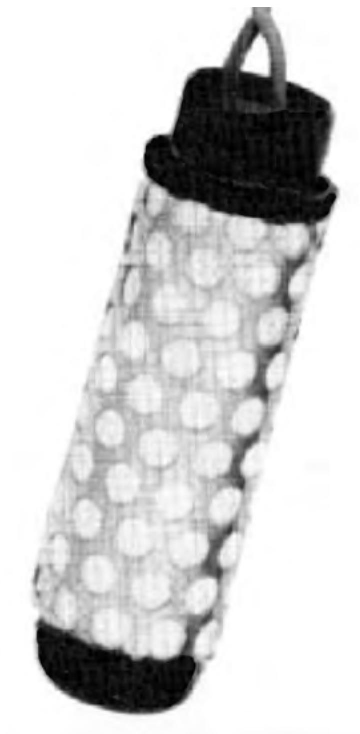
SUSTAINABLE AGRICULTURE TECHNIQUES

EM 8900 • Revised March 2013

Irrigation Monitoring Using Soil Water Tension

C.C. Shock, F.X. Wang, R. Flock, E. Feibert, C.A. Shock, and A. Pereira



Malheur Experiment Station, Oregon State University: *Clint C. Shock, director and professor; Rebecca Flock, former research aide; Erik Feibert, senior faculty research assistant; Cedric A. Shock, former research aide; Andre Pereira, visiting professor (associate professor, Department of Soil Science and Agricultural Engineering, UEPG, Parana, Brazil).*

Center for Agricultural Water Research, China Agricultural University, Beijing: *Feng-Xin Wang, associate professor*

Oregon State University | Extension Service

One of the most important tools we have been using at the Malheur Agricultural Experiment Station over the past two decades is the granular matrix sensor (GMS, Watermark Soil Moisture Sensor, Irrometer Co., Riverside, CA), which measures soil moisture. It is only about 3 inches long and normally is buried vertically in the ground.

Like gypsum blocks, GMS sensors operate on the principle of variable electrical resistance. The electrodes inside the GMS are embedded in granular fill material above a gypsum wafer. Additional granular matrix is below the wafer in the fabric tube, where water enters and exits the sensor.

Gypsum dissolved in water is a reasonable conductor of electricity. Thus, when the sensor contains a lot of water, the electric current flows well. When there is a lot of water in the soil, there is a lot of water in the sensor. As the soil dries out, the sensor dries out, and resistance to the flow of electricity increases.

The resistance to the flow of electricity (expressed in Ohms) and the soil temperature are used to calculate the tension of the soil water in centibars (cb). Soil water tension (SWT) is the force necessary for plant roots to extract water from the soil. Soil water tension reflects the soil moisture status. The higher the tension, the drier the soil.

Other devices for measuring soil water tension include tensiometers, gypsum blocks, dielectric water potential sensors, and porous ceramic moisture sensors.

What does a granular matrix sensor do for growers?

In the past, growers had to train themselves to guess when the soil was dry enough to warrant irrigation of their crop. Even with years of experience and well-developed agricultural intuition, it is very difficult to irrigate at the right moment consistently and to apply the ideal amount of irrigation water to maximize crop production. It would be helpful to have some consistent reference points of SWT for irrigation scheduling. The digital readout of the GMS provides reference points to help growers attain higher yields and better crop quality on their farms.

On a scale of 0 to 100 cb soil water tension, how wet is your field?

Roughly speaking, a GMS reads the following scale of SWT for a medium-texture soil:

- > 80 cb indicates dryness.
- 20 to 60 cb is the average field SWT prior to irrigation, varying with the crop, soil texture, weather pattern, and irrigation system.
- 10 to 20 cb indicates that the soil is near field capacity.
- 0 to 10 cb indicates that the soil is saturated with water.

What new information can a GMS give you?

