Measuring Soil Water

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The decision of when and how much irrigation water to apply is as old as irrigation itself. Two main methods have been developed to help irrigators make these decisions. One includes using evapotranspiration, rain and irrigation records to predict the need for irrigation and the other method involves measuring soil water content to determine the need for irrigation. This chapter will focus on measuring soil water and how to utilize the data.

Irrigation scheduling can answer the question of when and how much should I irrigate. Measuring soil water content provides critical information in the irrigation scheduling process. The biggest advantage of measuring soil water is that it combines the net effect of all of the factors that influence the availability of water in a soil for producing a crop into a single measurement, Figure 1.

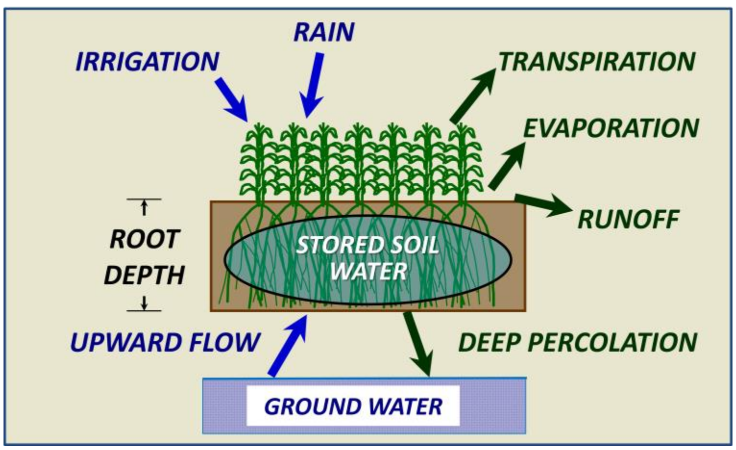

Figure 1. Factors influencing the availability of soil water for producing a crop.

Irrigation scheduling used with soil water monitoring equipment is like watching the fuel gauge on the tank at the irrigation well. It helps determine how long until fuel is needed and how much the tank will hold. By knowing how much fuel the tank can hold, it can be determined how long the fuel will last and how much additional fuel can be added to fill the tank. For example, if the gauge on a 1000 gallon tank reads1/4, it is known that about 750 gallons will be needed to fill the tank. If fuel is being used at the rate of 10 gallons per hour, we know that the tank will run dry in about 25 hours if not refilled. As a result, a schedule of when more fuel will be put into the tank before the tank runs dry can be determined. The same type of information is provided by monitoring soil water. Just like the gauge on the tank of fuel, soil water monitoring can help tell us how long until we need to irrigate and how much water the soil will hold.

Appearance and Feel Method vs. Soil Water Monitoring Equipment

The appearance and feel method is a technique by which soil cores are taken to the soil depth of interest and are analyzed by sight and feel to determine the water content of the soil. This method is a popular form of monitoring soil water because only a soil probe or auger is needed. It is flexible, in that you can check any point in the field and it may help to diagnose other crop production issues. However, the appearance and feel method is not recommended unless the person performing the procedure has experience and is self-calibrated to obtain accurate data. Working across different soil types makes this method even more difficult to master. The procedure is also fairly labor intensive; every time one must go into the field, take soil cores, and make determinations of the soil water content. Another disadvantage is at times the crop can have plenty of water deeper in the soil, but if the top layer is dry, it may be difficult to get a probe through to check the deeper levels.

The use of soil water monitoring equipment offers several advantages over the appearance and feel method. Most important is that the accuracy of the soil water content measurement is determined by the equipment that is installed and the precision of the installation, not just the experience of the person interpreting the soil sample. The data can be viewed in the field or on the internet, depending on the equipment. Some monitors can be permanently installed and left year round in the field. Soil water monitors installed in a field result in readings that are from the same site in the field all season. This may be preferred for irrigation scheduling because it answers the primary question, is the field getting wetter or dryer? On the other hand, monitoring only one site in a production field means that you must have confidence in the site and the installation process, as this represents your whole field. The most compelling reason to consider soil water monitoring equipment over the appearance and feel method is that it can take readings down to 4 feet deep or more; which is just not feasible with the appearance and feel method. Although soil water monitors will cost more money, the only labor requirements involve the installation and removal of the equipment each year along with time to interpret the data.

