

Irrigation Considerations and Soil Moisture Monitoring Tools

Jerry Wright, Dave Wildung, and Terry Nennich, University of Minnesota Extension Service

Soil moisture is generally the most limiting element in maintaining uniform plant growth and high quality produce within a high tunnel system. A full-season crop like tomatoes, peppers or cucumbers may require 15 or more inches of drip irrigation water to meet the crop’s daily water usage requirements throughout the season. To operate a drip irrigation system effectively and achieve high quality yield within a high tunnel system, a daily assessment of the soil moisture within the root zone is needed.

Irrigation systems should be designed and managed to assist a producer from planting through harvest. Too much water can reduce soil aeration and cause as much trouble as not having enough water, especially during critical growth periods like pollination and fruit development. An Extension Horticulturalist from Texas A&M University points out that even small amounts of water deficiency during certain stages can be detrimental to the plants. This deficiency can occur even before visible wilting occurs. He also mentions that even slight water deficiencies can cause slowed growth rate, lighter weight fruit and, in tomato, blossom end rot. Sanders from North Carolina likewise states that when soil moisture is allowed to drop below the proper level, the fruit does not expand to produce maximum size before it ripens, thus reducing yield and, if moisture is allowed to fluctuate too much, blossom end rot can occur and fruit is no longer useable.

The frequency of irrigation depends on many factors and can vary from once every five to ten days during the early weeks of growth to every day or two during fruit sizing and ripening. Soil water can be taken up by a plant and evaporated into the tunnel atmosphere at a rate of 0.05 inches to over 0.30 inches per day. This process is called evapotranspiration and is the combination of soil surface evaporation and water loss from the plant leaves by transpiration. The water evaporated in this process is often referred to as daily ET or crop water use.

The actual amount of water evaporated each day by a plant is very dependent on the plant’s canopy size, stage of growth, tunnel air temperature and intensity of sunlight (solar radiation). Hence, daily ET variation prohibits irrigating on a set frequency and supports the need for regular in-field soil water monitoring for effective water management. Granberry from the University of Georgia Extension Service states that proper irrigation scheduling is absolutely necessary if quality, yields and profitability are to be optimized and that irrigation scheduling becomes even more critical when drip irrigation is used in conjunction with plastic mulch and fertigation.
Establishing a water management plan for each crop is essential for maintaining a regular, consistent supply of soil water to 1) optimize an irrigated crop's growth, 2) enhance and protect the produce quality; 3) reduce seasonal growth and yield variability and 4) increase the chance for sustained profitability.

The intent of this chapter is to highlight the basic irrigation water management factors and tools that an operator should understand and implement during set-up of the irrigation systems as well as throughout the growing season. Also, we highly recommend that a new operator review as many as possible of the excellent web based publications from other states on how to manage an irrigation system for vegetables crops. Many of these are listed in the reference section at the end of this chapter.

**IRRIGATION WATERING STRATEGIES**

Deciding when to irrigate in a tunnel system is a daily decision that requires consideration of several factors by the operator. During the initial set-up, one should become very familiar with the soil profile and the drip irrigation system's average water application rate (inches per hour). In the soil profile, one should learn about the soil texture within the tunnel rows, the soil's available water holding capacity (AWC) in the top 12 to 18 inches, any potential root restricting layers, any soil drainage limitations and the optimum soil moisture levels for each crop.

During the growing season the operator needs to understand and assess the current soil moisture status in each plant row and how the different stages of plant growth, plant size and daily weather conditions, especially temperature and intensity of sunlight (solar radiation), affect the plant's daily crop water usage (ET).

Regular in-field assessment and past experience must both be used to make timely irrigation decisions. Most horticultural crops respond best to a uniformly moist soil profile. Wide fluctuations from wet to dry soil conditions generally will cause yield loss as well as reduced quality of the produce. Especially important is maintaining adequate soil water content during pollination and fruit development right up to harvest.

