DETERMINATION OF SOIL MOISTURE LEVELS

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WHY MEASURE SOIL MOISTURE?

The purpose of irrigation is to replenish the water stored in soil that has been extracted by living plants and used by them for their growth. Soils store this irrigation water for future use by the plants. Soils, depending on their texture and structure, can store and release limited quantities of water that varies among different soils. The measurement of soil water is useful in several ways as a guide to irrigation management.

Purpose 1

The prime purpose of soil-water measurement is to determine the need for irrigation or the right time to irrigate. Irrigating at the correct time before the soil has become too dry improves crop performance compared to allowing the soil to become dry enough to cause plant stress. Soil-water measurement can improve irrigation efficiency and water conservation by informing the grower that his field does not need irrigating until some time later.

Purpose 2

Another purpose of soil-water measurement is to measure the amount of water at 2 separate dates to permit calculation of water consumption by the crop between the dates of measurement. This tells the rate of water use by the crop during the measured period. The annual water requirement of the crop is determined when such measurements are continued for a year or more.

Purpose 3

The amount of water the soil is able to store from an irrigation can be calculated from the same measurements. This tells how much water can be applied effectively at an irrigation before loss by deep percolation occurs.

Purpose 4

Another purpose for soil-water measurement is to detect problems that may exist related to water in the root zone. The measurements can frequently serve as a guide for correcting problems when they have been detected and determined. A soil may have poor drainage so that irrigation water causes an excessively wet soil or possibly a rising water table. Soil-water measurement can alert the grower to the need for artificial drainage or guide him to limit irrigation until the soil returns to a normal wetness. Poor soil aeration will produce various tree symptoms difficult to explain. Poor aeration is usually associated with or caused by excessive soil wetness, a condition easily shown by soil-water measurement. Steps to correct it can be guided by continuing soil-water measurement.

TYPES OF SOIL–WATER MEASUREMENTS

Soil scientists and many others recognize that there are 2 distinct types of soil-water measurement that can be made (6). Simply stated, one measures the quantity of water in soil, the other measures the degree of wetness produced by the presence of water in soil. Each will be described, its uses stated and the methods for making the measurements outlined.

Quantity of Water

Quantity of water can be measured as the weight fraction of water compared to the weight of soil in which it is contained. It may be stated as the grams of water per gram of soil or pounds of water per pound of soil. Most often it is expressed as percent or grams of water per 100 grams of soil for which the symbol P_w is used meaning percentage of water on a weight basis. The soil is not dry when measured but the calculation is based on the dry weight of soil in which the water is contained.

The measurement is made by collecting a sample of

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the soil to be measured from the appropriate depth and location, placing it immediately in a water-tight container so that it will not dry during collection of further samples or transport to a laboratory. The sample is weighed as received in the laboratory and again after drying in an oven for 24 hours at 105° C. The weight of water lost (W) and weight of dry soil (S) are obtained from which the P_w is calculated. $P_w = W/S \times 100$ from these weighings.

Irrigation water and rain water, the sources of soil water, are usually measured and considered on a volume rather than a weight basis. It is, therefore, helpful to know the volume fraction of water in soil such as inches of water in a selected depth of soil. This is actually a depth fraction and not a volume fraction but the 2 are equal when related to an area of soil surface such as square meter, square foot, hectare, or acre. The symbol P_v is used meaning percentage of water on a volume basis.

Quantity of water as the depth fraction, volume fraction, or P_v can be measured directly by using an instrument called a neutron probe (4,5). The probe is inserted in previously prepared access holes that are lined with a metal casing. The probe contains radioactive materials that radiate fast neutrons able to pass unchanged through the metal casing and dry soil. The neutrons are changed to a lower energy form called slow neutrons when they encounter water molecules. A portion of the slow neutrons are deflected back to the probe where they are counted by a rate meter or cumulative counter. These counts when properly calibrated tell the amount of water in the soil on a volume basis. The probe can be placed at successive depths in the soil to measure the water content at each depth from which the total water content of the soil profile can be obtained.