Viewing the Data

Each piece of equipment has its own particular method for collecting and viewing the data. Some equipment requires going out into the field to get the reading and others put the data onto the internet. In fact, the most significant innovation in recent years with soil water monitoring equipment is the ability to put the data where the decision maker wants it. This can be in the field by the sensors, on the edge of the field, or next to a pivot road. Using radios or cell phone connections, the data can be put onto the office computer or the internet for easy access. The data logging process which comes with many of the newer monitoring systems can provide multiple readings each day and can be viewed as desired. Having multiple readings in a day provides a continuous record of soil water versus just a weekly data point that is normal when data is collected manually. The continuous data is useful in analyzing how rain and irrigations are infiltrating into the soil and in understanding how fast the crop is using water and from what depths. In general, the more readily accessible the information, the more costly the monitoring equipment will be.

The decision of where to have the data available is strictly a management decision. The least cost systems require going into the field where the more expensive systems can put the data on the internet. The systems that have a readout on the edge of the field or on the pivot road are in between. All of the systems that get the data to a computer have a significant advantage in that they log the data and the computer can then create graphs which help with data analysis. The most important thing is to get the data delivered to where it will be used by the decision maker. For most producers, it needs to be at least brought to the edge of the field or to the pivot road where it can be viewed from the pickup or 4-wheeler.

Data Analysis

Soil water monitoring equipment can generate a lot of data, but by itself, the data isn't very useful. To make good irrigation scheduling decisions, the data needs to be analyzed and carefully interpreted.

Managing irrigation using soil water data has the advantage of knowing more precisely how much water is stored in the crop root zone and at what depth the water is located. The objective early in the season on deeper root crops is to make sure that the crop has used some water in the lower two-thirds of the root zone before irrigation is applied and then maintaining this dryer zone into the summer. For corn and soybeans and other deeper rooted crops this would be in the second and/or third foot. Shallow rooted crops, especially on lower water holding capacity soils may need to be kept wetter. The dryer zone gives the advantage of being able to create some room to store water from rain or irrigation and allows for the observation of how the sensors respond as the soil dries and rewets. Irrigation water application is getting ahead if the monitors indicate the soil is rewetting. On the other hand, irrigation is needed if the monitor indicates the soil is getting drier.

With just a few calculations, the volume of water in the root zone can be found, which in turn helps determine how many days before the crop will experience water stress. At the same time, these calculations can determine how much water the soil can hold or how much irrigation water can be applied.

Another important calculation that soil water data can help with is how much water from rain and irrigation will be needed at the end of the season for the crop to reach maturity. The objective of monitoring soil water in this case is to apply just enough water to get top yields, leave the soil dry to capture off season precipitation, and all the while keep pumping to a minimum.

Sensor Placement

Determining the best site in the field for the soil water sensors to be placed is extremely important. Ideally, multiple sets of sensors would be installed in each field and the results averaged to determine the irrigation schedule. However, the reality is that most producers find it very challenging to even get one set of sensors in the field, so great care must go into selecting the best equipment, picking a good site and getting it installed properly. Each field should have its own set of sensors because of differences in rain, planting dates, irrigation system capacity, etc. Additionally, a second set of sensors should be installed if the field is split and planted into two different crops. Variable rate irrigation systems require a different set of sensors to schedule each of the different irrigation zones.

