TECHNIQUES OF SOIL MOISTURE MEASUREMENT

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INTRODUCTION

Soil acts as a reservoir to store water so that it is available to the crop or plants for healthy growth. The soil moisture is built up by rainfall (or irrigation water) and is depleted by the evapo-transpiration and deep percolation beyond rooting depth. The decline of soil water content due to under-irrigation will result in stress ofthe plant affecting adversely the photosynthesis activity and thereby the plant growth. On the other hand, over-irrigation results in poor utilization of water due to surface runoff and deep percolation losses, leaching of nutrients, production problems associated with excessively wet soil such as waterlogging, and increased incidence of plant disease.A tendency to over- or under-irrigate results due to the absence of information about the soil moisture status down the soil profile.Irrigation water management requires timely application of the right amount of water. Competition for water, high pumping costs, and concerns for the environment are making good water management more important. **Irrigation water Management requiresa combination of a method of soil moisture measurement and some method of irrigation scheduling.**

Measuring soil moisture detects if there is a water shortage that can reduce yields or if there is excessive water application that can result in water logging or leaching of nitrates below the root zone. Measuring soil moisture can also build an awareness and knowledge of each irrigated field that is invaluable for planning and management.Many tried and proven methods of estimating or measuring soil moisture are available. The method selected depends on a variety of factors such as accuracy, cost, and ease of use.

SOIL MOISTURE CONCEPTS AND TERMS

Soil Water

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 spaceas water and 50% air. This is a condition generally called field capacity or the full point.

Measurement of Soil Water

Soil moisture levels can be expressed in terms of soil water contentor soil water potential (tension).

Soil water content

Soil water contentismost commonly expressed as percentwater by weight, percent water by volume, or inches of waterper foot of soil. Other units such as inches of water per inch ofsoil also are used.

Water content by weightis determined by dividing the weightof water in the soil by the dry weight of the soil.

$$watercontentbyweight = \frac{wt.ofwater}{drywt.ofsoil}$$

It can be convertedto percent by multiplying by 100%.

Water content by volumeis obtained by multiplying the watercontent by weight by the bulk density of the soil. Bulk density ofthe soil is the relative weight of the dry soil to the weight of anequal volume of water (1 gm of water =1 cc volume). Bulk density for typical soils usuallyvaries between 1.5 and 1.6.

$$watercontentbyvolume = \frac{wt.ofwater}{drywt.ofsoil} X bulkdensityofsoil = \frac{vol.ofwater}{vol.ofsoil} = \frac{inchesofwater}{inchesofsoil}$$

Inches of water per footof soil is obtained by multiplying thewater content by volume by 12 inches per foot.

$$watercontentininchesofwaterperfootofsoil = \frac{inchesofwater}{inchesofsoil} X\ 12\ inches$$

By determining this value foreach layer of soil, the total water in the soil profile can be estimated.

Soil water potential

Soil water potential describes how tightly the water is held inthe soil. Soil tension is another term used to describe soil waterpotential. It is an indicator of how hard a plant must work to getwater from the soil. The drier the soil, the greater the soil waterpotential and the harder it is to extract water from the soil. Conversion of soil water potential to soil water content requiresinformation on soil water versus soil tension as shown in Fig. 1.