A GMS can tell you whether the rain last night was really enough to give your onions, for instance, a good drink. It can tell you whether an overcast day is reducing crop water use in a potato crop enough to delay the next irrigation. It can tell you whether you will need to irrigate more often in July than in June. Since the reading comes directly from the crop's root zone, it is a tool designed to provide one more piece of information to your agricultural intuition.

Is scheduling irrigation from SWT really feasible?

We have been using GMS at the Malheur Experiment Station for 26 years, and we can answer with a resounding YES. There is no replacement for the watchful eye of an experienced grower. But, imagine a talented stockbroker with great financial logic and intuition. Does he not excel even more after checking stock quotes on the Internet? The same is true for the grower. For example, walking down to your onion field every morning and checking the readout of six or more GMS will help you know when to irrigate the field. In fact, by doing so you usually can predict irrigations a day or two ahead of time.

Our research has allowed us to determine the threshold SWT of various crops growing on silt loam under different irrigation systems. We found that irrigating at these critical values has significant benefits to crops.

The SWT irrigation threshold varies not only by crop but also by soil texture, climatic factors, and irrigation method. The threshold values that maximize marketable yield are known for a wide array of commercial crops growing on different soils under different climatic conditions and irrigation systems (Tables 1–4, pages 7–9).

Let's talk more about how using SWT can MAXIMIZE growers' profits

- Less water used—An irrigation schedule based on a threshold SWT usually results in fewer irrigations per year, as it can help prevent overwatering.
- Less pumping energy consumed
- Lower crop stress, which can result in less pest and disease pressure
- Prevention of excessive leaching of mobile plant nutrients, especially nitrogen and boron
- Prevention of groundwater pollution
- Reduced wear and tear on irrigation systems

From our own experiments, crops that are irrigated according to SWT criteria have higher marketable yield, increased size, and increased produce quality.

How hard is it to collect SWT information?

The GMS can be read in several ways. One way is with a hand-held Watermark Soil Moisture Meter (Model 30KTCD-NL, Irrometer Co., Riverside, CA). The hand-held meter is used much like a voltmeter and is manually connected to the sensor wires with alligator clips. It is simple to use, but labor intensive. You should

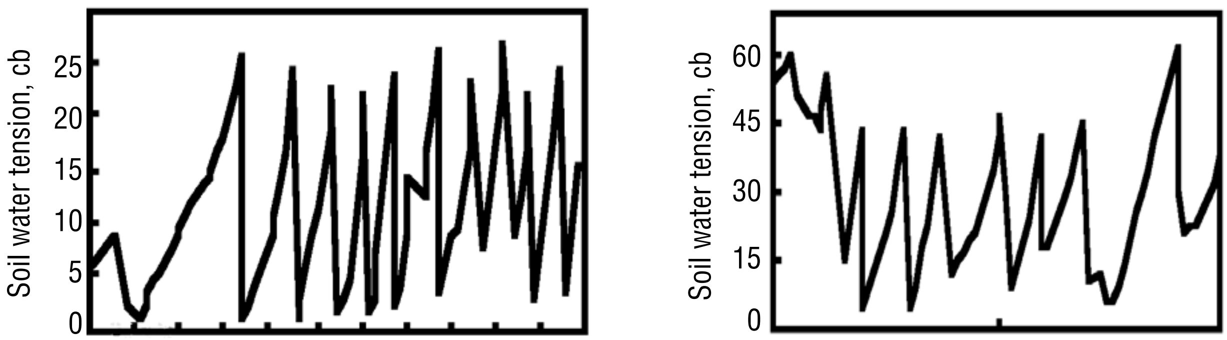


Figure 1. Variation of soil water tension (SWT) over a growing season for furrow-irrigated onions (left) and sprinkler-irrigated potatoes (right).

record the data from the meter by hand to make SWT comparisons over time.