The location should be selected based on the soil type, the slopes of the field, and the general location. Obtain a soils map that gives the approximate location of the different soil types found in your field. If you do not have a soils map, check with the local Natural Resources Conservation Service Office (NRCS), look up the soil in the county soil survey book, or look online at http://websoilsurvey.nrcs.usda.gov/app/. To ensure that you are in the soil type you have selected in the field, keep away from those areas of soil transition shown on the map.

Some fields have several different soil types. You generally need to select the soil type that is the most predominant and will represent the greatest area of your field. Coarse textured soils often require more irrigation than finer textured soils because they hold less water and are more prone to deep percolation loss. In fact, a silt loam will hold about two times as much plant available water as sand. The decision comes down to either over watering the finer textured area or suppressing yield on the coarser textured areas. Also, hillsides can have less stored water than level parts of the field because of runoff during heavy rains. The decision of what part of the field to monitor is a management decision that should be based on how much of the field is represented by the different soils and slopes and a location that provides easy access to install, maintain and remove the equipment.

The sensors should not be placed: within 75 feet of the edge of the field; in the two inside spans of a center pivot; in an area that may receive runoff; in areas that may have soil compaction such as close to driveways or turn rows; or when the field is muddy. Remember, this one site is to represent the entire field. For the best results, the sensors should be installed at least 1 to 2 weeks before readings are needed and while the crop is still small.

Once the irrigation season has started, make sure the soil water readings you obtain make sense. It is a good idea to double check how the selected site compares to the rest of the field. Differences may show up because of soil type, slope, or irrigation system uniformity. The procedure should only need to be completed a couple of times over a few weeks if the comparisons look good. One method to do this is to take the hand probe and check the soil 10 to 15 feet away from the sensors and compare it with other parts of the field. The exact soil water content is not needed, just a relative sense the soil's appearance and feel as compared to the soil in the rest of the field. If the field has different soil types, remember to take it into account on the comparison.

Depth of Soil Water Measurements

The depth to monitor soil water for irrigation scheduling depends on the crop being grown and the growth stage. Annual crops have a shallow root system when they first emerge and gradually get deeper as the season progresses and the root system develops. As the crop gets closer to maturity and the days get shorter and cooler, the depth that water can be pulled from, without causing water stress, can also increase. In order to use up as much stored soil water as possible before the crop matures and without reducing yield, it is best to know where water is in the soil profile. It is suggested to slowly use the water from the deeper depth in the last thirty to forty days before the crop matures by delaying a few extra days between each irrigation event. Table 1 gives the suggested root depth for irrigation scheduling versus stage of growth. The crop roots grow deeper into the soil than shown in the table, but to achieve full yields it is suggested to not force the crop to pull very much water from depths lower than shown.

The decision of how many sensors to install and at what depth is mainly a management decision. The suggestion is to have a minimum of three sensors evenly distributed through the suggested root depth for irrigation scheduling at the final growth stage as shown in Table 1. A fourth sensor is recommended for the crops with a 4 foot suggested rooting depth, which includes most of the crops grown in Nebraska. One of the easiest ways is to put in four sensors centered on each of the top 4 feet, in other words at 6”, 18”, 30”, and 42”. The even spacing of the sensors makes analyzing the data easier. More sensors may be better, but they generate more data that must be looked at each time before scheduling the next irrigation.

Soil Texture Layer Changes

The above discussion assumes that a soil has a uniform texture throughout the profile. If the soil profile has significantly different textures with depth, it is recommended to make some adjustments. First, sensors should not be installed closer than 4” to the depth where a soil textural change occurs. If monitors are placed in different soil types, the difference in water holding capacity of the two soil types will need to be taken into account.

Methods of Soil Water Measurement

The methods of soil water measurement fall into two broad categories. They include measurement of soil water potential and soil water content. Both measurements are needed for irrigation scheduling, but by knowing one of the measurements and the soil type, the other can be estimated or found on a chart.