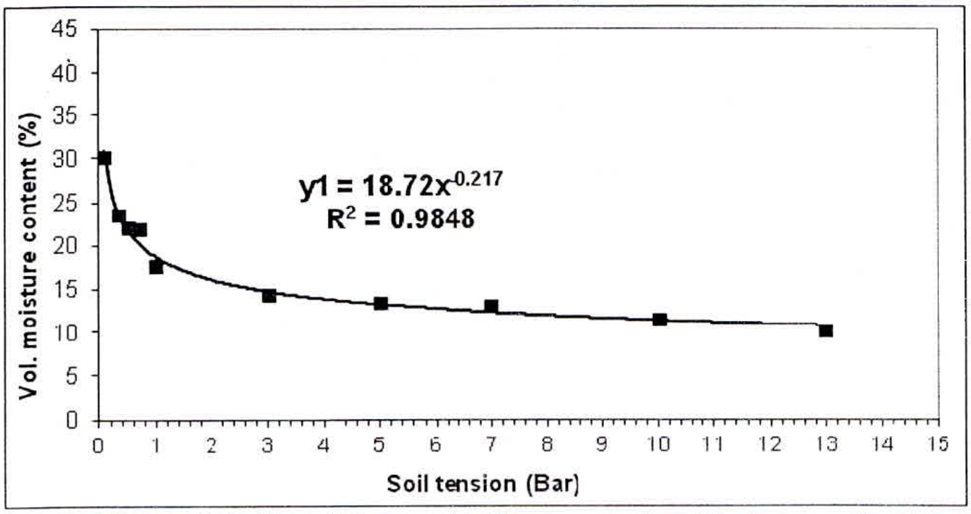

Figure 1. Soil moisture retention curve for silty loam soil

Field Capacity

Field capacityis the point at which the gravitational or easilydrained water has drained from the soil (drainage time is usually 48-72 hours after a significant irrigation or rainfall event). This is the point where most of the large pores have de-watered. Traditionally, it has beenconsidered as 1/3 bar tension. However, field capacity for manyirrigated soils is approximately 1/10 bar tension.

Wilting Point

Wilting pointis the soil moisture content where most plantswould experience permanent wilting and is considered to occurat 15 bars tension.

Available Water

Available wateris defined as the water held in the soil between field capacity and wilting point (Fig.2).The terms field capacity and wilting point are conceptual as the actual soil moisture values will vary in each soil depending on the soil texture and structure (Fig. 3). Table 1 gives common ranges of available water for soil types.

Readily Available Water

Readily available wateris that portion of the available waterthat is relatively easy for a plant to use. It is common to considerabout 50% of the available water as readily available water.Even though all of the available water can be used by the plant,the closer the soil is to the wilting point, the harder it is for theplant to use the water. Plant stress and yield loss are possibleafter the readily available water has been depleted.