The neutron device has several advantages over soil sampling for measuring water content. Soil sampling destroys the particular spot from which the sample is taken by removing the soil and altering the immediate surroundings so that a later measurement must be made elsewhere. The neutron device is nondestructive and measurements may be taken repeatedly from exactly the same soil and provides greater accuracy when comparing water content changes with time as in water depletion studies. Measurements in the field can be made much more rapidly than taking samples and needs no further laboratory effort. This advantage is especially great for moisture measurements at depths greater than 2 or 3 feet (61 or 91 cm).

The soil measured is a sphere around the probe. The measurement will be incorrect if the sphere is truncated by a sharp alteration or discontinuity of the soil such as the soil surface or a sudden change of texture in the soil profile. Distance of travel of neutrons varies inversely with moisture content of the soil, but measurements are usually not reliable closer than 6 inches to a discontinuity. The radiation hazard to an operator must be considered but is less than normal background if directions for use of the instrument and its shield are followed correctly.

The greatest advantage of the neutron meter is possibly the direct measurement of P_v, the form usually needed in irrigation and water use studies. Values of P_w obtained from soil sampling must be converted to P_v by the formula $P_v = P_w D_b$. D_b is the bulk density of the soil which is the ratio of the weight of a unit volume of undisturbed soil to the weight of the same volume of water. The bulk density must be determined by a separate measurement for each soil and each depth sampled. An undisturbed core of soil is carefully cut using a metal cylinder of known volume to make this measurement. The soil is trimmed so the cylinder is exactly filled and its dry weight determined in the laboratory.

Soil-water content is used for Purposes 2 and 3 where changes in water volume tell the rate of soil-water depletion by growing plants and show the soil profile capacity for holding water without excessive loss to deep percolation.

Relative Wetness of Soil (Water Potential)

Water is held in soil as films by attraction between water molecules and soil particles. The wetness of soil depends on the thickness of the water films, which depend in turn on the amount of water and the number of soil particles on which it is spread. Thin water films are held more tenaciously by the soil than thick water films and, therefore, require more energy for removal. Soil physicists describe the energy condition of soil water as a potential, which is usually called soil suction for easier understanding. It equates to the suction required to extract water from soil whether by a mechanical device or a plant root.

Water moves in soil in response to differences in suction. Thin water films have a greater suction than thick water films so water will move from soil with thick water films to soil with thin water films. Water films around the root become thinner when a plant root exerts suction to extract moisture, thereby creating movement of water from nearby soil where films are thicker. The rate at which this movement can occur is largely dependent on the thickness of the films through which the water is transported. The stress that a plant may endure is as likely to result from the slow rate of water movement as the films become thinner as it is from the greater suction required to extract water from thin films.

Soil suction can be measured directly by instruments called tensiometers, which have been adequately described (7, 8, 9). Most tensiometers for commercial use read directly in centibars (cb) of soil suction and have a practical limitation of reading between 0 and 80 cb. Zero suction is a state of soil saturation in soil-water terminology, and 15,000 cb is frequently equated with the soil suction at the permanent wilting point. It would seem that the tensiometer measures only a very small fraction of the range of soil water available to plants. Fortunately, the scale is not equally divided and the range from 0 to 80 cb includes from 50 to 90% of all of the water available to plants in most soils. Water held at suctions greater than 80 cb moves too slowly to supply the needs without producing stress for sensitive plants with small root systems. A tensiometer has the distinct advantage of measuring the wet part of the scale all the way to saturation. Many of the problems of citrus growing related to soil water are produced by excess wetness in the root zone, easily detectable with a tensiometer.

Tensiometers are usually installed at several points in an orchard judged as nearly as possible to be representative with respect to soils, tree variety, age and condition, and exposure. The soil should be examined to learn the position and concentration of roots when the general locations have been selected. Two or 3 depths can be selected for placement of the instruments based on these observations. One depth is the zone in which feeder roots are most concentrated, usually 8 to 18 inches (20 to 46 cm) below the soil surface. The next depth should be about twice the first depth where roots are still reasonably plentiful but much less concentrated. A third depth can be tried at 2 or 3 locations and its results evaluated if soil depth and root penetration are known to be great. The extra depth either can be extended to all locations or discontinued based on the evaluation.

