

## IRRIGATION MANAGEMENT S E R I E S

# TENSIOMETER USE IN SCHEDULING IRRIGATION

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### QUICK FACTS:

- Tensiometers continuously monitor soil water status, which is useful for practical irrigation scheduling, and are extensively used on high-value cash crops where low water tension is desirable.
- Tensiometers are ideal for sandy loam or light-textured soils.
- Measurement range is limited to less than one bar tension. Clay soils will still have plant available water past this limit, although the most readily available water is gone.
- Tensiometers may be used in clay soils for crops that need low soil water tension for maximum yield or high crop quality.

Tensiometers are soil water measuring devices that are sensitive to soil water change and useful for irrigation scheduling. Irrigation scheduling is a process to determine when to irrigate and how much water to apply. Applying too little or too much water in an untimely manner can result in yield reductions. Over irrigation wastes water, costs money to pump, and may leach nutrients beyond the root zone. Irrigation scheduling is important and can be achieved by monitoring soil water status with tensiometers.

Plant roots undergo tension as they pull the water out of a soil matrix. Tensiometers are devices that measure the soil water tension by acting like a mechanical root. This mechanical root is equipped with a gauge that continu-



Figure 1. Tensiometer.

ously registers how hard the root must work to extract water from soil. Tensiometers are particularly accurate at low tensions, which is the wettest part of the soil water range. They are popular with growers of high-value crops, such as vegetables and fruits on sandy soils.

A tensiometer is a sealed, water-filled tube equipped with a vacuum gauge on the upper end and a porous ceramic tip on the lower end. The basic components are a reservoir and cap, body tube, vacuum dial gauge, and a ceramic tip (Figure 1).

**Reservoir and cap.** The reservoir acts as a water supply for the body tube. The cap on the reservoir must provide an airtight seal for the tensiometer or the device will not work. Some models do not have an enlarged reservoir; the body tube works as a reservoir, and the cap directly seals the system.

**Body tube.** The body tube provides support and a liquid connection between the porous tip and the vacuum gauge. Tensiometers come in various lengths. Standard lengths are 6, 12, 18, 24, 36, 48, and 60 inches.

**Ceramic tips.** The ceramic tip is porous, but the openings are so small that when saturated with water, air cannot pass through within the range of soil water tensions to be measured. Water moving out through the porous tip causes the vacuum dial gauge reading to change indicating the suction, or tension, at which the water is being pulled by the surrounding soil.

**Vacuum gauges.** The vacuum gauge (Figure 2) is calibrated in centibar or hundredths of one "bar." A bar is the unit of pressure, either positive

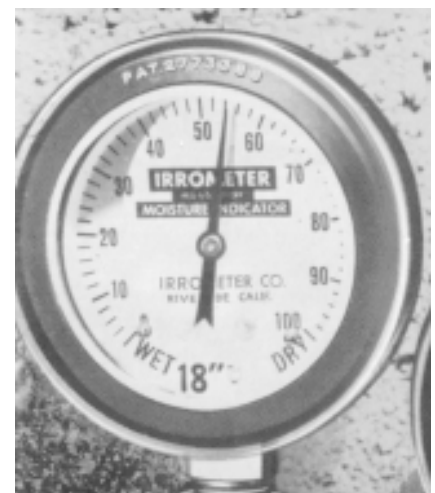


Figure 2. Vacuum dial gauge.

**Table 1.** Interpretation of Tensiometer readings

Reading (centibars)	Status	Explanation/Action
0	Saturated	Soil is saturated regardless of soil type. If readings persist, there is possible danger of waterlogged soils, a high water table, poor drainage and soil aeration; or the continuity of the water column in the tube may have broken.
5–10	Surplus water	Indicates a surplus of water for plant growth. Drainage continues and persistent reading indicates poor drainage.
10–20	Field Capacity	Field capacity for all types of soils. Additional water will drain as deep percolation carrying nutrients without opportunity for plant use. Sandy soils, however, have very little storage capacity, and suction values increase rapidly as water is removed by plants past 15 to 20. For sensitive crops, like potato, rapid irrigation may be required before damaging stress can develop.
20–40	Irrigation range	Available water and aeration good for plant growth in fine- and medium-textured soils. Irrigation is not required for these soils at this range. Coarse-textured soils may require irrigation in the 20 to 30 range and finer sandy soils at 30 to 40 centibar ranges.
40–60		Usual range for starting irrigation. At 40 to 50 centibar, irrigation may need to be started for loamy soils. On clay soils (silty clay loams, silty clays, etc.) irrigation usually starts from 50 to 60. Heavy clay soils still have some available water. Irrigation, however, ensures maintaining readily available soil water. The stage of growth and type of crop will influence the decision.
70	Dry	Stress range. However, crop is not necessarily damaged. Some soil water is available in clay soils but may be low for maximum production.
80		Top range of tensiometer accuracy; higher readings are possible, but tension within the water column inside tensiometer will break between 80 to 85 centibar. This has relationship to elevation of the area compared to mean sea level. At higher elevation, the water inside the tube may break at a lower reading according to atmospheric pressure.

