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Texas Agricultural Extension Service

Soil Moisture Monitoring

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Soil Moisture Storage

The amount of water that can be stored in a soil is affected by various factors, notably soil depth and texture. More water can be stored in a deep soil than in a shallow soil.

Soil texture affects the amount of water retained by a soil. For soils of equal depth, sandy soils have much lower water-holding capacity than clay soils. Fine textured soils (e.g., clays) generally have the highest capacity for holding water.

For dryland crops, the amount of water stored in soil at the time of planting greatly affects final crop yield. For instance, at Bushland on Pullman clay loam soil, grain yields of wheat, sorghum and sunflowers increased an average of 164, 385, and 158 pounds per acre, respectively, for each additional inch of plant-available water in the soil at the beginning of the season. And, in a year with total rainfall of only 2 inches during the growing season, dryland grain sorghum yields averaged 1,960 pounds per acre due to ample soil moisture at planting time. The amount of soil moisture remaining after the season is also an important factor in water available for the next crop, and efforts should be taken to keep it from escaping. Although not generally done in Texas, some dryland farmers in other western states plant only every other year thus allowing for soil moisture status to increase.

Soil Moisture and Irrigation Management

Irrigation management involves two basic decisions: when to irrigate and how much water to apply. A crop should be irrigated before a harmful level of moisture stress is reached. The most commonly recommended criterion for starting irrigation is to apply water when 50 percent of the available soil moisture (ASM) has been depleted. The amount of water to apply depends on the effective root zone depth of crop, the water-holding capacity of the soil, and the degree of moisture deficit allowed by management. Knowledge of the amount of water in the soil reservoir is very important to determining both when and how much to irrigate.

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Soil Moisture Sensing

Farmers should utilize soil moisture sensing methods to determine the water content of the soil. The plant-available water is considerably less than the total water content of the soil because the last remnants of moisture cling so tightly to the soil particles that plants cannot extract it.

Monitoring the water content of soil in irrigated fields throughout the growing season offers farmers a potentially high return on investment. By using soil moisture measurement, farmers can start irrigation before crop stress conditions develop, cutting yields. Soil moisture sensing methods will indicate when to irrigate before plants show visible symptoms. Also, unnecessary irrigations may possibly be eliminated. Soil moisture sensing devices are especially beneficial to producers with center pivot or drip irrigation systems because of their ability to respond rapidly to the situation being monitored. The principal methods of soil moisture sensing range from simple to relatively complex, as discussed below.

Feel Method

All producers should become proficient in estimating soil moisture by the feel method. The feel method consists of inspecting, squeezing and feeling of soil samples extracted with an auger or sharpshooter from different depths. Factors that enter into the estimate include soil cohesiveness, presence of free moisture, appearance, friability, presence of moisture outline in palm of the hand (the ideal soil moisture condition), and other sensory perceptions. Samples should be taken from the 1- and 2-foot levels and then deeper if those are dry. Coarse soils hold less water than tighter soils. Thus, the irrigator should determine his soil type.

Soil surveys published for most counties by the Soil Conservation Service-USDA show maps outlining the soil that will be found in an area. These maps are generally accurate and contain tables that show how much water each major strata of the soil series can contain (inches water per inch or foot of soil depth). For example, most soils in the High Plains hold 0.7 to 2.4 inches of plant-available water per foot of depth.

TABLE 1. GUIDE FOR ESTIMATING SOIL MOISTURE THAT IS AVAILABLE BY FEEL AND APPEARANCE (RISINGER ET AL., 1985).