For automatic reading and recording of GMS data, dataloggers are available. Both the Hansen AM400 (Mike Hansen Co., Wenatchee, WA) and the Watermark Monitor (Irrometer Co., Riverside, CA) are dataloggers that are installed at the edge of a field. These dataloggers can be programmed to collect and record data automatically from six or seven GMS and one soil temperature sensor throughout the day. You can view the data as numbers or graphs on the unit itself, or you can download it to a computer for easy viewing in graphing software or a standard spreadsheet application (Figure 1).

The data from field collection devices can readily be uploaded to the Internet using cell phone modems and graphically displayed in a web portal. This allows users to view the current soil moisture conditions from any Internet-enabled computer, making off-site management easier.

But my field is so BIG and that sensor is so small…

The success of the GMS hinges on how reliably a group of sensors represents the soil moisture of a field. That is why it is important to install the sensors at points in the field that accurately reflect the average root zone for the average plant. If part of the field has different water needs, create a second zone and install sensors at representative areas of that zone.

Granular matrix sensors usually are installed in a group of six or seven per irrigation zone. Each GMS provides information only about soil water tension in the immediate vicinity of the sensor. Because SWT varies from place to place in a field, and sensors also vary, six or more GMS will provide more reliable estimates of SWT for a field than a single GMS.

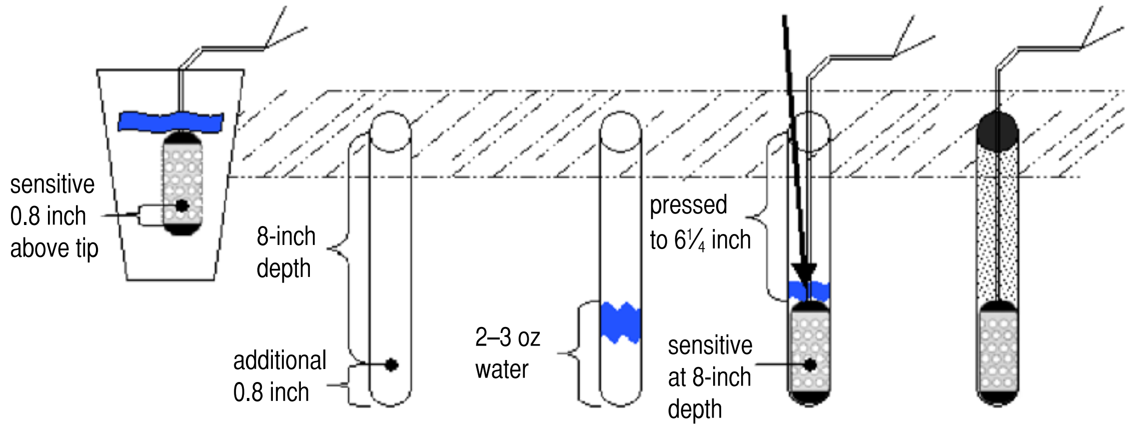
The sensors complete a simple electrical circuit. Thus, you can easily add an "extension cord" using normal electrical wire in order to collect information from many feet into the field. It is important to maintain clean, dry connections between the extensions and the sensor wires.

What about installation? Can I do it myself?

Installation is easy and requires few additional tools. You will need a ⅞" soil sample probe to create the right size hole for the sensor. Keep in mind that GMS are designed to accurately represent the relative amount of water in the field, so select an area that is not remarkable.