or negative, that has been adopted for the expression of soil suction. The bar is an international unit of pressure in the metric system and is equivalent to 14.5 psi (pounds per square inch) or 0.987 atmospheres. One centibar is also equal to 1 kPa (kilopascal).

A reading of zero corresponds to a completely saturated condition, regardless of the type soil. A reading of 80 indicates a very dry condition for sandy soils or sensitive crops. This also is the functional upper limit for tensiometer readings. A tension higher than 80 will cause the water column inside the tube to break rendering it nonfunctional.

A depth label is usually placed on the vacuum gauge or on the side of the tube to indicate the depth at which the ceramic tip will be set when installed. This is important for identification purposes.

The soil suction reading on the vacuum gauge dial is an indication of soil water availability for plant use

and does not require calibration for salinity or temperature. The readings have different meaning in terms of use for irrigation scheduling depending on soil type. Table 1 and Figure 3 suggest interpretation of tensiometer readings in relation to soil texture.

Each situation is different, so irrigators should monitor crop conditions, such as wheel track compaction or plow pans, that can affect root development and water movement in the soil.

## TENSIOMETERS WITH ELECTRONIC READER

Electronic technology has been added to the tensiometers to be remotely read and used to automatically start irrigation. The manufacturers have developed equipment that will read the tensiometer and turn on an irrigation controller or solenoid valve to initiate irrigation.

There are two systems currently available. One of the systems is com-

prised of an electronic switch that can be mounted on the vacuum gauge dial of the tensiometer and set to start irrigation at a certain reading. As the soil water tension rises, the gauge needle, which has a magnetic property, moves to a set reading and coincides with the eye of the switch. At this point the electric circuit closes and establishes a current flow to the controller or the solenoid valve, which turns the system on for irrigation. With the progress of irrigation, the soil water gets recharged. The tensiometer is very sensitive to soil water change, and the increase in soil water reduces the tension. The gauge needle falls back, electric current flow is discontinued, and the system automatically shuts down. These switches are normally operated by alternating current (AC) flow. The need for a direct (DC) current system should be specified at the time of ordering. Follow the manufacturer's instructions for installation.

The other automatic system operates by using a pressure transducer. In this system, the vacuum gauge is replaced by a pressure transducer, which senses any change in pressure and modifies the electric current flow to reflect that change. The reading is continuous. By directly attaching it to the tensiometer body in place of the vacuum gauge, it is connected to the tensiometer system. The transducer is read by an ammeter or voltmeter, which may be interfaced with a data logger or computer. The reading is translated into soil water tension. This information can be used to make decisions for controlling the irrigation system. The computer may be programmed to start an irrigation system at a certain value. The power requirement for the transducer input may vary, but many have requirements of less than 10 volts.

The automated versions of tensiometers enable remote system operation. The irrigation systems now can be controlled based on the soil water content.

## WORKING PRINCIPLE

Soil water exists primarily as thin films around and between soil particles and is bound to soil particles by strong molecular forces. As the soil dries, the water films become thinner and more tightly bound to soil