	Dominant Texture			
	FINE SAND AND LOAMY FINE SAND	FINE SANDY LOAM	SANDY CLAY LOAM AND LOAM	CLAY, CLAY LOAM OR SILTY CLAY LOAM
	Soil Moisture, inches of water per foot of soil at field capacity			
	0.60-1.25	1.2-1.5	1.4-1.9	1.5-2.3
Available soil moisture (ASM), percent	Soil Moisture Deficit (inches water per foot) of soil when feel and appearance of the soil is as described			
At field capacity (100 percent)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. Deficit = 0.00 in/ft	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. Deficit = 0.00 in/ft	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. Deficit = 0.00 in/ft	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. Deficit = 0.00 in/ft
75 to 100	Tends to stick together slightly, sometimes forms a very weak ball under pressure. 0.00-0.20 in/ft	Forms weak ball, breaks easily, will not slick. 0.00-0.30 in/ft	Forms a ball, is very pliable, slicks readily if relatively high in clay. 0.00-0.5 in/ft	Easily ribbons out between fingers, has slick feeling. 0.00-0.55 in/ft
50 to 75	Tends to stick together slightly, but crumbles easily, will not form ball. 0.20-0.45 in/ft	Tends to ball under pressure but seldom holds together. 0.30-0.65 in/ft	Forms a ball somewhat plastic, will sometimes slick slightly with pressure. 0.5-1.0 in/ft	Forms a ball, ribbons out between thumb and forefinger. 0.55-1.0 in/ft
25 to 50	Appears to be dry, will not form a ball with pressure. 0.45-0.60 in/ft	Appears to be dry, will not form a ball. 0.65-1.0 in/ft	Somewhat crumbly but holds together from pressure. 1.0-1.4 in/ft	Somewhat pliable, will ball under pressure. 1.0-1.5 in/ft
0 to 25	Dry, loose, single grained, flows through fingers. 0.60-0.25 in/ft	Dry, loose flows through fingers. 1.0-1.5 in/ft	Powdery dry, sometimes slightly crusted but easily broken down into powdery condition. 1.4-1.9 in/ft	Hard, baked, cracked, sometimes has loose crumbs on surface. 1.5-2.3 in/ft

Another guideline that has been available for many years for estimating soil water deficiency (inches) for different soil textures consists of a set of descriptive indicators (Table 1). This table can be used by the irrigator to estimate the amount of water needed to fill his soil profile back up to field capacity and is an excellent tool. The method is quick and can be used anywhere in the field.

Tensiometers

A tensiometer is an air-tight plastic column filled with water. It has a porous ceramic tip on the bottom end which is tightly embedded in soil. The tensiometer has a vacuum gauge at the top to measure soil tension or matric potential (i.e., "suction") exerted on the water by soil particles. Clay particles have a stronger affinity for water than sand or silt and therefore exert a stronger tension.

Soil tension draws water through the ceramic tip and creates a vacuum that registers on the gauge. Vacuum (suction) in the column varies according to soil moisture content. The drier the soil, the greater the tension and consequently the higher the reading on the vacuum gauge. After rain or irrigation, moisture moves from the soil back into the ceramic tip and reduces the tension.

Soil moisture tension is measured in bars, centibars (cb), or kilopaschals (kPa). Correlation between soil moisture tension and percent depletion of available water has been established for many soil series. Field capacity, the water content of soil soon after irrigation, is usually at −0.33 bars of tension. The permanent wilting point is the theoretical point of dryness after which plant roots cannot extract any more water from small pore spaces and thus die. The permanent wilting point is at approximately −15 bars, or −1,500 centibars (−1,500 kPa). This is approximately equivalent to a vacuum of 220 pounds per square inch (psi).

The range of soil moisture tension that can be measured using a tensiometer is zero to −1.0 bars (−100 cb) which is equal to one atmosphere (14.7 psi) suction. However, the usual range of operation is zero to about −0.7 to −0.8 bars (−70 to −80 centibars) tension. The reading is reliable within these limits. When the soil dries to a greater tension level, the ceramic tip will break suction (i.e., allow air to enter) and cease to operate correctly. After the tensiometer has broken suction, it may give false readings that indicate more moisture than is actually present. Thus, tensiometers are better for sandier soils or for irrigation situations such as orchards, where water is applied frequently.

Typical moisture contents of different soil types at field capacity, visual and permanent wilting points, and the area of reliability for tensiometers is shown in figures 1, 2 and 3. A separate tensiometer is needed for each soil depth to be measured. Tensiometers are available in lengths of 6 to 72 inches. The soil moisture is

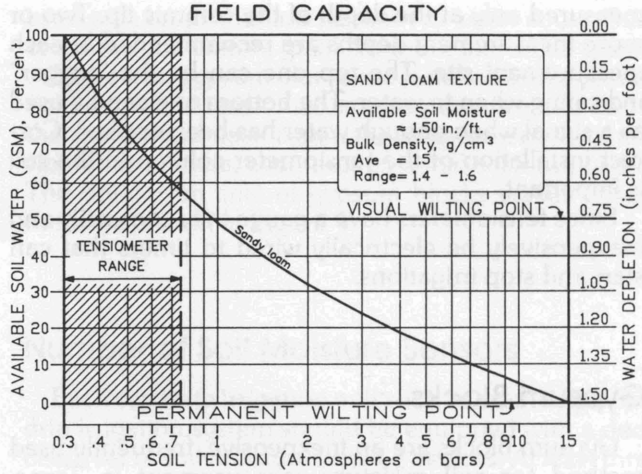

Figure 1. Relationship between water content and soil tension for a sandy loam soil.