The soil water potential methods measure the amount of tension or pull the plant roots are exerting on the soil water and how tightly water is held by the soil. This method more closely measures what the plant is dealing with to extract water from the soil, but a conversion chart is needed for each soil type to determine the soil water content and how it relates to field capacity and permanent wilting point.

The soil water content methods measure the amount of water in the soil, but a chart for each soil type is still needed to know how the reading relates to field capacity and permanent wilting point. Without this information it is imposable to know how the plant will react to any given soil water content.

The soil water potential methods include: tensiometers, soil moisture blocks, and watermark sensors. The soil water content methods include: appearance and feel, capacitance sensors, neutron probes, and TDR (time domain reflectometers). A few other methods are available that will not be discussed in this chapter and include: gravimetric, psychrometers, pressure plate, and heat dissipation sensors.

All measurement methods are only as good as the procedures used by the person installing the equipment or taking the soil samples. Always closely follow the manufacture installation instructions.

Tensiometers

Tensiometers directly measure the amount of tension or pull plant roots are exerting on the soil water and how tightly water is held by the soil. The tensiometer is a water-filled tube with a vacuum gauge at the top and a ceramic tip at the base. The tubes come in various lengths to allow the ceramic tip to be placed at various monitoring depths. When installed in the soil, water can pass through the ceramic tip to the soil or from the soil into the tensiometer. As water is pulled from the tensiometer, a vacuum is created and measured on the gauge. As the soil water is depleted, the vacuum in the tensiometer increases. When the field gets wetter from irrigation or rain and the soil water level increases, water moves back through the ceramic tip because the tensiometer is exerting a vacuum on the soil water around the tip. As water is pulled into the tensiometer, the vacuum is reduced and reflected in the gauge reading. This change in vacuum or soil tension is used to estimate the soil water content.

The advantage of the tensiometers is, once installed, the readings are easy to take and the time required is small. The disadvantages include cost, installation, maintenance, removal at the end of the season, and the risk of a late season freeze breaking the sensor. Tensiometers should only be used in coarser textured soils ranging from fine sands to fine sandy loams. Finer textured soils develop enough tension to drain the tensiometer and break the vacuum. This occurs even though soil water has not been depleted beyond the available soil water management guidelines. If tension breaks, maintenance is required to refill the tube with water and evacuate all air. This should be done after rain or irrigation has wetted the soil.

Soil Moisture Blocks

Soil moisture blocks or gypsum blocks measure the amount of electrical resistance between two wire mesh rings embedded in a gypsum material. The blocks are to be installed into the soil wet. The gypsum releases water to the soil and comes to equilibrium with the soil water level. As the soil water increases through irrigation or rainfall, water moves into the gypsum block and the electrical resistance decreases. As the crop uses water and the soil water decreases, water is pulled from the gypsum material into the soil and the electrical resistance within the gypsum block increases. The wire mesh rings are attached to wire leads that are brought to the soil surface. A specially designed meter is used to measure the electrical resistance which in turn reflects the current water potential in the soil.

Moisture blocks can be used in fine textured soils including silt loam, loam, silty clay loam and sandy clay loam. The disadvantages include: they can only be used one season and will not work in sandy soils.

Watermark Sensors

Granular matrix sensors, commonly know as Watermark Soil Moisture Sensors reduce the problems inherent in gypsum blocks by use of a granular matrix enclosed in a metal and plastic capsule. It may be used in all soil types, but is limited to a range of 0-240 centibars, which works well for most irrigated crops. The sensors operate on the same electrical resistance principle as gypsum blocks described above and require a different meter that is specially designed to measure the electrical resistance of the Watermark sensors. The meter is calibrated to read in centibars, the same units used with tensiometers, which in turn reflects the soil water potential.

Installation and operation of the Watermark sensors are similar to soil moisture blocks. The Watermark is more expensive than the soil moisture blocks, but by gluing on a length of PVC pipe, it can be easily retrieved at the end of each growing season and reused for several years.

