CHAPTER

# 5

# Tensiometers

As we noted in the Preface and Chapter 1, in this book, we shall study water as it moves through the soil–plant–atmosphere continuum (SPAC) and the ways to measure this water. Now that we have learned the basic physical definitions (Chapter 2), the structure and properties of water (Chapter 3), and the soil–water terminology (Chapter 4), we turn to the main topic of water in the SPAC. We first focus on water in soil. We begin by learning how to measure the status of water in the soil using a tensiometer.

## 5.1 DESCRIPTION OF A TENSIOMETER

A tensiometer is a device for measuring, when the soil is not too dry, the soil matric potential. In old terminology, the matric potential was called the *soil moisture tension* (Chapter 4). Because the instrument measures tension, it was called a *tensiometer*. For a review of the early literature on tensiometers, see Richards (1949). However, the instrument could have been called an "ergmeter" (Don Kirkham, Departments of Physics and Agronomy, Iowa State University, personal communication, February 10, 1994). As we saw in Chapter 4, we can express tension of water in soil in terms of tension head (using units of length) or in terms of potential energy per unit mass (e.g., ergs/gram) or potential energy per unit volume (e.g., joule/m$^3$ or dyne/cm$^2$; remember 1 bar $= 1 \times 10^6$ dyne/cm$^2$).

A tensiometer consists of a porous, permeable ceramic cup connected through a water-filled tube to a manometer, vacuum gauge, pressure transducer, or other pressure measuring device (Soil Science Society of America, 2008). As noted, we use the tensiometer to measure matric potential. A matric potential exists in soil when the soil is unsaturated and the water in the soil is under tension. We use a piezometer to measure water in saturated soil. A piezometer is an instrument used to measure pressure. Some soil physicists call the matric potential the pressure potential or the pressure head. In our work, we shall confine the terms

*Principles of Soil and Plant Water Relations*
http://dx.doi.org/10.1016/B978-0-12-420022-7.00005-7

*pressure potential* and *pressure head* to saturated soil (Chapter 4). Tensiometers do not measure osmotic potential because they are not sensitive to the osmotic effects of dissolved salts in the soil solution (Richards, 1965).

Because much soil–water theory and experimentation deals with the matric potential, we need to know how a tensiometer works (Kirkham and Powers, 1972, p. 29). Two key relationships that are necessary before soil physicists can model water in unsaturated soil are (1) the relationship between soil matric potential and soil water content and (2) the relationship between soil hydraulic conductivity and soil matric potential (van Genuchten, 1980).

Let us consider an impractical, but instructive, type of tensiometer in which a tension height $h_t$ is developed by means of the tensiometer porous cup in contact with moist soil (Figure 5.1). The small pores in a tensiometer cup serve to make connections between the soil water held in soil pores and a tension column. The pores of the cup must be smaller than the soil pores in which the tension is to be measured; otherwise, air may enter the cup. If air enters the cup, we have reached the air-entry value for that porous cup. Each porous cup has an air-entry value. Air comes out of solution. If air enters, we have cavitation, which is the formation of partial vacuums in a flowing liquid, as a result of the separation of its parts. Cavitation comes from the Latin word *cavitas*, which means a hollow or a cavity.

In Figure 5.1, we have dug a pit into the soil to accommodate the tensiometer. But it is usually impractical to dig a pit, so in Figure 5.2, a column of water of height $d_1$ extending into the ground is replaced by an

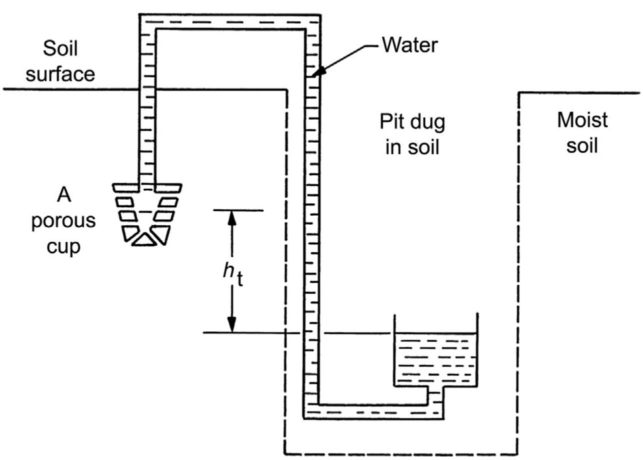


**FIGURE 5.1** A form of tensiometer. *From Kirkham and Powers (1972). This material is used by permission of John Wiley & Sons, Inc. and William L. Powers.*