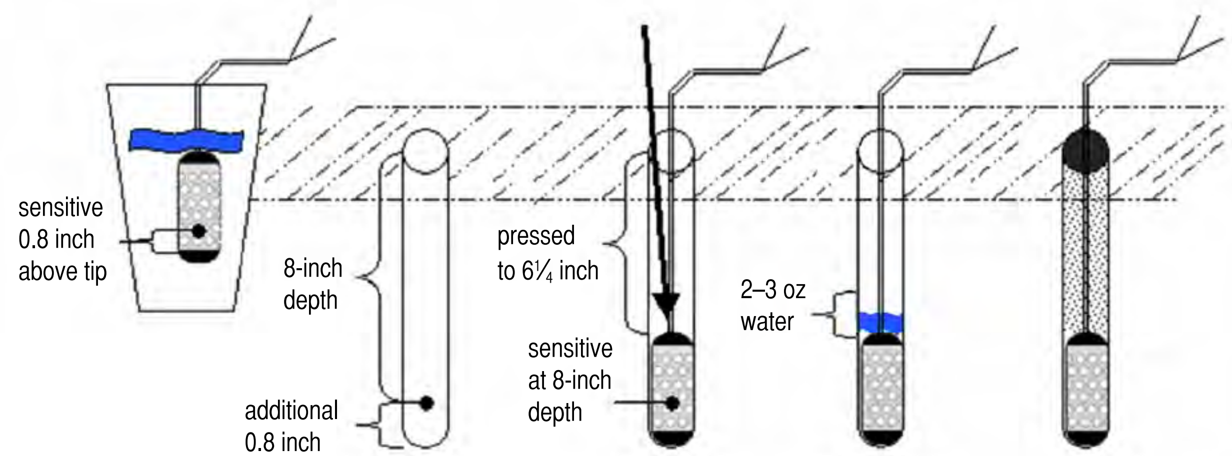
On page 4, Figure 2 (for coarse soils) and Figure 3 (for silty soils) illustrate the steps involved in installation. If you have attached a PVC tube to the sensor with glue prior to installation to make it easier to remove the sensors from the field, use the installation method in Figure 2.

The accuracy of the sensor relies on good contact with the soil. The GMS installation depth depends on the crop's root zone depth, but it also



1	2	3	4	5
Soak GMS several minutes until it reaches saturation.	Use ⅞-inch probe to remove soil to desired depth + 0.8-inch sensor tip.	Pour 2–3 oz of water into the hole.	Use dowel to insert the sensor. Expect snug fit.	Backfill the hole. Avoid any air pockets.

Figure 2. Installation procedure of a granular matrix sensor (GMS) in ***coarse*** *soil at an 8-inch depth in the soil.*



1	2	3	4	5
Soak GMS sev-eral minutes until it reaches saturation.	Use ⅞-inch probe to remove soil to desired depth + 0.8-inch sensor tip.	Use dowel to insert the sensor. Expect snug fit.	Pour 2–3 oz of water into the hole	Backfill the hole. Avoid any air pockets.

Figure 3. Installation procedure of a granular matrix sensor (GMS) in ***silty*** *soil at 8-inch depth.*

can be affected by soil depth and soil texture. For shallow-rooted crops, sensors installed at less than 12 inches deep are sufficient. For crops with a deep root system, also install sensors at greater depth within the root zone. The root zone depth might be greater in well-drained soils and less in clay soils or soils with compacted layers or poor drainage.

To install a GMS sensor, first soak the sensor for several minutes until it reaches saturation. Then make a hole in the soil using a soil sample probe with an external diameter corresponding to the sensor diameter. Since the sensitive area of the GMS is centered 0.8 inch above the tip, the hole should have an additional 0.8 inch of depth to provide the desired sensor installation depth.

The next steps depend on the texture of your soil. For coarser soils that have little tendency to lose their structure when saturated, pour about 2–3 oz of water into the hole and then place the sensor at the bottom of the hole (Figure 2). Silty soils tend to lose their structure when saturated and can seal around the sensor, thus impeding the entrance and exit of water. For silty soils, place the sensor at the bottom of the hole and then add about 2–3 oz of water to the hole (Figure 3).

Finally, regardless of soil type, backfill the hole with fine soil and use a tube, metal bar, or wooden stick to lightly compact the backfill dirt in order to prevent formation of a preferential path for rain or irrigation water to easily reach the sensor (Figures 2 and 3). Such a path is undesirable because it distorts soil moisture status, thus significantly compromising the reliability of the SWT data obtained by the GMS.