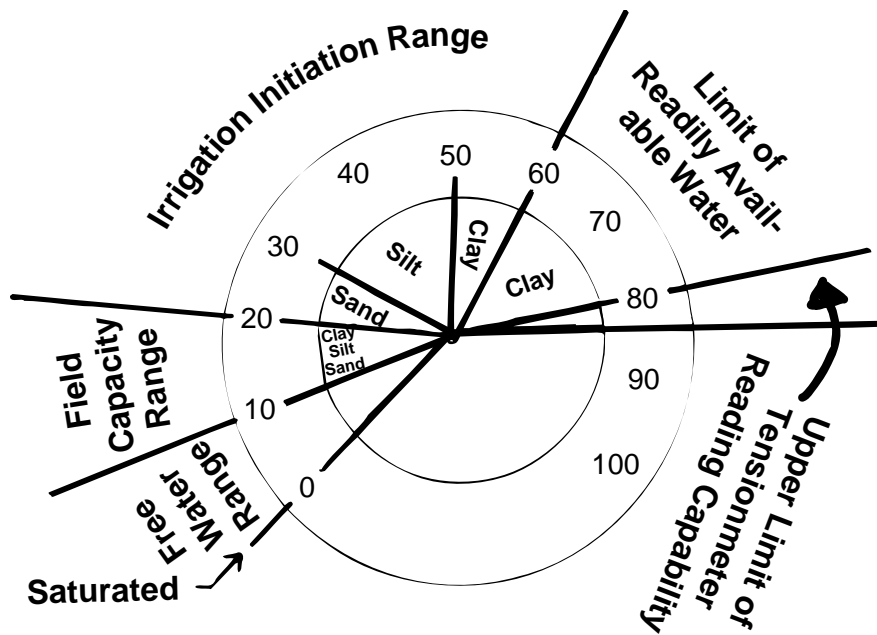


Figure 3. Interpretation of tensiometer readings.

the finer pores. Allow the tensiometer to stand upright, soon the tip will wet-up and free water will appear like a sweat. Refill as necessary to dispel all the air from the tensiometer. After letting it stand in a bucket of water overnight, seal the tensiometer and set it upright in the air. The air will start drying the tip. The gauge should read 70 when air dried. Periodic checking of the gauge reading will indicate if it is functioning properly. Repeat the wetting and drying cycle with the tensiometers that do not respond correctly the first time.

Distilled water treated with three to five drops of chlorine bleach per gallon may be used to inhibit algae growth. Manufacturers also provide solutions for water treatment that may be used according to direction. Distilled water available in a grocery store has been found adequate. If excessive air bubbles are noticed, boiling may be helpful, but the remaining waters need to be stored in an airtight container.

Some manufacturers provide a

matrixes. This increase in tension within the films now in contact with the tensiometer causes water to be drawn from the ceramic tip. The withdrawal of water from the ceramic tip creates a partial vacuum in the tensiometer. Water continues to be drawn until the vacuum created inside the tensiometer equals the tension of the water films outside. At this point equilibrium is reached and water ceases to flow. The vacuum gauge reading indicates the amount of suction or tension.

As water is added to the soil from rainfall or irrigation, the soil suction is reduced. The higher vacuum in the tensiometer causes soil water to be drawn into the tensiometer, and the vacuum will be reduced until a balance in tension is reached. The tensiometer continuously responds and maintains a balance with the soil water suction or tension and the vacuum gauge indicates the amount of tension, hence the name tensiometer.

## TENSIOMETER PREPARATION

As with any measurement device, proper care and maintenance are required. Check the tensiometer before installation in the field. If the tensiometer was used previously, begin by washing and rinsing it inside and out. Residues on the porous ceramic tip that were not removed by washing may be removed by sanding

lightly. Fill the reservoir and body tube with distilled water, taking care that the ceramic tip is wetted from one direction to avoid air entrapment in