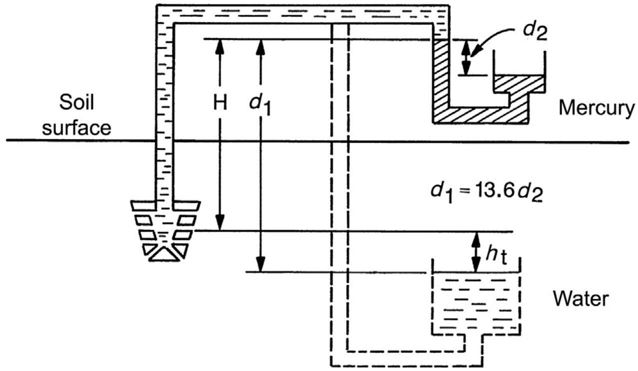


**FIGURE 5.2** Equivalent water and mercury tensiometers. *From Kirkham and Powers (1972). This material is used by permission of John Wiley & Sons, Inc. and William L. Powers.*

equivalent, and much shorter, column of mercury of height $d_2$ above ground. With distances $h_t$, $H$, $d_1$, and $d_2$ as shown in the figure, the tension height $h_t$ is given by $h_t = d_1 - H = 13.6d_2 - H$, where $d_1$ is replaced by $13.6d_2$ because $13.6\ \mathrm{g/cm^3}$ is the density of mercury, making 1 cm of mercury column give the same pressure as 13.6 cm of water column. In our equation, we consider that 13.6 is the specific gravity of mercury taken to be numerically equal to its density in gram per cubic centimeter. The units of specific gravity equal unity. Specific gravity is the ratio of the weight or mass of a given volume of a substance to that of an equal volume of another substance (water for liquids and solids; air or hydrogen for gases) used as a standard, and its dimensions are unity.

The pores in the porous cup and the reservoirs in the two figures (Figures 5.1 and 5.2) have been drawn large for instructive purposes. In practice, the reservoirs are made as small as practical to limit water flow to the soil from the cup. In the laboratory, one can use a porous plate apparatus (Figure 5.3) to measure soil moisture tension in soil cores. In Figure 5.3, the height $h_t$ is the tension height.

The tension height $h_t$ of a tensiometer cannot in practice exceed about 3/4 bar or about 750 cm of water column. (In Chapter 4, we showed that 1020 cm water = 1 bar.) This is due to air coming out of solution at the reduced pressure to break the continuity of the water column. The 750 cm value does not mean that water will not have a tension >750 cm in a soil, but that 750 cm of tension is all the tension that a tensiometer can measure (Kirkham and Powers, 1972, p. 30).

Dr L.A. Richards was one of the early developers of the tensiometer (see the Appendix, Section V, for his biography). Before he moved to the U.S. Salinity Laboratory in Riverside, California, he worked at Iowa State University (then called Iowa State College) in Ames, Iowa. In his laboratory in Curtiss Hall, the early tensiometers he used were water-filled