Sanders from North Carolina State University points out that with tomatoes, if soil moisture is allowed to fluctuate too much, blossom end rot can occur and fruit is no longer useable and that during fruit expansion stage, fruit cracking can occur if too much soil moisture fluctuation is allowed to occur.

The amount of soil water available to a plant and capable of being held within the soil profile is a function of both plant's potential rooting zone and the soil texture and organic content within the profile. Table 1 lists the typical soil water holding capacity ranges for several soil texture series (usually expressed in inches of water per inch of soil). For a typical sandy loam soil found in central Minnesota, the top foot of the soil profile might expect the soil profile to hold between 1.0 and 1.8 inches of water. These values are greatly affected by the actual organic matter content. Using data from the published county soil survey report or contacting your local SWCD office may help to identify a more accurate estimate of the soil texture and water capacity in the profile.

Most irrigated vegetable crops develop a relatively shallow rooting depth compared to dryland plants. Likewise for most vegetable crops the majority of the roots will be generally
found no deeper than 10 to 12 inches and, for some crops like onions, the depth might only be six inches. These depths are normally achieved within 30 to 40 days from planting.

To verify the actual rooting potential, a good practice especially during the first year or two of operation would be to investigate the actual rooting depth 30 to 50 days after planting. This can be done rather quickly by digging alongside one or two plants to physically observe where the majority of the roots are located in the soil profile. This type of investigation can also very quickly identify if there is also some type of rooting restriction that has been caused by the selected tillage action. It can also identify any natural barriers, such as layers of very coarse sand and gravel, which will prevent future root penetration. If the rooting depth is much shallower than anticipated, the amount of water being applied per irrigation should be adjusted to avoid over irrigating.

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Inches of water/inch of soil</th>
<th>In. water/ ft of soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Sand</td>
<td>0.02-0.04</td>
<td>0.24-0.48</td>
</tr>
<tr>
<td>Fine Sand</td>
<td>0.05-0.08</td>
<td>0.60-0.96</td>
</tr>
<tr>
<td>Loamy Sand</td>
<td>0.07-0.12</td>
<td>0.84-1.44</td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>0.08-0.15</td>
<td>0.96-1.80</td>
</tr>
<tr>
<td>Loam-Clay</td>
<td>0.14-0.20</td>
<td>1.68-2.40</td>
</tr>
</tbody>
</table>

Research literature is limited in identifying optimum soil moisture levels for most horticultural crops. Minnesota experiences and review of other states’ Extension bulletins suggest that soil moisture in the top foot should be maintained during the plant's critical periods especially at between 60 and 100% of the soil’s available water holding capacity. This is especially critical during pollination and fruit development in order to achieve optimum growth. (Sanders. 1997. Vegetable Crop Irrigation – North Carolina State University and Kemble, 2000. Basics of Vegetable Crop Irrigation. Alabama Cooperative Extension Service).

This soil moisture operating range is also commonly expressed as either a percentage of soil water depletion (0 to 40%) or as a range of soil water tension values (such as 10 to 35 centibars (cbs.)). This range provides a very workable soil moisture level for maintaining most drip irrigated vegetable crops on soils with fine sandy loam to a sandy loam texture.

Table 2 lists soil water deficit estimates for several soil textures at different soil tensions based on actual Minnesota soil evaluations. For example, if a sensor positioned at the six-inch depth in a sandy loam soil reads 50 cbs, the table suggests that the soil is 0.7 inches depleted in the one-foot soil profile. This means that this site can hold 0.7” of additional water to return the tension back to 10 centibars or less, which is called at field capacity or full. If the reading was at only 30 cbs, the soil could only hold around 0.5 inches of additional water. The 0.5-inch deficit for the sandy loam soil could also be referred to as being 30% depleted (0.5/1.7 x100%) and likewise the 0.7-inch deficit reading would be equivalent to around 40% depletion (0.7 /1.7 x 100) assuming 1.7 inches is the AWC of one-foot of soil.
### Table 2. Soil Tension Versus Soil Water Deficit – Inches Per Foot