Location with respect to a tree is usually based on expected differences in rate of water extraction. The south side dries faster in the northern hemisphere, and is usually favored because of its early warning potential. The north side could be chosen if management prefers to allow the soil to reach a drier condition before irrigation. The application of irrigation water should also be considered. Tensiometers should be positioned where irrigation water by flood, sprinkler or drip method of application will be sure to wet the soil in which the tensiometer is installed. This means within 12 to 18 inches (30 to 46 cm) of the edge of the furrow or basin or emitter, and with sprinklers at a spot where the water falls normally. The location of tensiometers will be on the west side of the trees if trees are sprinkler irrigated from middles that run north and south. The location with respect to the tree canopy should be near the drip line as long as it meets the requirements stated above.

Installation is usually accomplished by preparing a hole in the soil having the same diameter as the tensiometer body and the exact depth of the desired installation. It can be prepared by a coring tool, a soil auger, or a pointed rod that is hammered into the soil. The tensiometer is pushed firmly into the prepared hole and should reside with a tight fit so that the porous cup is in close contact with undisturbed soil that contains active roots. Some physical protection around the instrument is desirable after installation to avoid damage from equipment, field workers or possibly frost.

The proper use of tensiometers involves taking readings periodically, such as 2 or 3 times a week at the same time of day, preferably before the day warms up, and keeping them filled with water as needed. The readings are most useful when plotted on graph paper so that the changes with time are easily observed and used to plan irrigations in advance and to evaluate the timing and amount of previous irrigations. The charts can be used as guides to improve the timing of irrigations, both to prevent delayed irrigations from causing plant stress and excessive irrigation from causing nutritional and aeration disorders. The charts clearly demonstrate the need for change in water application as the seasons cause different water-use rates.

Symptoms sometimes arise in orchards suggesting a problem that is not readily discernible. Tensiometers installed in the troubled area will quickly reveal if the problem is caused by or related to too much or too little water. Excess soil water can be more damaging to citrus roots than dry soil, a point that adds value to the ability of tensiometers to measure very wet soil.

Soil suction can also be measured by another type of instrument called electrical resistance blocks (1, 2, 3). Readings from resistance blocks are obtained by a Wheatstone bridge that is connected to electrical leads from a block and reads ohms resistance to the passage of electrical current through the block or by a conductivity meter that reads a relative conductivity value which can be converted to ohms resistance by a conversion table supplied with the meter. Conversion of ohms resistance to soil suction requires a calibration of the blocks that may be supplied by the manufacturer. The user may have to perform his own calibration if one is not provided or accept the proposition that he can tell wet from dry without a calibration and ignore the closer readings.

The range of soil suction that can be measured by electrical resistance blocks extends from about 30 to 10,000 cb. They cover the dry range of available soil moisture and complement the wet range covered by tensiometers. The precision of blocks is much less than tensiometers in the range that both are able to measure but improves at higher soil suctions if water extraction is not too rapid. The slow movement of water in soil or in the pores of the blocks at high soil suctions creates a lag in readings if water extraction is rapid.

Installation of electrical resistance blocks is accomplished with much the same procedure as used with tensiometers. The obtaining of readings periodically, their plotting on a chart and interpretation also follows that described for tensiometers. The choice of instrument is based mainly on the soil, the stress sensitivity of the plants grown and the evaporation demands of the climate.

Tensiometers can be used in either saline or non-saline soils; block readings are adversely influenced by saline soil and should be restricted to non-saline soils. Tensiometers can measure most of the available water in sandy soils and loam soils. Resistance blocks cover more of the available water in clay loams and clay soils. Tensiometers should be used for sensitive plants in climates of high evaporative demand. Blocks can be used for less sensitive plants grown in mild climates.

SUMMARY

Soil suction or soil wetness should be measured to determine the need for irrigation or its withholding or to determine if excessive wetness or dryness exists that may affect a plant's health. Soil suction is measured directly by tensiometers or indirectly through suitable calibrations by electrical resistance blocks.

Soil-water content is measured to determine water-use rates and seasonal total use by plants. It is also used to determine the storage capacity of soil, and to estimate the efficiency of application by relating this to water applied. Soil-water content is measured on a weight basis by obtaining soil samples for oven drying and weighing. It is measured on a volume basis by use of a neutron probe or by conversion from the weight basis using soil bulk density values obtained from a separate sampling.

The form of soil water needed should be obtained directly from the appropriate measurement. Soil moisture characteristic curves are not unique and should not be used to convert from one type of measurement to the other.

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