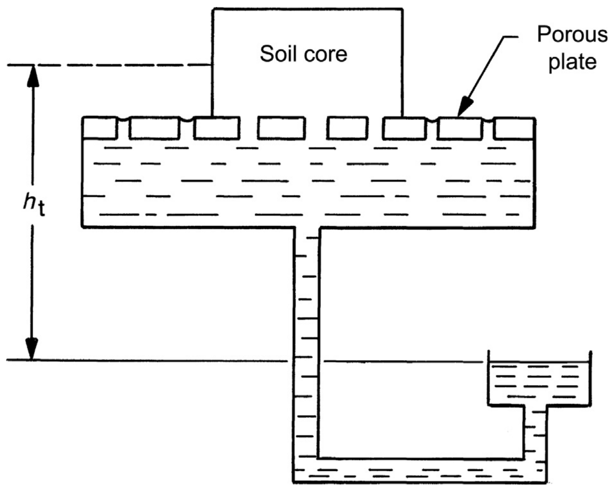


FIGURE 5.3 Porous plate apparatus. *From Kirkham and Powers (1972). This material is used by permission of John Wiley & Sons, Inc. and William L. Powers.*

tensiometers. To have a long enough water tube, he drilled a hole through the ceiling of one of the floors in Curtiss Hall so the tube could span the length of two floors. When one of his successors, Don Kirkham, moved to Iowa State in 1946, this hole was still in Curtiss Hall. Mercury manometers obviate the need to drill holes through ceilings to take measurements with tensiometers.

For values of $h_t$ >750 cm, pressure apparatus may be used. To see how a pressure apparatus works, we consider Figure 5.4. In this figure, three capillary tubes are shown with the heights of the water rise as $h_{t1}$, $h_{t2}$, and $h_{t3}$. The bottoms of the capillary tubes rest either on a porous ceramic plate or a porous membrane. A bell jar covers the capillary tubes and pressure may be introduced in the jar. The figure is drawn for the case of initially

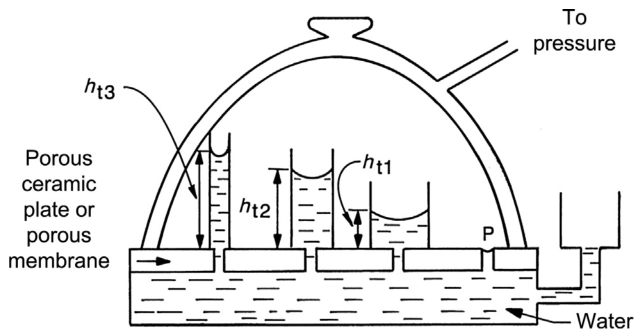


FIGURE 5.4 Pressure apparatus. *From Kirkham and Powers (1972). This material is used by permission of John Wiley & Sons, Inc. and William L. Powers.*

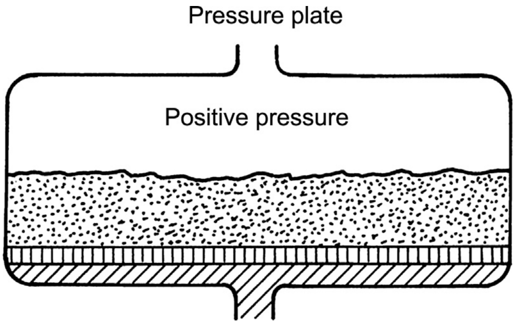


**FIGURE 5.5** Pressure plate. Inside the plate, soil is on a porous membrane. The heavy steel plate allows high pressures to be applied. *From Baver, Gardner, and Gardner (1972). This material is used by permission of John Wiley & Sons, Inc.*

atmospheric pressure. If now a pressure equal to a $h_{t1}$ cm of water column is applied, the column $h_{t1}$ will drain to the top level of the membrane. If $h_{t2}$ cm of pressure is applied, column $h_{t2}$ will drain to the top level of the membrane, and if $h_{t3}$ cm of pressure is applied, all three will drain. If a porous membrane is used, pores in the membrane such as the one at $P$ will not drain unless pressures of about 30 or more bars are applied. At high pressures, a bell jar cannot be used. Instead, pressure equipment made of heavy steel plate, called pressure plate or pressure membrane apparatus, is used (Figure 5.5). It works up to a pressure of 30 or even 100 bars (Kirkham and Powers, 1972, p. 32).