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>10</th>
<th>30</th>
<th>50</th>
<th>70</th>
<th>100</th>
<th>1500*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>0.0</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Fine Sand</td>
<td>0.0</td>
<td>0.3</td>
<td>0.4</td>
<td>0.6</td>
<td>0.7</td>
<td>1.1</td>
</tr>
<tr>
<td>Loamy Sand</td>
<td>0.0</td>
<td>0.4</td>
<td>0.5</td>
<td>0.8</td>
<td>0.9</td>
<td>1.4</td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>0.0</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
<td>1.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Loam – Clay</td>
<td>0.0</td>
<td>0.2</td>
<td>0.5</td>
<td>0.8</td>
<td>1.0</td>
<td>2.4</td>
</tr>
</tbody>
</table>

*1500 centibars is permanent wilting point and this deficit value is equal to the soil's total available water holding capacity as represented in Table 2.

The frequency of irrigation events is very dependent on the size of the plants, the sunlight intensity (solar radiation) and the ET rate at which soil water is removed by the plant. For the first few weeks after transplanting, the frequency of irrigation generally might only be once every 5 to 10 days.

Sanders from North Carolina points out that it is important for the soil profile to be refilled with water at each irrigation. Frequent light irrigations during early growth may result in shallow root systems. Then, as the plants start to develop a larger canopy, the irrigation frequency may increase to once every day or every other day depending especially on the amount of sun intensity. This rate of irrigation may continue until late August and then be reduced as the day length decreases and the plant's leaves start to age.

Soil water can be taken up by a plant and evaporated into the tunnel atmosphere at ET rates of 0.05 inches to over 0.30 inches per day. The actual amount of water evaporated or ET each day by a plant is very dependent on the plant's canopy size, stage of plant growth, tunnel air temperature and intensity of sunlight (solar radiation). Hence, daily ET variation prohibits irrigating on a set frequency and supports the need for regular in-field soil water monitoring for effective water management.

For a full canopy row crop like tomatoes or peppers, daily water usage (ET) might be sustained for several days at 0.25 to 0.30 inches per day or even higher on very clear days. This is especially true during the long daylight hours in June and July (0.30" is approximately equivalent to 5 - 40 gallons of water per 100 feet of plant row per day, dependent on the plant canopy width and density).

Table 3 shows the range of water replacement needs for several different plant canopy widths and various ET rates. Scientists from Oregon State University suggest that during
peak: water use times in a greenhouse setting cucumbers and tomatoes may require 1 to 3 quarts of water per day depending on the plant size and daily weather conditions (Hemphill, 2004. Commercial Vegetable Production Guide for Field and Greenhouse Crops).

<table>
<thead>
<tr>
<th>Table 3. Estimated Amount of Irrigation Water Needed (Gallons Needed per Day/100 feet of row) for Different Plant Canopy Widths and Daily ET Rates.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Canopy Width</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Feet</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>2.5</td>
</tr>
</tbody>
</table>

During the crop's critical growth periods, an irrigation event it should re-wet the upper rooting depth up to 90 to 100 percent of soil's water holding capacity. The actual amount of irrigation needed to return the soil to full (also called field capacity) is difficult to determine but can be estimated by using Table 3 and then refined as the season goes along. For example, if the deeper soil profile does not show a change within 24 hours after irrigation or, in fact becomes drier, the application depth or pumping time should be increased slightly during the next irrigation. On the other hand, if the deeper soil becomes too moist after irrigation, consider reducing the application amount by shortening the operating time a little. Applying too much water in the soil can be detrimental to plant growth and will increase the risks for leaching of some of the nitrogen from the rooting zone.