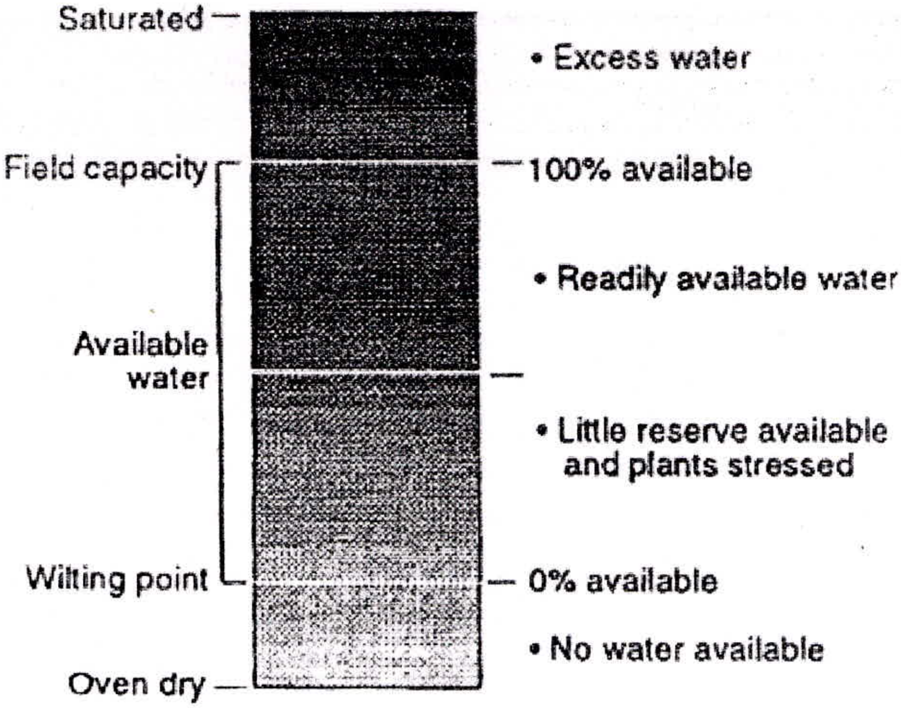

Figure 2. Available water in the soil

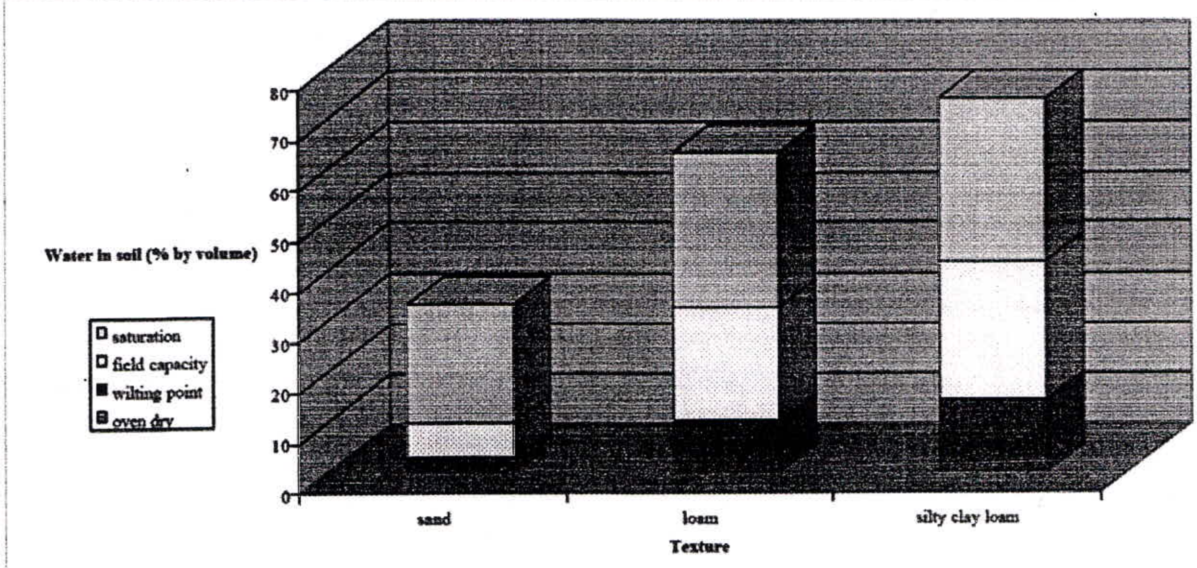

Figure 3. Typical water content for various soil types

Note: Oven dry soil is represented by 0% moisture. The top of the lower bar represents wilting point. The top of middle bar represents field capacity. The top of upper bar represents saturation. Plants can also access gravitational water, represented by upper bar, before it percolates down into the soil profile.

Table 1. Available water capacities for various soil types

Soil type	Inches water per foot of soil
Fine sands	0.7 - 1.0
Loamy sands	0.9 - 1.5
Sandy loams	1.3 - 1.8
Loams	1.8 - 2.5
Silt loams	1.8 – 2.6
Clay loams	1.8 – 2.5
Clays	1.8 – 2.4

METHODS OF MEASURING SOIL MOISTURE

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

Quantitative Methods

Quantitative methods include gravimetric method, neutron scatter method, and di-electric constant methods. 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.

Gravimetric method (oven dry and weight)

Basic principle:The gravimetric method is a direct, absolute technique for estimating the total (both available and unavailable) water content of soils. The method involves drying a soil sample in an oven (at 105° C for 24 hours*)* 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.Soil samples need to be placed immediately in re-sealable plastics bags to avoid changes in moisture content. 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.

Advantages:The method is relatively inexpensive, simple, and highly accurate.

Disadvantages:The method is time-consuming, labour-intensive, and difficult in rockysoils.A lab oven, soil sampling equipment, and weighing scale arerequired.

Availability of instruments: Lab ovens and weighing scales are available from manyscientific instrument companies. Soil sampling equipment is available from manyvendors.