Watermark sensors have the advantage of being easy to install, low cost, reusable, and it is easy to add extension wires to run several hundred feet across a field to a data logger or a readout point located at the edge of the field.

Capacitance Sensors

Capacitance sensors measure the dielectric constant of the soil in order to find its water content. Since the dielectric constant of water is much higher than that of air or soil minerals, the dielectric constant of the soil is a sensitive measure of water content. Because of the difference in the dielectric constant between water and air and the very small amount of soil the sensors evaluates, any air gap around the sensor will cause large errors. Always closely follow the manufactures installation instructions to minimize this problem.

The sensors come in a variety of configurations, but basically consist of a pair of electrodes (either a group of parallel spikes or circular metal rings) which form the capacitor with the soil acting as the dielectric in between. This capacitor works with an oscillator to generate an AC field. Changes in soil water content are detected by analyzing the results with the electronics.

The advantage of the capacitance sensors is that they allow for a great deal of flexibility in their design configuration and the cost of the electronic components is relatively low. Because of this, they are the most common fully electronic soil water sensors on the market today. Several companies produce systems, and they all look quite different. Some models are designed to be installed at one location for the entire season, and other models are designed to be portable. The portable models are generally of two types: one being designed with electrodes that are pushed into the soil and the other operates from within an access tube that needs to be installed in advance. Another advantage is that most systems come with a factory calibration that can be used in all soil types, even though developing a calibration for the soil the sensor will be used in may improve the accuracy some.

The disadvantage of the capacitance sensors is that they need to be very precisely installed to avoid any air gaps between the sensor and the soil. The systems are in the upper end of the cost range for sensors used in production agriculture and some researchers have reported observing accuracy problems.

Neutron Probes

Neutron probes use a small radioactive source to determine the amount of water in the soil. An access tube must be installed each year and is used so the probe can be lowered to the desired depth in the soil. The neutron probe, when calibrated, provides very accurate soil water measurements. Most people consider it to be the standard to compare other methods to. However, due to cost, state regulation and licensing requirements relating to using a radioactive device, and the time required to go to the access tubes and take the readings, the neutron probe is primarily used as a research tool. The neutron probe is only designed as a portable probe and cannot be left in one place all season continuously taking reading and having the data recorded.

TDR (Time Domain Reflectometers)

A time-domain reflectometer (TDR) is an electronic instrument used to locate faults in metallic cables or locate discontinuities in a connector, printed circuit board, or any other electrical path. The use of TDR in soil water measurement focuses on characterizing the discontinuities created by two or more parallel metal rods inserted into the soil. The device propagates an electromagnetic wave through the sensor and very precisely analyzes the travel time. The key to TDR's success is that it can very accurately determine the dielectric constant of the soil and the water in it. The dielectric constant of water is much higher than that of air or soil minerals, thus it is a good measure of the water in the soil.

The advantage of TDR is that it measures soil water very precisely and the factory calibration works well in all soils. The disadvantage is that the complex electronic equipment costs more than other methods and rods must be correctly inserted into the soil.

Table I. Suggested root depth for irrigation scheduling versus stage of growth.

Root Depth (ft.)	Corn	Soybeans	Grain Sorghum	Spring Grains	Winter Wheat	Alfalfa	Sugar Beets	Dry beans	Established pasture	Potatoes
1.0	Vegetative	Vegetative	Vegetative					Vegetative		Seeding
1.5								Initial flower pod set		Bloom
2.0	12 leaf	Early bloom			Fall growth		June 1	Beginning pod fill	Cool season	
2.5	16 leaf	Full bloom	Flag leaf	Joint	Spring growth		July 1	Full seed fill		Maturity

3.0	Silking	Pod elongation	Boot	Boot	Joint		July 15	Warm season
3.5	Blister		Bloom	Flowering	Boot		Aug. 1	
4.0	Beginning dent	Full seed fill	Dough	Dough	Dough	Establish ed stand	Sept. 1	