Sensor troubleshooting

The sensor operates by completing an electric circuit. It is not uncommon for a frayed wire to “short circuit” the sensor, causing it to read zero continually, or for a cut wire to create an “open circuit,” causing an unreasonably high reading. If sensors are wet and readings should be low, a few common default error numbers include 199 and 250, depending on the datalogger. Do not remove sensors from the soil by pulling on the wire since this can destroy the GMS.

Even with proper maintenance, sensors have a limited lifetime before they physically wear out or their sensitivity is compromised. Replace the unit at that time. Check sensors in the spring before use; dry sensors should have high readings, and sensors soaked in water for 1.5 minutes should read between 0 and 4 cb.

What is the bottom line for cost? Can I really afford this?

GMS systems as a whole are relatively inexpensive. With yield and quality increases and greater savings on water, energy, fertilizer, and other inputs, costs are quickly recovered.

For more information

Shock, C.C., A. Corn, S. Jaderholm, L. Jensen, and C.A. Shock. 2002. Evaluation of the AM400 Soil Moisture Data Logger to Aid Irrigation Scheduling. Oregon State University, Malheur Experiment Station, Special Report 1038: 252–256. Available online at http://www.cropinfo.net/AnnualReports/2001/Hansen2000.php

Shock, C.C. 2003. Soil water potential measurement by granular matrix sensors. In Stewart, B.A. and T.A. Howell (eds.). *The Encyclopedia of Water Science*. Marcel Dekker. pp. 899–903.

Shock, C.C. and C.A. Shock. 2004. Comparison of the AM400 and Irrometer Monitor for Precise Irrigation Scheduling. Oregon State University, Malheur Experiment Station Special Report 1055: 257–260. Available online at http://www.cropinfo.net/AnnualReports/2003/HansenIrrometer2003.php

Shock, C.C. and F.X. Wang. 2011. Soil water tension, a powerful measurement for productivity and stewardship. *HortScience* 46:178–185.

Shock, C.C., R. Flock, E. Feibert, C.A. Shock, and J. Klauzer. Revised 2013a. *Drip*

Irrigation Guide for Onion Growers. Oregon State University Extension Service publication EM 8901. Available online at http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20425/em8901.pdf

Shock, C.C., F.X. Wang, R.J. Flock, E.P. Eldredge, and A.B. Pereira. Revised 2013b. *Successful Potato Irrigation Scheduling*. Oregon State University Extension Service publication EM 8911. Available online at http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20498/em8911.pdf

For more Extension publications on irrigation management, visit the OSU Extension website at http://extension.oregonstate.edu.

Acknowledgment

Funding to help prepare this publication was provided by an Oregon Watershed Enhancement Board grant.

Product sources

Watermark Soil Moisture Sensor—Irrometer Co., Riverside, CA

Dielectric Water Potential Sensor (Model MPS-2)—Decagon Devices, Inc., Pullman, WA

Hand-held Watermark Soil Moisture Meter (Model 30KTCD)—Irrometer Co., Riverside, CA).

Hansen AM400 Datalogger—Mike Hansen Co., Wenatchee, WA

Watermark Monitor Datalogger—Irrometer Co., Riverside, CA

Trade-name products are mentioned as illustrations only. This does not mean that the Oregon State University Extension Service either endorses these products or intends to discriminate against products not mentioned.

Quick Facts

- Soil water tension indicates the soil water status and helps a grower decide when to irrigate, thus avoiding under- and over-irrigation.
- Crops that are sensitive to water stress are more productive and have higher quality if they are watered precisely using soil water tension (SWT) than if they are under- or overirrigated.
- The optimum soil water tension for a particular crop depends primarily on crop needs, soil texture, and climate.
- Common instruments to measure soil water tension include tensiometers, gypsum blocks, granular matrix sensors, dielectric water potential sensors, and porous ceramic moisture sensors.
- Treasure Valley onions on silt loam are irrigated at a SWT of 20 to 25 cb. Potatoes growing on the same site and soil type are irrigated at a SWT of 30 to 60 cb, depending on the irrigation system.
- "Soil water potential" is the negative of "soil water tension." A soil water potential of – 20 cb is the same as a soil water tension of + 20 cb. Also, cb (centibars) is the same as kPa (kilopascals).
- Granular matrix sensors provide good estimates of soil water tension for many soils.
- Sensor readings can be conveniently logged, providing a record of soil moisture conditions to aid growers in timing irrigations.
- Sensors and wiring need to be checked and loggers require minimal, but necessary, maintenance. Keep loggers clean and dry and replace their batteries as needed.