Neutron scatter method

Basic principle:The neutron scatter device, often referred to as neutron probe, measures total soil water content in a volume of soil (6-12 inch sphere) by measuring the amount of hydrogen in the measurement area. By far the largest hydrogen-containing compound in the soils is water. The neutron probe, which consists of a source of fast, high-energy neutrons and a detector housed in a unit, is lowered into an access tube installed in the soil. The probe unit is connected by a cable to a control unit at the surface. The probe is lowered to specific depth to make readings throughout the root zone. Fast neutrons emitted from the source pass through the access tube into the surrounding soil and gradually lose energy through collisions with hydrogen molecules of soil water. As a result of the collision, a cloud of slow neutrons is reflected back that is measured by the detector contained in the probe unit. The size and density of the cloud depends mainly on soil type, access tube material and soil water content. 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 commonly used materials. Calibrations should also be developed for soils high in organic matter and some ions such as boron. Neutron probe access wells should be installed at least to the rooting depth.

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

Disadvantages:The major disadvantages are the use of radioactive material requiring a licensed and extensively trained operator, the high equipment cost ranging between $3,500–$4,500, and extensive calibration required for each site. The neutron probe is inaccurate when measuring the top 8 inches of soil because portions of the neutrons escape.

Availability of instruments: Neutron probes manufacturers include Campbell PacificNuclear International, Troxler Electronics, and Geoquip.

Di-electric constant methods

Basic principle:The di-electric constant methods measure the capacity of a nonconductor (soil) to transmit high frequency electro-magnetic waves or pulses. 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 near 2 to 5 and that of water is 80 when measured between 30 MHz and 1 GHz.

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)

Time domain reflectrometry (TDR)

The TDR device consists of an electronic meter connected through a cable to two parallel conducting probes (rods) placed into the ground. The device sends a high-frequency transverse electromagnetic wave through the cable and conducting probe into the soil. The signal is transmitted through 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 probe length, the propagation velocity can be computed. The faster the propagation velocity, the lower the di-electric constant, and thus lower the soil moisture.

Probes 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 probe if so calibrated. The probes are installed from the surface to a maximum depth of usually 18-24 inches. Probes can be permanently installed to provide water content at different depths. If deeper measurements are needed, a pit is usually dug after which the probes. 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 $6000 to $10000; 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 dielectric completing a capacitance circuit, which is part of a feedback loop of a high frequency transistor oscillator. The frequency varies between manufacturers 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 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. Ifproperly calibrated and installed, the probe's accuracy can be good. Typical costs are near $4,000.

Hand-held 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.

Advantages:The advantages of the TDR and FDR equipment is they are relativelyaccurate (±1 to 2%); can provide direct readouts of volumetric, plant-available soilmoisture percentages or continuous readings if used with a data logger; don't needcalibration; and are relatively unaffected by salts in soil. The TDR is more accurate andless affected by salts while the FDR can detect "bound" water in fine particle soils, whichis still available to plants. Thus, if you have extensive acreages salt-affected soils, theTDR instrument would be preferable, while if you are dealing with primarily finetextured,non-saline soils, the FDR instrument would be preferable. In general, theseinstruments are accurate, reasonably affordable, and easy to use.

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

Availability of instruments: Manufacturers for TDR include Campbell Scientific, StevensVitel, Spectrum Technologies,Environmental Sensors Inc., and Imko. The hand-held display units are very portable andquite easy to use and interpret. Field offices desiring continuous monitoring of soilmoisture will need to use a data logger. Manufacturers for FDR instruments include Aquaterr Instruments, Delta T Devices, and Decagon Devices.

Qualitative Methods

Qualitative methods include use of porous blocks/electrical resistance blocks, and tensiometers. 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 potentialare 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 (Fig. 1) 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 the porous blocks and tensiometers 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.

Porous blocks/electrical resistance blocks

Basic principle:Porous blocks operate on the principle that the electrical resistance of a porous block is proportional to its moisture content. The porous blocks are made of gypsum, glass-gypsum matrix, ceramic, nylon, and fiberglass. Two electrodes are embedded inside the block with a cable extending to the surface. The blocks are buried in the soil at the desired depth of measurement. The water moves in and out of the block in equilibrium with the moisture content in the surrounding soil. The electrical resistance is measured between the two electrodes by attaching aportable meterto the cable (Fig. 4). The measurement is related to soil water tension. The manufacturer usually provides calibration to convert meter readings to soil tension. Higher resistance readings mean higher soil water tension and lower block water content.

