimetric soil sampling
- neutron scatter
- di-electric constant

Each of these methods can provide the user a quantitative soil moisture value usually in inches of water per foot of soil. Multiple measurements can be made in the rootzone, typically in one-foot increment. Adding up each individual depth readings will provide the total moisture content of the rootzone. By comparing the total rootzone content of date one to that of a subsequent date, the amount of moisture depletion or recharge in inches can be determined.

<u>Gravimetric Soil Sampling</u>.
The gravimetric method is a direct, absolute technique for estimating the **<u>total</u>** (both available and unavailable) water content of soils. The method involves drying a soil sample in an oven (105°C) to determine the amount of water in the soil (by subtracting the oven-dry weight from the initial field soil weight). The weight of the water is then divided by the oven-dry soil weight to obtain the water content by weight (g/g). If a specific volume of soil is used, the volumetric water content can be determined. This method is time consuming, labor-intensive, and requires sampling equipment, weighing scale and an oven. A large number of samples must be taken to overcome the inherent spatial variability of soils and water content. Since this method is destructive, samples cannot be taken from exactly the same point on subsequent sampling dates. This method is commonly used to calibrate indirect methods such as neutron probe or di-electric constant methods.

<u>Neutron Scatter</u>
The neutron scatter device, often referred to as neutron probe, measures **<u>total</u>** soil water content if properly calibrated by gravimetric sampling. This method estimates the amount of water in a volume of

soil by measuring the amount of hydrogen in the measurement area. By far the largest hydrogen-containing compound in soils is water. The probe supplies a source of fast, high-energy neutrons and a detector housed in a unit, which is lowered into an access tube installed in the soil. The probe unit is connected by cable to a control unit at the surface. The probe is lowered to specific depth to make readings throughout the rootzone.

Fast neutrons emitted from the source pass through the access tube into the surrounding soil gradually lose energy through collisions with other atoms. Hydrogen molecules in the soil are most effective in slowing the fast neutrons since they are nearly equal in mass. As a result of the collisions, a cloud of slow or thermolized neutrons is produced. The detector contained in the probe unit measures this cloud. The size and density of the cloud depends mainly on soil type, access tube material and soil water content. Generally the measurement size is a 6 to 12-inch spherical shape. The number of slow neutrons counted in a specific interval of time is linearly related to the total volumetric soil water content.

Calibration or the relationship of the neutron count to volumetric water content is necessary when using different access tube materials. Steel electrical metal conduit, PVC and aluminum are the most common materials used. Calibrations should also be developed for soils high in organic matter and some ions such as boron.

The neutron probe allows a rapid and repeatable measurement of soil water content to be made at several depths and locations within a field. The ability to repeat measurements at the same location minimizes the effects of soil variability. When calibrated, neutron probes are considered among the most accurate methods for measuring total soil water content.

Neutron probe access wells should be installed at least to the vine rooting depth. The neutron probe is inaccurate when measuring the top 8 inches of soil because portions of the neutrons escape. Neutron probes are available from $3500 - $4500, depending on features. Additional costs in dollars and time are required for special licensing, operator training, handling, shipping and storage procedures.

Di-electric Constant Methods

The di-electric constant methods seek to measure the capacity of a nonconductor (soil) to transmit high frequency electro-magnetic waves or pulses when inserted into the soil. The resultant values are related through calibration to soil moisture content.

The basis for use of these instruments is that dry soil has di-electric values are near 2 to 5 and that of water is 80 when measured between 30 MH_z and $1GH_z$.

Two approaches have been developed for measuring the di-electric constant of the soil water media and estimating the soil volumetric water content:

- Time domain reflectrometry (TDR)
- Frequency domain reflectrometry (FDR)

Both TDR and FDR do not use a radioactive source reducing cost of licensing, training, monitoring when compared to neutron probe.

Time Domain Reflectrometry (TDR)

The TDR device propagates a high-frequency transverse electromagnetic wave along a cable attached to parallel conducting probe inserted into the soil. The signal is reflected from one probe to the other, then back to the meter, which measures the time between sending the pulse and receiving the reflected wave. By knowing the cable length and waveguide length, the propagation velocity can be computed. The faster the propagation velocity, the lower the di-electric constant, and thus lower soil moisture.

Waveguides are usually a pair of stainless steel rods, which are inserted into the soil a few inches apart. The measurement is the average volumetric water content along the length of the waveguide if so calibrated.

Waveguides are installed from the surface to a maximum depth of usually 18-24 inches. Pairs of rods can be permanently installed to provide water content at different depths. If deeper measurements are needed, a pit is usually dug after which the waveguides are inserted into the undisturbed pit wall. The soil disruption can change water movement and water extraction patterns, resulting in erroneous data.