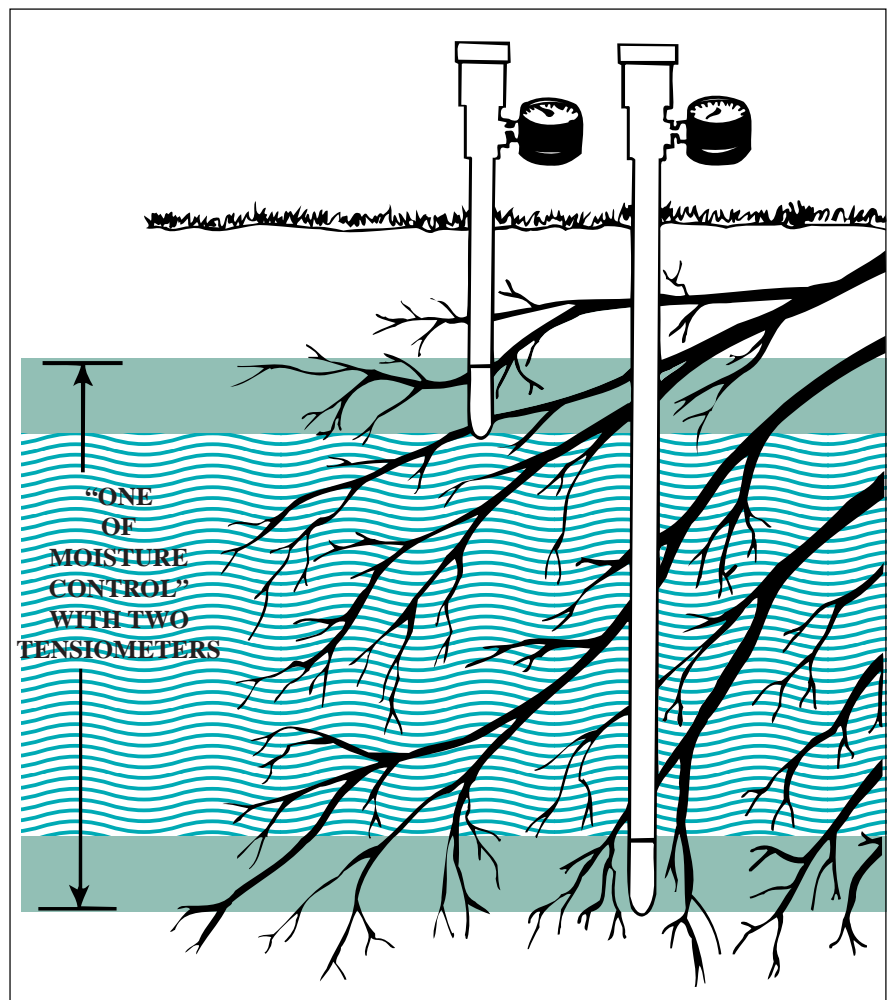


Figure 4. Zone of soil water control with a two-tensiometer station.



hand-operated vacuum pump to help remove air from the tensiometer. Operating the pump when the tensiometer is filled with water and the tip is submerged in water helps remove gases from the pores of the ceramic tip and solution. After each pumping, refill the tensiometer completely with water and repeat until no more bubbles are observed. The tensiometer is then sealed by screwing the reservoir cap down securely.

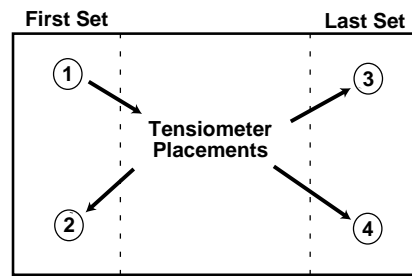
If tensiometers are not to be installed immediately, cover the tips with a plastic bag to prevent evaporation or let them stand in a bucket of water until installed.

## TENSIOMETER INSTALLATION

**Depth selection.** The number of tensiometer installation sites required will depend on the crops grown and field conditions. Fewer stations of tensiometers are needed when a single crop is grown in large blocks of uniform soil. If the soils are varied or different crops are to be grown, more stations are necessary. Stations need to be selected to represent an area, and care should be taken not to cause excessive compaction or destruction of plants around during installation, which may alter the condition.

Except for very shallow-rooted crops, tensiometers are normally installed in groups of two or more to characterize the soil in the top half to three quarters of the root zone. If the potential root zone is less than 12 inches, a single tensiometer may be installed in the center of the zone at 6 inches deep. With deeper-rooted crops, one tensiometer should be placed at the upper one quarter of the rooting depth and another at the lower quarter point or three quarters of the depth (see Figure 4).

In deeply rooted crops or situations where there is a distinct break in soil textures, three or more tensiometers may be needed. An example might be 18 inches of sand overlying a silty soil growing corn where 3 to 4 feet of the root zone is to be managed. One tensiometer might be placed at 6 inches, a second at 18 inches and a third at 2 to 3 feet. The differences in tension readings would make it possible to



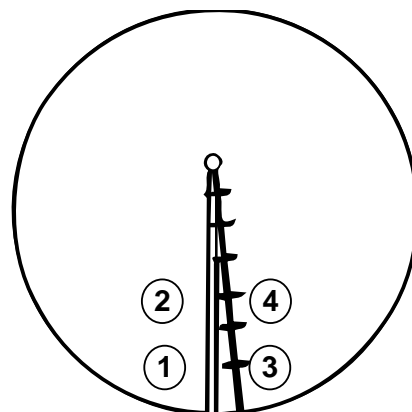
**Figure 5.** Furrow system station arrangement.

better assess the soil water conditions. Almost 70 percent of crop water is supplied by the top half and only 10 percent from lower one fourth of the rooting depth. Irrigators, therefore, often manage only the top half or three-fourths of the root zone. Tensiometers should be long enough to reach the desired depth and diaphragm vacuum gauges not touching the ground. They should never be set in a hole.