The frequency of irrigation applications can differ for each crop during the growing season and should be managed differently it at all possible. Every soil profile also acts differently; therefore continuous monitoring of the soil moisture response is needed. An operator needs to be open to readjusting the irrigation time and or frequency as necessary to meet the crop's water needs and to maintain soil water levels within the optimum range.

Several soil water-monitoring tools are available to assist an operator in irrigation scheduling. Soil moisture sensors like tensiometers or electric resistance blocks are the most highly recommended by the authors, as well as many other irrigation specialists. Detailed discussion on soil moisture sensor options and installation can be found later in this chapter.

Below are several water management tips that a first time operator especially should consider in the planning stage as well as during the growing season. These are based on the authors' field experiences with growers and with high tunnels at the University of Minnesota North Central Research and Outreach Center at Grand Rapids:

- Learn about the soil texture and profile characteristics of the soil resources within the high tunnel.
- Order an appropriate number of soil moisture sensors for each crop and tunnel unit well in advance of the planting season to have them ready for installation shortly after transplants are placed in the tunnel. Sensor options and installation instructions are given later in this chapter.
• Run the new drip irrigation system for at least two-hours shortly after spring tillage of the rows/beds and before plastic mulch and transplants are installed to observe how the applied irrigation water distributes itself within the soil profile. To observe the distribution, dig a cross section into the soil profile at 30, 60, 90 and 120 minutes intervals after the irrigation is started and visually observe the wetted area's width and depth movement over this time. This wetted area over the course of the growing season may change a little as the soil profile compacts slightly over time. This practice also serves at getting the soil bed moisture content ready for transplanting.

• After the plastic mulch and transplants have been installed, identify the locations where you would like to have several pairs of soil sensors and then install the sensors (see installation instructions near the end of the chapter).

• Establish a schedule for reading the soil sensors every 1 to 2 days and chart the readings into a graphic format by using a computer spreadsheet or utilize a sensor data logger to take the measurement. Presenting the readings in a graphic format makes it very easy to observe how fast the soil moisture changes over time and how much the reading changes after an irrigation event. Also record the length of time each irrigation event operates and the date for each event.

• Examine the root development of several plants 40 to 50 days after planting to observe how they are interacting within the soil profile and the irrigation zone.

Soil Water Moisture Monitoring Options

Several soil water-monitoring tools are available to assist in irrigation scheduling. These include soil probe, soil moisture sensors, and crop water use estimators. When using drip irrigation and plastic mulch, it is strongly encouraged by the authors and many others that one chose some type of in-soil moisture sensing device that can be placed for the whole season. These should be located at two or more sites in the tunnel and at least two depths in the soil profile at each site. Regardless of the tool selected to assist the manager, the soil moisture status of a drip irrigated crop needs regular monitoring. This should be done at least every other day, if not daily, to assist the irrigation manager in making irrigation decisions.

Soil probe or small shovel is the most commonly used device by conventional large-field irrigators to monitor the soil moisture level. Small soil samples are obtained at different depths and then their feel and appearance are compared to a descriptive chart to make an estimation of its moisture deficiency. Since this method requires frequent probing, it will become very destructive to any plastic mulching material over time and also could very easily cut the drip tubing if one does not remember to check its location before probing. Hence, this method is not recommend by the authors for conducting regular soil water monitoring on plastic mulched beds in a tunnel. This method, however, could be used to
periodically check how far the irrigation water is penetrating in other areas of the tunnel not monitored by a sensor. A chart describing the soil appearance at different moisture levels can be viewed in the University of Minnesota Extension Service bulletin *Irrigation Management Consideration for Sandy Soils* at [http://www.extension.umn.edu/distribution/cropsystems/DC1322.html](http://www.extension.umn.edu/distribution/cropsystems/DC1322.html)

Soil water sensors come in several designs that monitor the soil moisture by either measuring the soil water tension, electrical resistance, or soil capacitance to estimate the actual available water in the profile. Soil water tension is a soil water property, expressed in centibars (cbs) of suction pressure, which indicates the energy required by plant roots to extract water from soil particles. A soil tension reading of 10 cbs or less means that, for a sandy soil, the water holding capacity is full. As the soil's moisture content decreases because of plant root uptake, the soil water tension in the soil profile increases. Table 3 lists estimated soil water depletion amounts (inches per foot) for several soil textures at different soil water tensions that were obtained in the lab from some Minnesota soils.