Table 1. Soil water tension (SWT) as irrigation criteria for onion bulbs as reviewed by Shock and Wang, 2011.

SWT (cb)	Location	Soil type	Irrigation system	Soil moisture sensor depth (inches)
8.5	Piauí, Brazil	Sandy	Microsprinkler	—
10	Pernambuco, Brazil	—	Flood	—
15	São Paulo, Brazil	—	Furrow	—
10–15	Malheur County, Oregon	Silt loam	Drip	8
17–21	Malheur County, Oregon	Silt loam	Drip	8
27	Malheur County, Oregon	Silt loam	Furrow	8
30	Texas	Sandy clay loam	Drip	8
45	Karnataka, India	Sandy clay loam	—	—

Table 2. Soil water tension (SWT) as irrigation criteria for potato as reviewed by Shock and Wang, 2011.

SWT (cb)	Location	Soil type	Irrigation system	Soil moisture sensor depth (inches)
20	Western Australia	Sandy loam	Sprinkler	—
25	Maine	Silt loam	Sprinkler	—
25	Luancheng, Hebei Province, China	Silt loam	Drip	8
30	Lethbridge, Alberta, Canada	Sandy loam	Sprinkler	—
30	Malheur County, Oregon	Silt loam	Drip	8
50	California	Loam	Furrow	—
50–60	Malheur County, Oregon	Silt loam	Sprinkler	8
60	Malheur County, Oregon	Silt loam	Furrow	8

Table 3. Soil water tension (SWT) as irrigation criteria for cole crops as reviewed by Shock and Wang, 2011.

Common name	SWT (cb)	Soil type	Irrigation system or measurement equipment	Soil moisture sensor depth (inches)	Location, season
Broccoli (*Brassica oleracea* var. *italica*)	10–12	Sandy loam	Subsurface drip	12	Maricopa, AZ; fall–winter
Broccoli	50, 20[1]	Silt loam	Lysimeters in rain shelter	4	Agassiz, British Columbia, Canada; spring
Cabbage (*Brassica oleracea* var. *capitata*)	25	Loamy sand and sand	Lysimeters in rain shelter	4	Tifton, GA; spring and fall
Cauliflower (*Brassica oleracea* var. *botrytis*)	10–12	Sandy loam	Subsurface drip	4	Maricopa, AZ; fall–winter
Cauliflower	25[2]	Sandy loam	Furrow and flood	7	Bangalore, India; winter
Cauliflower	20–40	Sandy loam	—	—	Skierniewice, Poland; spring–summer
Collard	9	Sandy loam	Subsurface drip	12	Maricopa, AZ; fall–winter
Mustard, greens	6–10	Sandy loam	Subsurface drip	12	Maricopa, AZ; fall–winter
Mustard, greens	25[2]	Loamy sand and sand	Lysimeters in rain shelter	4	Tifton, GA; spring and fall

[1]SWT of 50 cb during plant development, then 20 cb during head development.
[2]Twenty-five cb was the wettest irrigation criterion tested.

Table 4. Soil water tension (SWT) as irrigation criteria for other field and vegetable crops as reviewed by Shock and Wang, 2011.