## 5.2 TYPES OF TENSIOMETERS

Tensiometers have three types of read-outs: mercury manometer assemblies, vacuum dial gauges, and pressure transducers. Instruments that have mercury manometers are attached to tubes of varying lengths with porous cups at the base that are inserted into the soil (Figure 5.6). Mercury manometers are no longer available commercially. This is due to the fact that mercury cannot be sent through the mail (Mary C. Knapp, State Climatologist for Kansas, personal communication, September 7, 2011). (Consequently, the mercury thermometers at the official weather station for Manhattan, Kansas, have been replaced by thermometers with a digital display, which is constantly changing.) However, even though mercury manometers have fallen out of favor, one still can build custom-made mercury tensiometers. They then can be employed for special purposes, for example, measuring the matric potential of soil in greenhouse pots. They provide excellent accuracy (Loyd R. Stone, Department of Agronomy, personal communication, June 8, 2013).

Tensiometers now used have read-outs using vacuum dial gauges or pressure transducers. Soilmoisture Equipment Corporation (Santa Barbara, California) provides tensiometers with vacuum dial gauges,

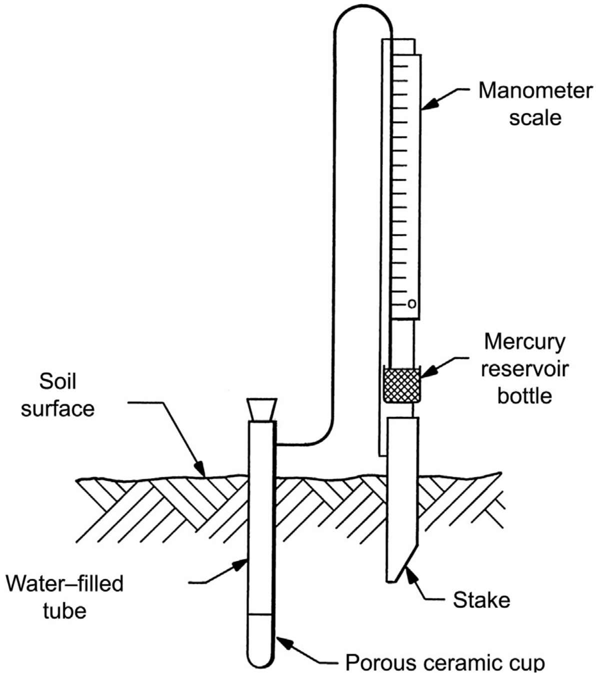


**FIGURE 5.6** A mercury manometer type of tensiometer. *Redrawn from a figure in a Soilmoisture Equipment Corp., Santa Barbara, California, brochure. Reproduced by permission of Soilmoisture Equipment Corp.*

including the "Jet Fill" (Figure 5.7) for fixed installation and the "Quick Draw" probe (Figure 5.8), which is a portable probe designed for rugged field use. Vacuum dial gauge tensiometers can be obtained for different depths from Soilmoisture (6-, 12-, 18-, 24-, 36-, 48-, and 60-in depths or 15, 30, 46, 61, 91, 122, and 152 cm, respectively). Laboratory-built tensiometers can operate at deeper depths. They are termed *advanced tensiometers* and can be used to monitor landfills at depths from 0.15 to 30 m (Hubbell and Sisson, 1998). For greenhouse work with pots, Soilmoisture's Model 2100F with a vacuum dial gauge (ceramic cup: 0.6 cm diameter; 2.4 cm long) can be used because it is a miniature tensiometer (Zhang and Kirkham, 1995).

The Tensimeter™ (Figures 5.9 and 5.10) sold by Soil Measurement Systems (Tucson, Arizona) is a fast, simple, and portable method to read tensiometers with 1 mbar sensitivity using a pressure transducer. This method was originally described by Marthaler et al. (1983), and a diagram of the tensiometer is shown in Figure 5.11. Any ordinary tensiometer can be used. The tubing is closed off with a septum stopper, which forms an airtight seal during and after insertion of a syringe needle through the stopper. The air pressure in the upper end of the tubing is measured by