Soil water tension is best monitored in the field by tensiometers or estimated indirectly by the use of electrical resistance sensors (blocks) that are placed in the soil profile at various depths. A tensiometer has a vacuum-pressure gauge mounted to the waterfilled tube to observe the soil tension measurement at any time. The unit requires the tube to be filled with water and serviced to remove any entrapped air before installation into the soil. The tensiometer is installed in the soil with the porous ceramic tip placed at the desired depth. As the soil dries, water is pulled out the tube and the vacuum gauge indicates the soil water tension at that moment. When the soil is re-wetted, the soil water tension is lowered and the tube takes back some lost water. (Smajstrla. 2002. Tensiometers for Soil Moisture Measurement and Irrigation Scheduling. University of Florida; Harrison. 1993. Irrigation Scheduling Methods. The University of Georgia).

Tensiometers come in several lengths, such as 6, 12, 18 inches and longer. A 6 and 12-inch tensiometer would make an excellent pair of sensors at a given site. Tensiometers can be used many years if properly cared for at the end of each season.

![Electrical resistance sensors](image)

Electrical resistance sensors consist of a formed block (3/4 inch in diameter and 1 to 2 inches long) that contains a water absorption material like sand or gypsum in which electrodes to measure the electrical conductivity of the solution are embedded. Electrical resistance between the electrodes varies with the soil water content, and this has been related to soil water tension. Gypsum based blocks generally will only last for one year while other sensors made with a more durable sandy material can be used for many years. (Thomson. 1996. Using Soil Moisture Sensors for Making Irrigation Management Decisions. Virginia Cooperative Extension; Shock. 1998. Instrumentation for Soil Moisture Determination. Oregon State University)

Electrical sensors are read by a portable monitoring meter that is manually connected to each sensor each time it needs to be read. Alternatively, a small data logger could be used to monitor 4 to 8 sensors two or times a day and save the operator much time each day.

Resistance sensors generally work in a much wider range of soil textures and soil water tensions than tensiometers. Some sensor types like the Watermark granular matrix sensor
operate as well as a tensiometer in sandy textured soils and are more often preferred by users and the authors because of their ease of installation.

Tensiometers can cost between $50 and $75 dollars each depending on the length of tube. A service unit pump is also required to prepare the tubes for usage. Long lasting electrical resistance sensors may cost somewhere around $30 each and the portable meter around $275.

There are a few portable soil moisture probes, but the sensors that are placed in one spot for the whole growing season generally do the best monitoring of the soil water status within annual crops. Portable sensors are usually of a capacitance or time-domain (TDR) soil water measurement technique that estimates the volumetric water content. These devices are typically much more expensive than the tensiometers or resistance blocks and have to be inserted into the soil bed each time a reading is taken.

Soil moisture sensors like the tensiometer or the electrical moisture sensor should be installed into the plants’ active rooting zone within 1 to 2 weeks after transplanting or emergence and removed only at the end of the season.

Soil water sensors should be used to monitor at least two soil depths (1/2 and 2/3 the active root zone) and at one to two sites within the same crop type. Sensors are typically installed at 4 to 6 inches and 8 to 12 inches below the soil surface and within 5 to 8 inches of a drip water-emitter device and a plant's main stem. Sensors should be regularly read every day or two at the same time of the day all through the growing season. The readings should be recorded and plotted on a time-based graph or spreadsheet for each assessment.
The graph below shows an example of how to present the measured readings over a one-month period.