Proper installation of blocks is important for reliable readings. Good soil contact with the blocks is essential. 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 centi bar (cb). For most sandy soils, this would be outside the level of available water. Price varies by manufacturer and type of block but generally is in the range of $5-$15 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 encased 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.

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. The blocks tend to deteriorate over time and 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.

Availability of instruments:Manufacturers include Soil Moisture Equipment Corp., Delmhorst, Watermark, Measurement Engineering Australia, and many vendors sell these products.

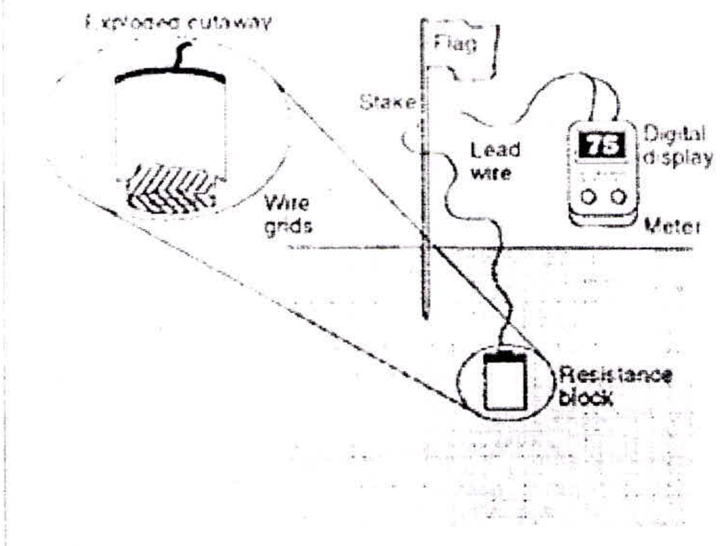

Figure 4. Use of gypsum block and electronic meter

Tensiometers

Basic principle: Tensiometers are water filled plastic tubes with porous ceramic cups attached on one end and a vacuum gauge and airtight seal on the other (Fig. 5). These devices should be installed at the desired depth in the soil with the ceramic cup in good contact with soil particles. The water in the tensiometer eventually comes to pressure equilibrium with the surrounding soil water through the ceramic cup. When soil dries, water is pulled out of the tensiometer through the ceramic cup into the soil creating a tension or vacuum in the tube. As the soil is re-wetted, soil water re-enters the cup reducing the vacuum and the tension in the tube. The vaccum gauge measures soil moisture tension, an index of how tightly water is held in the soil. A soil moisture retention curve is developed for each horizon of the soil to determine soil water content.Most tensiometers have a scale from 0-100 centibars. A lower (near 0 cb) reading indicates saturated soil conditions.

Tensiometers require careful installation and maintenance to ensure reliable results. Installations should be protected from field hazards and have good soil contact with the ceramic cup. 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.

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 100 cb. Thus they're not suited for measurements in dry soils.

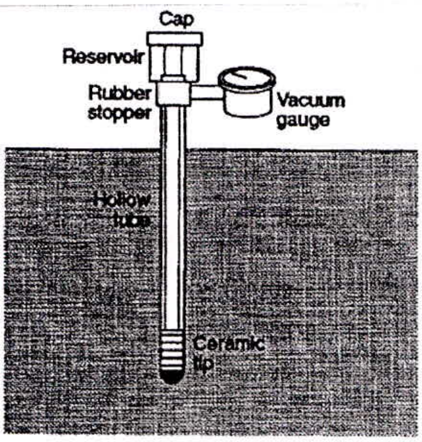

Figure 5. A typical tensiometer

Using tensiometers and resistance blocks in the field

Placement in the soil - To best determine moisture conditions for the full soil profile, place sensors in the root zone. For soils without restrictive layers, about 70% of the roots are in the top 50% of the root zone. Table 2 gives normal rooting depths for common crops (mature crops) along with recommended placement depths. Install sensors early enough in the season to make them useful for scheduling any irrigation. Install at least two sensors at each site except for shallow-rooted crops or shallow soil underlain by gravel. Place the sensors at 1/3 and 2/3 of the crop rooting depth (Figure 6). For example, with corn, sensors would be placed at about 12 to 18 inches and 24 to 36 inches.