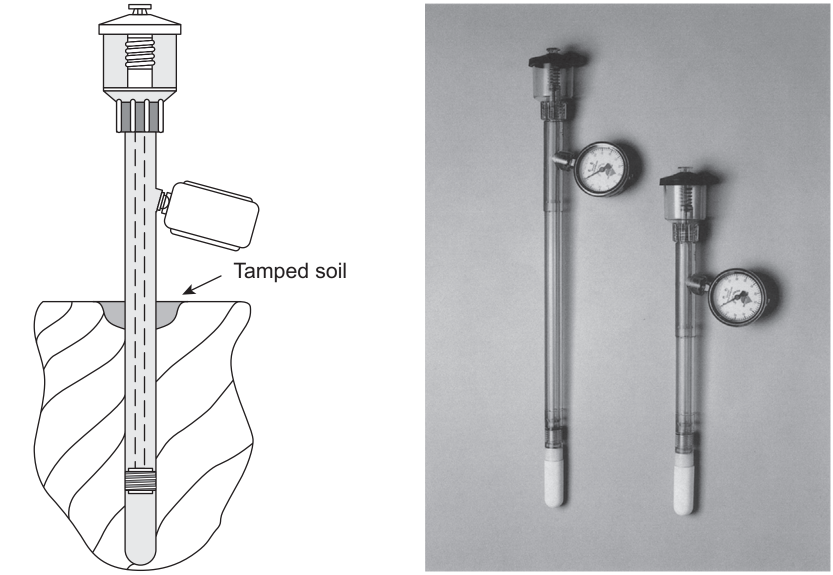


**FIGURE 5.7** The "Jet Fill" tensiometer of Soilmoisture Equipment Corporation. *Courtesy of Soilmoisture Equipment Corp., Santa Barbara, California.*

inserting a syringe needle attached to a pressure transducer through the septum (Figure 5.12). A guide tube keeps the transducer system in a vertical position when placed on the tensiometer and centers the needle in the septum. The inside diameter of the guide tube fits the outside diameter of the stopper and plexiglass tube. The transducer consists of a steel enclosure with a steel transducer membrane separating the enclosure into an upper chamber and a lower chamber. The upper chamber is at atmospheric pressure. Through the syringe needle, the air pressure in the lower chamber equilibrates with the pressure inside the tube, causing a small deflection of the steel membrane. This deflection changes the resistance of silicon semiconductors embedded into the membrane. A shielded four-lead wire connects the silicon element with a resistivity meter. The meter is calibrated to read directly in millibars (mb) (which can be converted to centibars, cb) or centimeters of water. Unlike vacuum gauges, the readings with the Tensimeter™ give a singular reading to the nearest unit (e.g., a value in centibars) (Loyd R. Stone, personal communication, June 8, 2013). (To keep plants under well-watered conditions, Loyd Stone irrigates when a tensiometer at the 50 cm depth reads 50 cb.)

In field use, the tensiometers are inserted into the soil for permanent use during a season. To operate the Tensimeter™, one simply places the transducer over a tensiometer. The needle probe penetrates the septum stopper of the tensiometer. The tension inside the tensiometer is measured