**Site selection.** Location of the tensiometers in the field generally depends on the type of irrigation system used. For large fields, generally, there will be at least four stations or locations in each field.

If the tensiometers are installed in a flood-irrigated field, stations will be located at the top and bottom of the first and last sets (Figure 5). Each station should be far enough in from the top or bottom of the field so it is not affected by initial wetting effects or by ponding of water.

Under a sprinkler system, use two stations on each side of the pivot when it is in its normal stop position (Figure 6). Set one station on each side near the middle of the pivot, and



**Figure 6.** Center pivot station arrangement

one station on each side near the outer tower of the pivot, usually about the middle of the outer span. The stations on each side should be far enough away from the pivot so the sprinklers will not wet them when the system is stopped or until after the system is moving. This system of positioning stations on flood or sprinklers will give start and stop indicators for the irrigation sequence.

Tensiometers may be installed using a soil auger or a probe. Manufacturers also provide simple coring tubes. Placement should be in a crop row to avoid traffic. Where furrow irrigation is used, the tensiometers may be angled slightly to place the tip under the furrow. The electronic tensiometers may require a cover to safeguard the electric connections from sprinkler or rain water. If a valve cover box is used, the tensiometer tips need to be slanted out to be in the crop area. The hole should be small enough to create resistance to insertion of the tensiometer and shaped to form close soil contact at the tip. This may be accomplished by returning a little loosened portion of the soil from the depth of placement back into the hole and adding a little water. When the tensiometer is pushed for placement, the soft soil will move around the tip to conform to the rounded shape and make a good contact. Tensiometers must be handled with care—the tips may break if handled roughly.

Ceramic tips of the tensiometers must be kept wet until installed. Steady and firm pressure may be applied while inserting the tensiometer until it reaches the desired depth. The depth label on the tensiometer will identify the root zone being monitored as either deep or shallow. Tensiometer locations need to be marked both in the row and at the edge of the field. A brightly painted wooden stake or a metal rod with a colored flag attached are good markers. Locating tensiometers in tall crops can be a problem. A written log of the station locations also is recommended.

## SERVICE

Tensiometers are weatherproof, except for freezing, and generally require very little service. When first installed, there may be tiny air bubbles

clinging to the sides of the body tube. However, after one cycle of soil water use, which creates a high vacuum, the bubbles will rise to the top and can be eliminated by refilling. The amount of bubbles will depend on the gas originally present in the vacuum gauge and the amount dissolved in the water. Servicing is best done soon after irrigation. Tensions are low and air that may have been drawn into the cup at high tensions can be eliminated by refilling. Tensiometers return to equilibrium rapidly at low tensions. They also respond quickly to a very minute withdrawal of water from the system. If much air is drawn into a tensiometer at low tensions, the porous cup may be defective, and the tensiometer may need to be replaced. Some air entry is unavoidable. When using a number of tensiometers, watch for tensiometers that accumulate abnormal amounts of air. The colored fluid concentrate supplied by the manufacturer for control of algae helps to spot collected air bubbles in the tensiometer.

Some tensiometers may require gauge adjustments. The pointers may be adjusted to read zero at the atmospheric pressure of the location of use by opening a screw provided to let air enter into the seal gauge. This may be needed to take care of the difference of pressure due to elevation change. In others, this is accomplished by adjusting to zero with the tensiometer cup standing in a bucket of water. The depth of water outside of the tensiometer in the bucket must not stand too high to avoid outside pressure.

Tensiometers should be removed from the field before freezing. The water can freeze and break the ceramic tip or the body or damage the vacuum gauge. Tensiometers need to be emptied before long-term storage. This prevents salt deposition in the porous material with evaporation or rusting of the gauge.