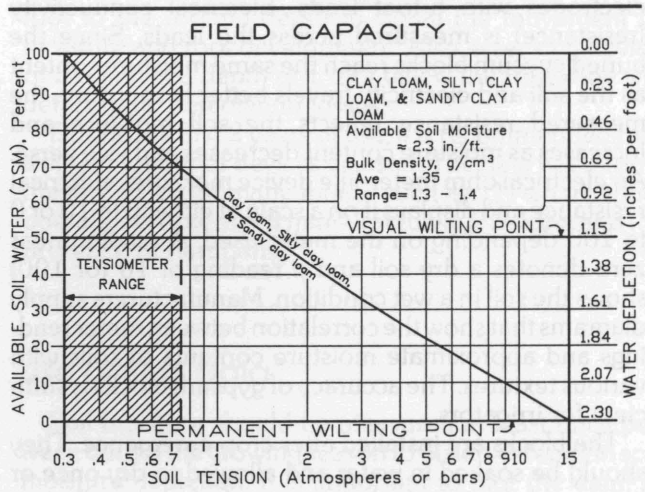

Figure 2. Relationship between water content and soil tension for a clay loam, silty clay loam, or sandy clay loam soil.

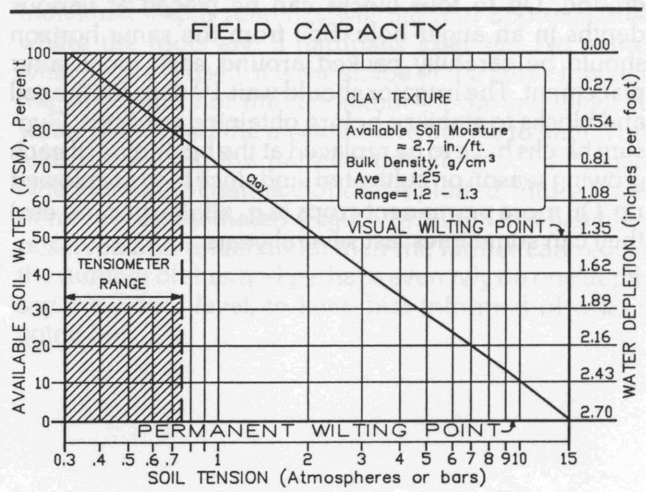

Figure 3. Relationship between water content and soil tension for a clay soil.

measured only at the depth of the ceramic tip. Two or more measurement depths are recommended at each measurement site. The top one can be the "trigger" indicating when to water. The bottom one can be used as a signal when enough water has been applied. Correct installation of the tensiometer column in the soil is important.

Since tensiometers have a gauge they can easily and inexpensively be electrically wired to timers that can start and stop irrigations.

Gypsum Blocks

Gypsum blocks are an inexpensive, frequently used method for soil moisture measurement in Texas. Gypsum blocks are permeable ceramic gypsum cylinders about 1 inch long cast around two stainless steel electrodes with 6-foot leads. Electrical conductivity (resistance) is measured across the leads. Since the buried gypsum blocks reach the same moisture content as the soil and electricity travels better in moisture, the measured resistance reflects the soil moisture and increases as moisture content decreases and vice versa. An electrical ohm meter-like device measures electrical resistance and displays it on a scale of either 0 to 10 or 0 to 100 depending on the meter used. A reading near zero denotes a dry soil and a reading of 10 (or 100) shows the soil in a wet condition. Manufacturers supply diagrams that show the correlation between meter readings and approximate moisture contents of soils with various textures. The accuracy of gypsum blocks is sufficient for irrigators.

The blocks are installed after crop emergence. They should be soaked in water and allowed to dry once or twice and then soaked again just before installation. Gypsum blocks should be placed in holes created either with a soil auger or a rod driven or pushed into the ground. Up to four blocks can be placed at various depths in an auger hole. Soil from the same horizon should be carefully packed around each block after placement. The irrigator should wait 10 days for the soil and blocks to stabilize before obtaining readings. Gypsum blocks have to be replaced at the beginning of each growing season on cultivated land since they are plowed up. On more permanent crops (e.g., alfalfa, pecans, etc.) they can sometimes last several years.