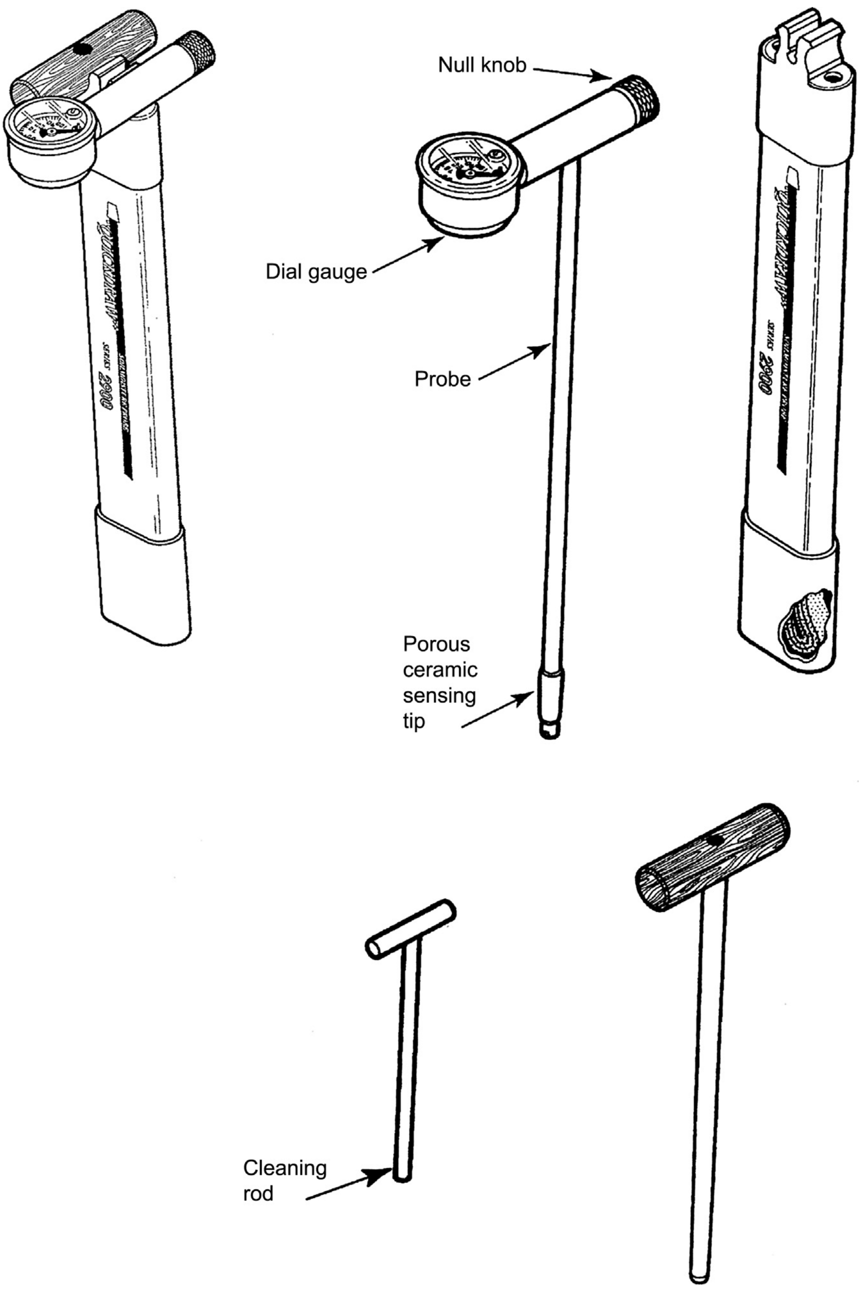


**FIGURE 5.8** The "Quick Draw" tensiometer of Soilmoisture Equipment Corporation. One side holds a soil corer and the other side holds the tensiometer. *Courtesy of Soilmoisture Equipment Corp., Santa Barbara, California.*


**FIGURE 5.9** Photograph of the Tensimeter™ of Soil Measurements Systems. The needle that punctures the septum stopper, shown diagrammatically in Figure 5.11, is inside the plastic cylinder at the right. The needle is also shown diagrammatically in Figure 5.12. *Courtesy of Soil Measurement Systems, Tucson, Arizona.* (For color version of this figure, the reader is referred to the online version of this book.)

and digitally displayed (in mb or cm). One can get as many as 45 readings per septum (45 needle insertions) before the rubber septum needs to be replaced (Loyd R. Stone, personal communication, June 8, 2013). One can take about 75 readings (read 75 tensiometers) per hour; it takes about 15 s per reading. Readings can be hand-recorded because this is a cheap and accurate method. In a subsurface drip irrigation study of corn (*Zea mays* L.) in the western part of Kansas, dozens of tensiometers were installed for several seasons (Darusman et al., 1997a,b; Lamm et al., 1997), and speed in taking readings was important when measuring numerous tensiometers.