## TROUBLE SHOOTING

A tensiometer that is out of water or leaking will remain at zero on the gauge, or the reading will fluctuate in the low suction range. Two or more successive zero readings may be a sign of a malfunction and should be investigated. If the gauge remains at zero, refill with water and use a hand

pump to remove air. The tensiometer may have been empty because of dry soil. If the tip was dry, fine air bubbles will rise rapidly for several minutes and then cease. If larger bubbles rise and continue, a leak is indicated, and the source should be determined. If the bubbles rise from the bottom, remove the tensiometer and replace the tip. If the bubbles enter from the side, the body tube may be cracked and should be fixed. If bubbles rise from the gauge, the leak may be in the gauge or the threaded connection. A leaky gauge needs to be replaced, but a threaded connection can be resealed. If no large bubbles rise, yet the reading remains at zero, the reservoir cap may be cracked or the seal may be defective. Inspect for an 'O' ring. There needs to be one for a proper seal. In most cases, the trouble is easily corrected.

A damaged vacuum gauge may stick in one position or may not respond smoothly with changes in soil water. Check a suspect gauge against one known to be in good working order, or replace the suspect gauge with a new one. Readings higher than expected, especially after irrigation, are generally not tensiometer failure. The irrigation water may not have penetrated to the depth of the tensiometer tip.

## DRAWBACKS

The major criticism of the tensiometer is that it functions reliably only in the wet range of soil water at readings of about 80 centibars or less. At higher readings, the porous tip may leak air, and the gases will be drawn out of the water. At low pressure, the water will vaporize causing discontinuation of the tension column or vacuum. The gauge reading will fall to zero. This is not as serious as it may seem because most of the available water in coarse-textured soils and about 50 percent or more in fine-textured soils have already been used at this range.

Another criticism is the price, which ranges from \$45 to \$60. When used in large quantities, the cost may seem prohibitive. Irrigation scheduling, however, has been shown to easily pay for itself through increased yields or reduced pumping. Proper handling may extend the useful life, and the cost may be spread over many

seasons making it cost-effective.

Finally, the ceramic tip may gradually fill with precipitates because of soil water movement through the pores. This slows water transfer through the tip and increases the time required for the tensiometer to respond to a change in soil-water conditions. Some slowing does no harm, but if the response time becomes too slow, a new tip should be installed. The response time may be improved by rubbing the exterior of the tip with fine sandpaper or soaking the tip in a mild acid solution. The amount of plugging depends on the soil water chemistry and the manner of use.

Where tensiometers can be left in the ground, the tip porosity remains satisfactory for several years in most soils. But each time the tensiometer is removed from the soil, tip life is reduced. This is particularly true if the soil is calcareous or saline. In extreme cases, where the tensiometer is installed and removed several times per season, the tip may need to be replaced after one year of use. To minimize this damage, a tip that is removed from the soil should be protected from drying until the tensiometer has been emptied, cleaned, and dried.

Before winter storage, the tensiometer needs to be cleaned and flushed with distilled water. Flushing is done by filling the tube and letting the water drain out of the tip by gravity. If stored where frost protection is not available, make certain all the water from the system had been drained. The gauges will hold some water that is not readily visible. The vacuum pump may be used to remove the water by holding the tube horizontal with the gauge in upright position. At the time of reuse, the preparation process should be repeated.

## GENERAL GUIDELINES

- Place two or more tensiometers of different lengths near one another (a station), usually in the crop row. Two stations may be enough in a small field with uniform soil and slope, but four stations is the usual minimum recommendation. The location of stations will depend upon the type of irrigation system. With furrow irrigation, this may be at the upper and lower quarter

points of the first and last set in the field. For a center pivot, it may be in the outer and middle spans, with pairs of stations at the start point and at the end point of the pivot.

- Tensiometer stations should be located in representative areas of the field. Do not position tensiometers in low spots or on knobs, and place them where the plant population is representative of the field.

- Tensiometer installation depth is determined by the active root zone of the crop. For example, for a corn crop on a deep soil, three tensiometers, installed at depths of 12, 24, and 36 inches, are recommended at each station.
- Wait 24 hours after installing the tensiometer to obtain reliable readings. If the soil was dry at in-

stallation, irrigation or rainfall may be needed before obtaining satisfactory readings.

- Tensiometers should be left in the field for the duration of the growing season. The roots of the crop must grow around the porous tip for reliable readings. Moving the tensiometer during the growing season is not recommended.

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