Use the shallow sensor to judge when to start irrigating. Use the deep sensor to determine how much water to apply. If readings of the deep sensor rise faster than the shallow sensor, apply more water with each irrigation. If readings of the deep sensor remain wet, then there is more chance for deep leaching of water and nutrients.

For row crops, place the blocks or tensiometers between plants in the row. Avoid locations where field or irrigation equipment could damage the sensors. Select a uniform area and make an effort not to disturb or compact the soil near the sensors.Identify the depth of the sensors to insure correct recording by the person reading them during the season. Mark the locations well using flags or stakes. When using blocks, identify the lead wires and attach them to the stake.

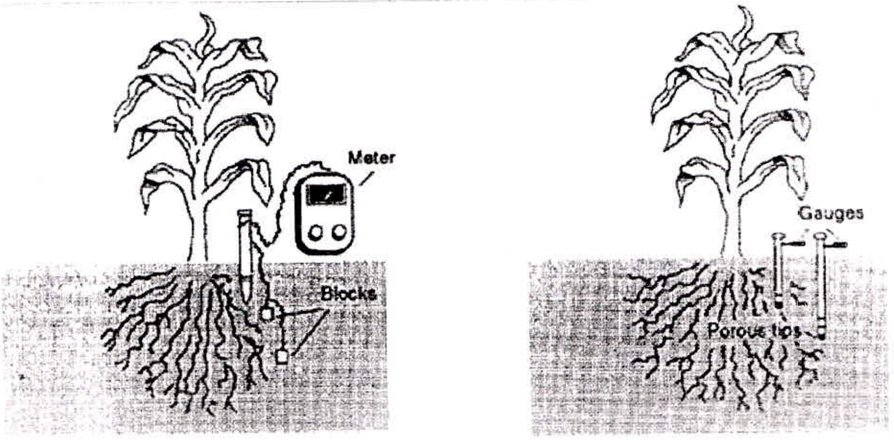

Figure 6. Placement of soil moisture sesors and tensiometers in the root zone

Table 2. Crop rooting depths and soil moisture instrument placement depths

Crop	**Rooting depth (foot)**	**Soil sensor depth (inches)**	
		Shallow	**Deep**
Corn	3 – 5	12 – 18	24 – 36
Alfalfa	4 – 6	18	36
Soybeans	2 – 3	12	24
Potatoes	2 – 3	12	24
Small grains	3 – 4	12	24
Field beans	2 – 4	12	24
Sugar beets	2 – 4	12	24
Pasture or grass	1 – 2	12	18 – 24
Sorghum	3 – 4	12 – 18	24 – 36
Turf or lawns	1	6	12
Annual vegetables	1 – 2	6 – 12	12 – 18
Small fruits	1 – 2	6 – 12	12 – 18
Asparagus	2 – 3	12	18 – 24

Location in the field— Select at least two sites in each field (four is preferable), one near the start of the irrigation cycle and one near the end of the irrigation cycle. Use two sites for each crop where more than one crop is in the same field.Where there is more than one soil type, place sensors in the predominant soil types. Avoid locations that are low areas, tops of hills, near the edges of fields that may get uneven irrigation, or any other area that is not representative of the field. Locate the site so that it is accessible from a road or trail. It is very important to place sensors where they can be found easily for reading, especially as the crop matures. Put markers or flags in the row and on the side of the field. Reduce foot traffic around the sensors to minimize soil compaction. Do not locate the sites too far from field roads so that extra effort is required to find and read the instruments.

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 at which 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.

Observable soil characteristics method (or feel method)

Basic principle:Soil moisture can be evaluated qualitatively by feeling the soil.A set of observable soil characteristics (Table 3) are used to estimate the percentage of plant-available moisture in the soil profile or within the root zone of desirable vegetation.