Some low-cost soil moisture data loggers (e.g., http://www.mkhansen.com/, http://www.irrometer.com/, and http://www.specmeters.com/) that can be left in the field to record one or more times a day are also available. These devices can take readings from several sensors and produce summary graphics like the graph above. The actual data shown in this graph are from readings recorded by a Hansen data logger with Watermark soil moisture sensors at two depths used in drip irrigated tomatoes grown in a high tunnel at the North Central Research and Outreach Center in Grand Rapids. Irrigation events for most high tunnel vegetable crops when grown on sandy soils should be initiated whenever the shallower sensors read between 25 and 35 centibars. During critical growth periods, like fruit sizing in tomatoes, the sensor range might need to be kept even wetter, between 15 and 25 centibars in especially the upper 5-8 inches of the profile. If the deepest sensor does not respond to an irrigation event, it's possible that the amount of water applied was not sufficient in amount to move to the sensor. To correct this situation, one should run the next few irrigations slightly longer to see if the deeper sensors respond. If more than one crop is under the same irrigation system, soil sensors should be placed in each crop to assist an operator in assuring that no crop is over or under irrigated. For additional information on moisture sensors, check out the websites listed in the reference section or contact a local irrigation supplier or a web based product contact listed at the end of this chapter.

Instructions on sensor installation are described in a later section of this chapter or can be found in the manufactures' literature.

Daily soil moisture accounting is an excellent method used by many conventional crop irrigators to estimate soil moisture by simply keeping a running balance sheet of the estimated daily crop water usage (ET) in relationship to the incoming rain and irrigation.
No research has been done in Minnesota to refine the current outdoor ET prediction models for usage within a high tunnel system; therefore this method is not an acceptable tool at the present time. Based on current open field ET research in Minnesota, however, we should expect that most high tunnel plants will take-up soil water and evaporate into the tunnel atmosphere at a similar ET range (0.05 inches to over 0.30 inches per day) for the same plant growth and the same climatic conditions. We should also expect that the actual ET within the tunnel will be somewhat higher (10-20%) than in the open field, as the average air temperature for given day might be 10 to 20 degrees warmer than outside conditions.

Table 4 presents expected outdoor daily ETs for a full-canopy crop within central Minnesota at different weekly periods based on long-term average outdoors solar radiation and maximum daily air temperature. Even though this Table was developed for outside conditions, it might be used to understand the ET potential difference between inside and outside conditions. The projected ET for a given outside air temperature for a given time could be compared to the projected ET for the tunnel air temperature that might be 10 to 20 degrees warmer for that same day. For example, if the air temperature for a day in July during the 9th week was 70°F outside and 90°F inside the tunnel, the Table would suggests that the outdoor ET would be around 0.17 inches. Inside the tunnel, the ET might be 0.25 inches for the same crop. Since this table is based on only average solar radiation for each time period, these ET estimates might be at least another 15 to 20% greater on cloud-free days in full sunlight.