Neutron Probes

A neutron probe consists of a neutron source, a neutron counter, and a compiler/readout instrument. The probe part, which is surrounded by the casing, is lowered into an aluminum tube that has been inserted in a bored hole to a desired soil depth. The radioactive source emits "fast neutrons" which bounce off the hydrogen atoms present in soil water. With each collision, the neutrons lose energy and speed. The number of deflected "slow neutrons" is then detected by the counter, and this number of slow neutrons is correlated with the soil water content. The compiler/readout instrument calculates and displays the results, usually as inches of water per foot of soil.

Neutron probes are perhaps the most accurate but are also the most expensive and time consuming instruments. The Texas Department of Health requires a license for possession and operation of a neutron meter. In most cases, they are not practical for individual farmers to buy or use.

Gravimetric Methods

The gravimetric method of soil moisture measurement consists of determining the water loss from a soil sample upon heating to 220°F for 24 hours. The gravimetric method is very accurate and is the standard method by which all other sensing methods are determined. However, for farm use, it is too slow and requires expensive scales and a drying oven.

Infrared Guns

A new method for measuring soil moisture is the infrared gun. It actually measures the temperature of the crop canopy and compares it to the air temperature. A healthy plant with plenty of soil moisture will always be cooler than the surrounding air.

This technology is very expensive, but it is extremely fast and requires no installation of tubes, etc. Since the research involved with this device takes into account the particular crop being monitored and the level of stress it can endure, it goes one step further than the other methods that merely show soil moisture conditions and must have the user infer how the crop is being affected.

Comparison

Neutron probes and infrared guns are too expensive and impractical for most farm operations. Thus, the choice of soil moisture sensing equipment usually centers on tensiometers vs. gypsum blocks, in addition to the feel method.

Tensiometers have a relatively narrow measurement range (zero to −0.7 or −0.8 bars tension). This range includes about 45 percent of the available water in a sandy loam soil (i.e., from 100 percent down to 55 percent of field capacity) but only about 25 percent of available soil water for clay loams and clays (i.e., 100 to 75 percent of field capacity). A gauge reading of 80 indicates 55 percent of field capacity for sandy loam soils and about 75 percent in clay soils (figures 1, 2 and 3). Thus, on a clay loam or clay soil, tensiometers will not have sufficient operating range to reach 50 to 55 percent available soil moisture (ASM). Tensiometers are the most advantageous on crops where frequent irrigation is practiced to maintain the moisture at 50 to 75 percent of field capacity.

Gypsum blocks will measure soil moisture tension over a much wider range of available soil moisture than tensiometers but they are said not to be as sensitive at high moisture contents. Also, gypsum blocks require very close contact with soil to give representative readings. This condition is more difficult to obtain with a coarse-textured soil such as loamy sand than with a fine-textured soil. Gypsum blocks might work best when used with crops that are resistant to water stress. Such crops include cotton, grain sorghum and small grains.

Since new gypsum blocks are installed every year on field crops and tensiometers are retrieved at the end of the season and used again, the long term costs of tensiometers are less, even though initial costs are higher. The breakeven cost of gypsum blocks versus tensiometers is shown in Figure 4.

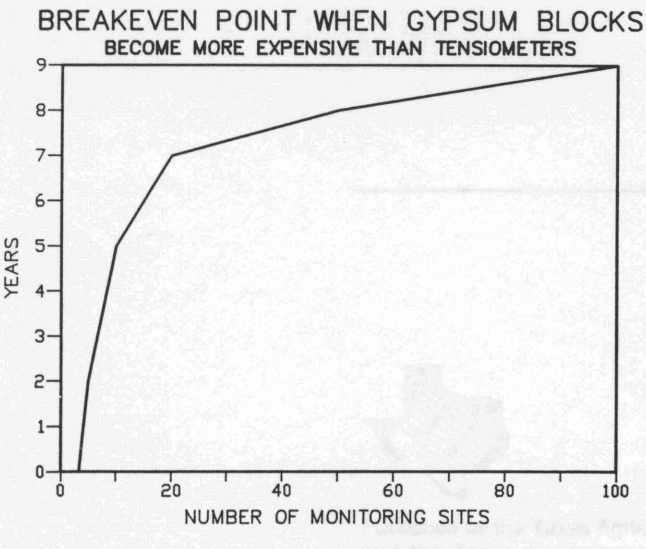

Figure 4. Number of years and monitoring sites before gypsum blocks become more expensive than tensiometers.