Advantages:This method is fast and simple and 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 especially if they are inexperienced in using it. This method is not adequate for estimating soil water content for management decision making.

Table 3. A field guide for estimating plant available moisture by feel and appearance*(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.)*[Procedure for use of Table: Determine the textural category (Coarse, Light, Medium, Heavy) of thesoil.Take a palm-full of soil, form a ball of the soil and, making a fist, squeezewith the pressure of a strong hand shake. Open hand and compare your observation ofthe soil condition against the descriptions in the column for the textural category youhave chosen. Also try forming a ribbon of the soil material between your thumb andforefinger. Consider taking separate samples from various depths or zone(s) of interest inthe soil profile, keeping in mind that textural categories may vary with depth. Use soil probe for taking samples.]

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 throughfingers.	Dry, loose, flowsthrough fingers.	Dry, powdery, oraggregates easily breakdown into a powderycondition.	Hard, baked, cracked,sometimes has loosecrumbs on surface.
25 to 50%	Appears to be dry, willnot form a ball.	Appears to be dry, willnot form a ball.	Somewhat crumbly butwill hold together frompressure.	Somewhat pliable, willball under pressure, nowater stains, clods flattenwith applied pressure.
50 to 75%	Moist, tends to sticktogether slightly butcrumbles easily, will notform a ball, will not formribbon.	Moist, tends to ballunder pressure butseldom holdstogether.	Moist, forms a ball,somewhat plastic; willsometimes slick slightlywith pressure, forms aweak ribbon between thethumb and forefinger.	Moist, forms a smoothball with define fingermarks, will ribbon outbetween thumb andforefinger.
75 to near Field Capacity (<100%)	Wet, tends to sticktogether slightly, mayform a very weak	Wet, forms a weak ball,breaks easily, will	Wet, forms a ball and isvery pliable; slicksreadily if relatively highin	Wet, easily ribbons outbetween fingers;

	ballunder pressure, darkenedcolor, will not ribbon.	notslick, forms slight wetoutline on hand, makes aweak ribbon between thethumb andforefinger.	clay, light to heavysoil/water coating onfingers, ribbons betweenthumb and forefinger.	slickfeeling, uneven mediumto heavy soil/watercoating on fingers.
At Field Capacity (100%)	Wet, forms a weak ball,loose and aggregatedsand grains remain onfingers, darkened color,wet outline of the ball isleft on the hand.	Wet, forms a soft ball,medium to heavysoil/water coating onfingers.	Wet, forms a soft ball,medium to heavysoil/water coating onfingers.	Wet, forms a soft ballthat resists deformation,slick, sticky, thicksoil/water coating onfingers.
Above Field Capacity (>100%)	Free water appears whensoil is shaken or bouncedin the hand.	Free water will bereleased with kneading.	Can squeeze out freewater.	Puddles and free watercomes to the surfacewhen shaken or bouncedin the hand.

IRRIGATION SCHEDULING WITH SOIL MOISTURE INSTRUMENTS

Soil moisture measurement is an integral part of any irrigationscheduling program. Soil moisture readings can be used bythemselves to schedule irrigations, but they are most valuablewhen used in combination with other methods of schedulingsuch as a simple checkbook method or a computer model. Soilmoisture readings can determine initial soil moisture balancesand update those balances throughout the irrigation season.

Where the soil moisture readings are the basis for schedulingirrigations, take readings at least once every two days. Where thereadings are used to update other scheduling methods, readingonce or twice per week may suffice. Record all readings (Table 4). The soil moisture readings, along with rainfall and irrigationamounts and crop condition, can help in management and futureplanning.

Table 4. Example form for soil moisture and irrigation records

Field Number:…………..			Crop:…………….		Year:……………….		
Date	Rainfall (mm)	Irrigation (mm)	Soil moisture				Comments
			Site #1		Site # 2		
			Shallow	Deep	Shallow	Deep	

Soil moisture instruments measure current moisture levels in thesoil and cannot predict future readings. It is possible for soilmoisture readings to change rapidly during high wateruse periods,from one day to the next, for example. Crop water use canbe especially high on hot, windy days. Unless all of the field canbe irrigated in one day, start irrigations before the sensors callfor water.