<table>
<thead>
<tr>
<th>Week after Emergence</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature °F</td>
<td>50-59</td>
<td>60-69</td>
<td>70-79</td>
<td>80-89</td>
<td>90-99</td>
</tr>
<tr>
<td>1</td>
<td>0.06</td>
<td>0.09</td>
<td>0.12</td>
<td>0.15</td>
<td>0.18</td>
</tr>
<tr>
<td>2</td>
<td>0.07</td>
<td>0.10</td>
<td>0.14</td>
<td>0.17</td>
<td>0.20</td>
</tr>
<tr>
<td>3</td>
<td>0.07</td>
<td>0.11</td>
<td>0.14</td>
<td>0.18</td>
<td>0.22</td>
</tr>
<tr>
<td>4</td>
<td>0.08</td>
<td>0.21</td>
<td>0.15</td>
<td>0.19</td>
<td>0.22</td>
</tr>
<tr>
<td>5</td>
<td>0.08</td>
<td>0.12</td>
<td>0.15</td>
<td>0.19</td>
<td>0.22</td>
</tr>
<tr>
<td>6</td>
<td>0.08</td>
<td>0.12</td>
<td>0.15</td>
<td>0.19</td>
<td>0.22</td>
</tr>
<tr>
<td>7</td>
<td>0.09</td>
<td>0.13</td>
<td>0.17</td>
<td>0.20</td>
<td>0.24</td>
</tr>
<tr>
<td>8</td>
<td>0.09</td>
<td>0.13</td>
<td>0.17</td>
<td>0.20</td>
<td>0.24</td>
</tr>
<tr>
<td>9</td>
<td>0.09</td>
<td>0.13</td>
<td>0.17</td>
<td>0.21</td>
<td>0.25</td>
</tr>
<tr>
<td>10</td>
<td>0.09</td>
<td>0.13</td>
<td>0.17</td>
<td>0.20</td>
<td>0.24</td>
</tr>
<tr>
<td>11</td>
<td>0.09</td>
<td>0.13</td>
<td>0.17</td>
<td>0.20</td>
<td>0.24</td>
</tr>
<tr>
<td>12</td>
<td>0.08</td>
<td>0.12</td>
<td>0.16</td>
<td>0.20</td>
<td>0.24</td>
</tr>
<tr>
<td>13</td>
<td>0.08</td>
<td>0.12</td>
<td>0.16</td>
<td>0.20</td>
<td>0.24</td>
</tr>
<tr>
<td>14</td>
<td>0.08</td>
<td>0.12</td>
<td>0.16</td>
<td>0.20</td>
<td>0.23</td>
</tr>
<tr>
<td>15</td>
<td>0.07</td>
<td>0.11</td>
<td>0.14</td>
<td>0.17</td>
<td>0.21</td>
</tr>
<tr>
<td>16</td>
<td>0.07</td>
<td>0.10</td>
<td>0.13</td>
<td>0.16</td>
<td>0.19</td>
</tr>
<tr>
<td>17</td>
<td>0.06</td>
<td>0.09</td>
<td>0.12</td>
<td>0.15</td>
<td>0.18</td>
</tr>
<tr>
<td>18</td>
<td>0.06</td>
<td>0.09</td>
<td>0.12</td>
<td>0.15</td>
<td>0.18</td>
</tr>
<tr>
<td>19</td>
<td>0.05</td>
<td>0.08</td>
<td>0.10</td>
<td>0.12</td>
<td>0.15</td>
</tr>
</tbody>
</table>

More information on Table 4 can be reviewed in the University of Minnesota Extension bulletin AGFO-1322 *Irrigation Scheduling-Checkbook Method* located on the internet at [http://www.extension.umn.edu/distribution/cropsystems/DC1322.html](http://www.extension.umn.edu/distribution/cropsystems/DC1322.html).
Soil Moisture Sensor Installation Procedures

To install electrical resistance type soil water sensors, like the Watermark soil moisture sensors; tensiometers or other similar devices follow the steps outlined below along with the instructions given by the respective sensor manufacturer. Sensors should be placed in the plant row shortly after the transplants have been set or after the new seedlings have emergence.

1. First, soak all sensors in clean water for 1 to 2 hours to help remove the air and then allow each to dry for four or six hours. Repeat this step two more times. For tensiometers, a vacuum service pump should be used after each drying to help purge any trapped air. Prior to placing the sensors into the soil, soak them at least (5) minutes. If the sensors were used in a previous season, evaluate them for damage to the sensor surface, wire leads or suction gage on the tensiometer and discard the sensor if the sensor surface looks plugged or damaged.