Number of Soil Moisture Sensors

Each separate irrigation unit such as a center pivot or drip irrigation system should be equipped with a dedicated set of soil moisture sensing devices. At least three sensing stations are needed per irrigation unit. At each station, soil moisture should be measured at several depths. One device or reading can be obtained at every foot to the rooting depth to signal the movement of moisture and root development. Also, a sensing device or reading at a depth of 1 foot below the root zone will detect deep percolation losses.

During the first 2 years of use, it is recommended that a large number of devices be used. The data will inform the farmer about many things, such as: (1) where roots operate; (2) how much rainfall actually is caught; and (3) presence of hardpans.

Use of SMS Data

Soil moisture should be measured at least once per week during the growing season to observe trends in soil moisture depletion. It is important to plot the data! A composite group of all depths and all strata in a field should be kept. This is what the farmer will use to adjust the irrigation frequency and amount he is applying. The individual depth readings will tell him approximately where the roots are, if hardpans exist, etc. No matter what device is used, it is the shape of the curve that tells the story, and not the magnitude of the numbers! As water is depleted the plotted curve begins to flatten out as it is reaching the permanent wilting point. Irrigate when the slope changes. Once it is plotted, future irrigations can be estimated (Figure 5). After this has been observed and understood, then the farmer can reduce the number of sites and perhaps even rely on one depth, say the 2-foot level, to keep him informed of what is going on.

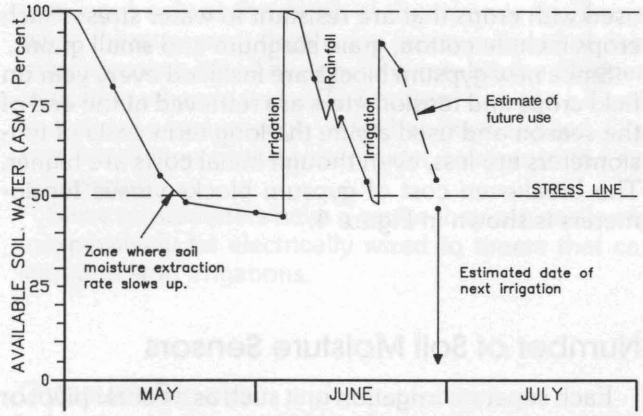

Figure 5. Soil moisture content (composited from all depths and all sites) over time. When the curve begins to flatten out, the crop has reached a point where extraction of water is difficult and harmful. Once the slope of extraction is determined, future irrigation dates can be predicted by projecting distance down to the intersection of the stress line.

Pre-Season Soil Moisture Survey

Pre-season soil moisture surveys, where available, provide the irrigator with an estimate of (a) the amount and distribution of water stored in the root zone profile; and (b) the amount of water needed to recharge the root zone soil profile to field capacity. By knowing the amount of soil water stored in the plant root zone prior to planting, irrigators can make important decisions such as crop selection, seeding rate, necessity of preplant irrigation or tillage practices.

For example, the preplant soil moisture survey conducted annually by the High Plains Underground Water Conservation District No. 1 uses a network of permanent monitoring sites at 3- to 5-mile intervals. Measurements of total soil moisture are made each winter using a neutron probe at 6-inch intervals to a soil depth of 7 feet.

Data published from pre-season soil moisture surveys are usually expressed in terms of moisture deficit; i.e., inches of water per foot of soil needed to wet the soil to field capacity within the root zone. This allows irrigation plans to be made for bringing the root zone up to field capacity prior to planting. Often, only the top half of the root zone may need additional moisture, and an irrigator may want to accept the probability that as much as half the needed amount will be received from precipitation. For example, if the soil moisture survey shows only a 2- to 4-inch moisture deficit, furrow dikes could be installed to capture an expected 3 inches of spring precipitation rather than apply a preplant irrigation. On the other hand, a large moisture deficit of 6 to 8 inches in the root zone would probably indicate the need for preplant irrigation in addition to precipitation.

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