Common name	SWT (cb)	Soil type	Irrigation system or measurement equipment	Soil moisture sensor depth (inches)	Location, season
Alfalfa grown for seed	200–800	Fine sandy loam, loam, silt loam	Sprinkler and surface flood	4–72	Logan, UT; summer season of the perennial crop
Beans, snap (*Phaseolus vulgaris*)	25[z]	Loamy sand	Lysimeters in rain shelter	4	Tifton, GA; spring and fall
Beans, snap	45	Sandy clay loam	—	6	Bangalore, India; fall–winter
Beans, snap	50	Clay loam	Furrow and drip	12	Griffin, NSW, Australia; summer
Carrot	30–50	—	Sprinkler	—	Nova Scotia, Canada; spring–summer
Carrot	40–50	—	Microsprinkler	6	Nova Scotia, Canada; spring–summer
Celery	10	Sandy loam	Drip	8	Santa Ana, CA; fall–winter
Corn for sweet corn	10–40	Sand	Drip	6	—
Corn for sweet corn	30	Carstic soils	Drip	12	Champotón, Campeche, Mexico; spring–summer
Corn for sweet corn	50	—	—	—	Utah; spring–summer
Corn for grain	30	Loamy fine sand	Sprinkler	6	Quincy, FL; spring–summer

Table 4 continues on page 9

continued—*Table 4. Soil water tension (SWT) as irrigation criteria for other field and vegetable crops as reviewed by Shock and Wang, 2011.*

Common name	SWT (cb)	Soil type	Irrigation system or measurement equipment	Soil moisture sensor depth (inches)	Location, season
Corn for grain	50	—	—	—	Utah[5]
Cucumber	15–30	Fine sand and sandy clay	Drip	8	Piikkio, Finland; spring–summer
Lettuce, romaine	<6.5	Sandy loam	Subsurface drip	12	Maricopa, AZ; fall–winter
Lettuce, leaf	6–7	Sandy loam	Subsurface drip	12	Maricopa, AZ; fall–winter
Lettuce	<10	Red earth	Drip	12	NSW, Australia
Lettuce	20	Clay loam, sandy loam	Sprinkler, drip	6	Las Cruces, NM; summer-fall
Lettuce, romaine	30[1]	Clay loam	Surface	12	—
Lettuce, crisphead and romaine	50	Sandy loam	Sprinkler	6	Salinas, CA; spring–summer
Radish	35	Silt loam	Drip	8	Luancheng, Hebei Province, China; summer–fall
Radish	20	Sandy clay loam	Control basin and furrow	7	Bangalore, India; winter
Rice	16	Sandy loam	Flood	6–8	Punjab, India; summer–fall
Spinach	9	Sandy loam	Drip	—	Maricopa, AZ
Squash, summer	25[1]	Loamy sand and sand	Lysimeter	—	Tifton, GA; spring, summer, and fall
Sweet potato	25, then 100[2]	Loamy sand and sand	Lysimeters in rain shelter	9	Tifton, GA; summer
Sweet potato	25–40	Silt loam	Drip	8	Ontario, OR; summer
Tomato	10	Fine sand	Drip	6	Gainesville, FL; spring
Tomato	20	Sand	Drip	6	Coruche, Portugal; spring–summer
Tomato	12–35[3]	Clay	Drip	4–8[4]	Federal District, Brazil; fall–winter
Tomato	50	Silt loam	Drip	8	Yougledian, Tongzhou, Beijing, China; summer
Watermelon	7–12.6	Sandy loam	Drip	12	Maricopa, AZ; spring–summer

[1]Twenty-five cb or 30 cb was the wettest irrigation criterion tested.
[2]SWT of 25 cb during plant development, then 100 cb during root enlargement.
[3]Thirty-five, 12, and 15 cb during vegetative, fruit development, and maturation growth stages, respectively.
[4]Tensiometer depth was 4" during the vegetative growth stage, 6" in the beginning of the fruit development stage, and 8" from thereon until the irrigations were stopped.
[5]Taylor, S.A., D.D. Evans, and W.D. Kemper. 1961. *Evaluating Soil Water*. Utah Agricultural Experiment Station Bulletin 426.

Published November 2005. Revised March 2013.