2. Next, select at least one or preferably two locations within the same crop for the sensors to be placed. All sensors should be located in a representative soil type in the tunnel and somewhere between 1/3 and 2/3ths of the way along the row at a point that will allow easy access to read the sensors. Each sensor should be positioned within the plant row approximately 4 to 6 inches from a healthy plant and also a similar distance from a drip irrigation emitter. At each site one sensor should be set 4 to 6 inches below the ground surface and another set at 8 to 12 inches below the surface depending on the crop’s rooting zone. The deeper sensor must also be located within the drip wetted zone and active rooting area.

3. To install a sensor in the soil, first make a pilot hole with a soil probe or small spade a little deeper than desired. To get good sensor contact with the soil, pour a little dry soil and water into the new hole. The sensor maybe positioned in the pilot hole either vertically or at a slight angle. Then slightly push it into the wet soil and re-packed the hole with the excavated soil. Avoid over-packing the replaced soil. If the deeper sensor contains wire leads, draw the lead wire through a soil probe tube or a plastic pipe and hold the sensor on the end. Push the probe and sensor into the hole to the desired depth until set firmly. Fill the hole by adding some dry soil and a little water in short steps, and firm the soil with a tamping stick until the hole is filled.

4. Mark each sensor to indicate its depth. For the sensors with wire leads, tag each sensor or creating one or more knots at the wire end to indicate the depth position (for example one knot means shallow and two knots means a deep sensor). Wrap the extra lead wire around a nearby stake to keep it from getting in the way of the walking paths.
5. Taking sensor reading one to two days after installation to allow the added water to become equalized in the soil. Sensors should be read every two to three days in the early season and then every day or two during rapid growth periods. Readings should be recorded in a notebook or spreadsheet along with each irrigation event (including time run). This will allow tracking of the soil water changes in the soil profile throughout the growing season.

6. Irrigate when the average readings of the shallow sensors within a given crop reach the desired threshold level (25 to 35 cbs.). The amount of water that should be applied depends on a lot factors and needs to be selected and refined based on previous irrigation events. Keep a watch on the deeper sensor and if the reading gets drier after an irrigation, lengthen the next irrigation event by 30 minutes.
References and Websites


Irrigation Water Management Product Sources

NOTE: This is a partial list of local and web based suppliers of irrigation water management materials. Mention of the suppliers is not intended to be an endorsement of their product or a preference over other suppliers. Use of trade names and equipment does not constitute endorsement by University of Minnesota nor is it a criticism applied of products not mentioned.

Ag Resources, Inc. (tensiometer, soil sensors, data monitor and accessories)
35268 State Highway 34
Detroit Lakes, Minnesota 56501
phone # 218-847-9351 E-mail: dgbari@tekstar.com

Berry Hill Irrigation (tensiometer, soil sensors, data monitor and accessories)
3744 Highway 58
Buffalo Junction, VA 24529
phone # 1-800-345-3747 or website: http://www.berryhilldrip.com

GEMPLER'S (soil probe, tensiometer, soil sensors and accessories)
P.O. Box 44993
Madison, WI 53744-4993
Phone: 1-800-382-8473 or website: http://www.gemplers.com/

Irrometer Company (tensiometer, soil sensors, data monitor-logger and accessories)
P.O. Box 2424
Riverside, CA 92516
Phone: (951) 689-1701 or website: http://www.irrometer.com

Jordan Seeds
6400 Upper Afton Rd.
Woodbury, Minnesota 55125
phone # 612-738-3422

M. K. Hansen Company (soil moisture data monitor-logger and soil water sensors)
2216 Fancher Boulevard
East Wenatchee, WA 98802
Phone: (509) 884-1396 or website: http://www.mkhansen.com/

Spectrum Technologies, Inc (tensiometer, soil sensors, data monitor and accessories)
23839 W. Andrew Rd.
Plainfield, Illinois 60544
phone# 800-248-8873 or website: http://www.specmeters.com/

TRICKL-EEZ Company (tensiometer, soil sensors, data monitor and accessories)
4266 Hollywood Rd
Saint Joseph, MI49085
phone # 269-429-8200 or website: http://www.trickl-eez.com