TDR units are relatively expensive at near $8000; however, once properly calibrated and installed, the TDR technique is highly accurate. Since surface measurements can be made easily and in multiple sites, it works well for shallow rooted crops.

Frequency Domain Reflectometry (FDR)

This approach uses radio frequency waves (RF) to measure soil capacitance. The soil acts as the di-electric completing a capacitance circuit, which is part of a feedback loop of a high frequency transistor oscillator. The frequency varies between manufacturer but are generally near 150 mhz. The soil capacitance is related to the di-electric constant by the geometry of the electric field established around the electrodes. The di-electric constant is then related to the volumetric water content as discussed in the TDR method. Two distinct types of instruments use the FDR techniques—an access tube method and a hand-held push probe.

Access Tube Type

An access tube of PVC material is used similar to the neutron probe in that the electrodes are lowered into the access well and measurements are taken at various depths. It is necessary to ensure a very close fit between the walls of the access tube and the soil to ensure reliable values. Air gaps affect the travel of the signal into the soil. Calibration to soil volumetric water content is required (especially in clayey soils and those with high bulk densities) to ensure accurate values. If properly calibrated and installed, the probe's accuracy can be good.

Many of the same advantages of the neutron probe are available with this system including rapid measurements at the same locations and depths over time. Typical costs are near $4,000.

Another variant of this technology is the use of a permanent installation, which reads multiple depths. These are used in conjunction with electronics to make frequent readings and transmit results to a central data collection device. These automated devices can typically cost $12,000 for an array of four sites in a field.

Hand-Push Probe

The other type of capacitance device is a hand-push probe, which allows rapid, easy, near surface readings. These probes provide a qualitative measurement of soil water content on a scale from 1 –100 with high readings equaling higher soil moisture content. Probe use in drier soils and those containing stones or hard pans is difficult. Deeper measurements are possible using a soil auger to gain access to deeper parts of the rootzone. The probe is best used in shallow rooted crops. Cost is moderate at near $500.

QUALITATIVE METHODS

- Tensiometer
- Porous Blocks

These methods measure how tightly (measured in tension units) the soil moisture is held by soil particles. Soil water tension, soil water suction or soil water potential are all terms describing the energy status of soil water. As the tension increases, water extraction becomes more difficult for the plant. The relationship between soil tension and soil moisture content is not linear and is often different in each soil and can vary by depth. Therefore, these qualitative methods are used to determine the status of plant water availability not a quantity of water contained in the soil. Qualitative measurements of soil moisture have often been called a measurement that indicates when to irrigate rather than how much to irrigate.

Since each of these devices measure only a single point measurement and are generally not portable, an array of measurements is necessary to represent the moisture content in the rootzone. Typical depth locations are ¼, ½, and ¾ of the rootzone. The number of sites in a field is determined by field size and soil variability. Typically, a minimum of three sites is necessary to characterize even the most uniform field.

Tensiometers
Tensiometers are water filled plastic tubes with hollow ceramic tips attached on one end and a vacuum gauge and airtight seal on the other. These devices should be installed at the desired depth in the soil with the ceramic tip in good contact with soil particles. The water in the tensiometer eventually comes to pressure equilibrium with the surrounding soil through the ceramic tip. When soil dries, soil water is pulled out through the tip into the soil creating a tension or vacuum in the tube. As the soil is re-wetted, the tension in the tube is reduced, causing water to re-enter the tip, reducing the vacuum.

Most tensiometers have a scale from 0-100 centibars. The practical operating range is from 0-75 centibars. A lower (near 0 cb) reading indicates saturated soil conditions. Readings of near 6-10 cb indicate the soil is near field capacity for coarse textured soil, while readings of around 25-30 cb is about field capacity in fine textured soils. At near 75 cb, coarse textured soils will be nearly 100 percent depleted of available water but is only about 35 percent for fine textured soils.

Tensiometers require careful installation and maintenance are to insure reliable results. Installations should be protected from field hazards and have good soil contact with the ceramic tip. After extreme drying/wetting cycles, refilling may be necessary to replenish water and remove entrapped air. Price varies with tensiometer length, from $50-$75. Tensiometers that use a portable pressure transducer to measure tension are available resulting in less cost for each tube and more cost for the portable meter.

Porous Blocks
Porous blocks are made of gypsum, glass/gypsum matrix, ceramic, nylon, and fiberglass. They are buried at the depth of measurement desired. Overtime, the blocks come to equilibrium with the moisture content in the surrounding soil. Therefore, the subsequent measurement is related to soil water tension.