Use soil moisture readings to schedule irrigation so the irrigationcycle can be completed before crop stress occurs. Table 5 givesguidelines for irrigating using tensiometers and resistanceblocks. Starting irrigations early is important during periods ofhigh water use or critical growth stages to prevent excessivedepletion of the soil moisture reserve. Since most irrigation systemsdo not have enough pumping capacity to keep up duringtimes of high water use, the soil water reserve helps get throughthose periods.

During periods of lower water use and after rainfall, it is especiallyimportant to monitor the soil sensors. Stop irrigation whenboth the shallow and deep readings indicate the soil moisture isnear field capacity.Irrigation waterapplication may be terminated after it is determined that adequatesoil moisture reserves are available for the crop to mature.

Table 5. Soil tension readings for available soil moisture

Soil type	**Soil tension (potential) (centi bars)**		
	At Field capacity	**For Optimum range of soil moisture***	**At 50% depletion of available moisture (needs irrigation)**
Loamy sand/ sandy loam	10 – 15	30 – 50	45 – 60
Loam/ silt loam	10 – 20	35 – 55	50 – 70
Clay loam/ clay	15 – 20	40 – 60	60 – 100

*Optimum range of the soil moisture is the range in which crop stress is minimum and yields are optimum.

SUMMARY

In summary, a variety of methods are available for measuring soil moisture. The method and equipment selected will depend on ease of use, cost of equipment, applicability to drier conditions, and desire to monitor continuous changes in soil moisture. Soil moisture readings are useful to determine how much water is available for the crop, when to start irrigating, and how much water to apply. Soil moisture monitoring can help conserve water and energy, minimize pollution of surface and ground water, and produce optimum crop yields. Efficient scheduling of irrigation water applications gives the highest return for the least amount of water. Additional sources of information on soil moisture can be found on the Web.

REFERENCES

Gardner, Walter H. 1979. How water moves in the soil. Crops and Soils Magazine. American Society of Agronomy, Inc., Madison, Wisconsin.

Gardner, Walter H. 1986. Water content. Pages 493–544 *in* Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods - Agronomy Monograph 9 (2nd Edition). American Society of Agronomy - Soil Science Society of America. Madison, Wisconsin.

Hal Werner. Measuring soil moisture for irrigation water management. on web at agbiopubs.sdstate.edu/articles/FS876.pdf

Metelerkamp, Bruce. 2001. Sowacs (Soil water content sensors and measurement), on web at www.sowacs.com.

Prichard, Terry L. Soil moisture measurement technology. University of California Davis. on web (pdf file) at ucce.ucdavis.edu/files/filelibrary/40/975.pdf.

Risinger, Mike, A. Wayne Wyatt, and Ken Carver. 1997. Estimating soil moisture by feel and appearance. High Plains Underground Water Conservation District No. 1.

Rogers, Danny H., and William M. Sothers. 1996. Soil, water and plant relationships. Irrigation Management Series. Cooperative Extension Service. Manhattan, Kansas.

Saskatchewan Highways and Transportation. 1993. Moisture by Speedy Tester. STP 205-4. Standard Test Procedures Manual.

Schenk, H. Jochen, and Robert B. Jackson. 2002. Rooting depths, lateral root spreads and below-ground/above-ground allometries of plants in water-limited ecosystems. *In* Journal of Ecology 90:480–494.

Schneekloth, Joel, Troy Bauder, Israel Broner, and Reagan Waskom. 2002. Measurement of soil moisture. Colorado State University Cooperative Extension Drought and Fire Tip Sheets. On Web at www.ext.colostate.edu/drought/soilmoist.html.

Soil moisture measurement methodology. on web at www.water.tkk.fi/wr/kurssit/HYDMET/dload/Maavesien_kosteuden_mittaus.pdf

USDA, Natural Resources Conservation Service. 1997. Soils. National Engineering Handbook 210-vi-NEH, Part 652 Irrigation Guide, Chapter 2.