> Electrical Resistance Blocks. Two electrodes are buried inside the block with a cable extending to the surface. The electrical resistance is measured between the two electrodes using a meter attached to the cable. Higher resistance readings mean lower block water content (and higher soil water tension)
>
> Porous blocks require the same careful installation as tensiometers; good soil contact is important. Maintenance required, however, is much less than tensiometers. Gypsum blocks are proven to breakdown in alkaline soils and will eventually dissolve, necessitating an abandonment or replacement. Soils high in soluble salts may cause erroneous readings, since salts influence soil conductivity and resistance. Gypsum blocks are best suited for finer textured soils since they are not

generally sensitive below 100 cb. For most sandy soils, this would be outside the level of available water. Price varies by manufacturer and type of block but generally are in the $5-$15 range with the necessary meter near $200.

A newer type of gypsum block consists of a fine granular matrix with gypsum compressed into a block containing electrodes. The outside surface of the matrix is incased in a synthetic membrane and placed in a perforated PVC or stainless steel protective cover. The construction materials enhance water movement to and from the block, making it more responsive to soil water tensions in the 30-200-cb range. This makes them more adaptable to a wider range of soil textures.

Thermal Dissipation Blocks. Thermal dissipation blocks are made of a porous, ceramic material. Embedded inside a porous block is a small heater and temperature sensor attached by cable to a surface meter. A measurement is made applying voltage to an internal heater and measuring the rate heat is conducted away from the heater (heat dissipation). The rate of heat dissipation is related to moisture content and, therefore, soil tension.

Thermal dissipation sensors are sensitive to soil water across a wide range of soil water contents; however, to yield water content they must be individually calibrated. These blocks are considerably more expensive than electrical resistance blocks. Price ranges from $150-$600 for the meter and $35-$50 per sensor.

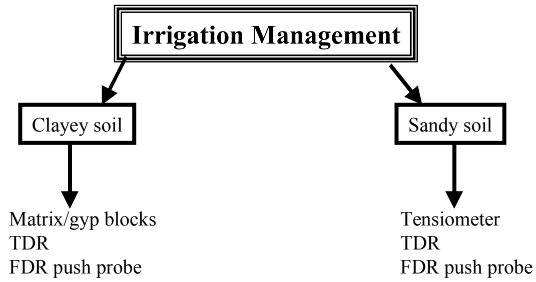
CHOOSING A VINEYARD MOISTURE DEVICE

Throughout this discussion of quantitative and qualitative measurement devices, the advantages and disadvantages of each device were stated. In an attempt to summarize these, following are charts indicating the best use of these devices in the vineyard, depending on the following variables:

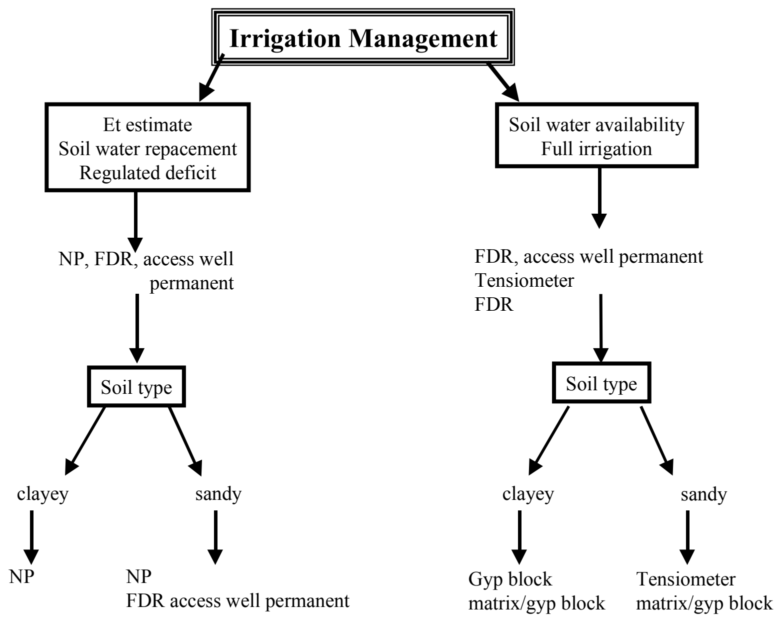
- Vineyard age (developing/mature)
- Irrigation management method
- Soil type

The following choices do not include cost as a factor:

Developing Vineyard



Mature Vineyard



NP = neutron probe
FDR = Frequency domain reflectometry
TDR = Time domain reflectometry

Gyp block = standard gypsum block
matrix block = granular matrix block
tensiometer = tensiometer

So where do we go from here? Additional topics that need be addressed are (1) instrument placements in relation to the vine and (2) when to take readings.