When using the Tensimeter™, one must distinguish between the reading on the read-out and the potential at the point in question in the soil (where the measurement is being taken). These are two different values. Let us assume we have a tensiometer that is 160 cm long. To calibrate such a tensiometer (160 cm long), Loyd Stone puts the ceramic cup in a container of water, so that the ceramic is just covered (Loyd R. Stone, personal communication, July 9, 2013). He puts the tensiometer in a


**FIGURE 5.10** Photograph of the Tensimeter™ in field use. *Courtesy of Soil Measurements Systems, Tucson, Arizona.* (For color version of this figure, the reader is referred to the online version of this book.)

completely erect position and lets the ceramic cup wet up for a couple of days. He then reads the read-out on the Tensimeter™. There is no tension, so the read-out should read −160 cm because that is the length of the hanging column of water under tension. Then he places the 160-cm-long tensiometer in the field. If he gets a reading of −180 cm, he knows that there is a matric potential of −20 cm. He must subtract the length of the hanging column of water (−160 cm) to get this value. So the matric potential at the point in question in the soil is −20 cm. If he gets a reading of −140 cm, he knows that he has a submergence (pressure) potential of 20 cm (a positive value) at the point in question in the soil. A matric potential is always negative. He calibrates each tensiometer of a different length, so he knows how much length to subtract from his readings. Marthaler et al. (1983) also explain this procedure with the Tensimeter™. The stem length of the tensiometer must be subtracted from the reading on the Tensimeter™ to get the matric potential (or pressure potential, if there is one). However, with vacuum gauges, the stem length does not need to be subtracted because when one sets them up, one adjusts the gauge to read zero. However, if one did not adjust the vacuum gauge to read zero, its reading reflects the length of the tensiometer. One then could read a submergence potential with the vacuum gauge because the needle would fall and read a lower value, indicating a pressure potential (Loyd R. Stone, personal communication, July 9, 2013). If the needle rises, then one has a matric potential. The reading on a mercury tensiometer also

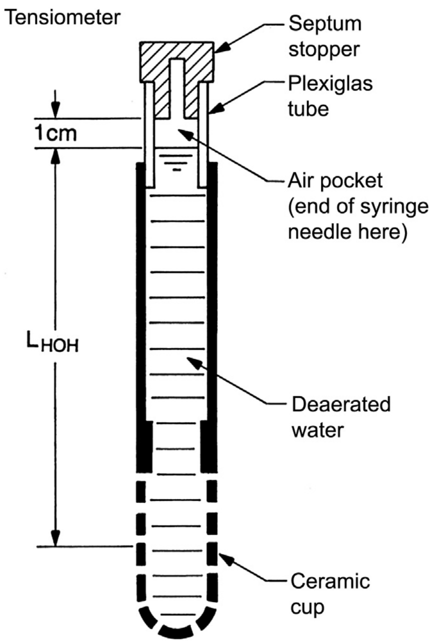


**FIGURE 5.11** Diagram of a tensiometer with septum stopper. The needle of the Tensimeter™, shown in Figure 5.9, punctures the septum stopper. *From Marthaler et al. (1983). Soil Science Society of America: Madison, Wisconsin. Reprinted by permission of the Soil Science Society of America.*

includes the length of the tensiometer. To zero the value on a mercury tensiometer, see Section 5.4 in this chapter. To know the direction of movement of water between two tensiometers, one also must consider the gravitational potential energy and add it to the matric potential, which we did in Chapter 4.

Whether one uses tensiometers with transducers or vacuum gauges depends on cost (Loyd R. Stone, personal communication, June 8, 2013). For example, if one needs just a few measurements and a transducer costs $2000 and a vacuum gauge costs $90, then buying a few vacuum gauges would be the proper procedure. However, if one wants to instrument a field with many tensiometers, then the financially reasonable approach is to buy the transducer.

Electrical resistance sensors are available for estimating soil moisture tension (International Atomic Energy Agency, 2008, p. 123). They consist of a porous body (block) in which a pair of electrodes is embedded. Either the sensor itself is made of $CaSO_4$ (known as gypsum or hydrated plaster of Paris) or there is a pellet of $CaSO_4$ embedded in the sensor body. The sensor may be buried at any desired depth in the soil. The porous sensor exhibits a soil moisture characteristic curve in the same way as does a soil

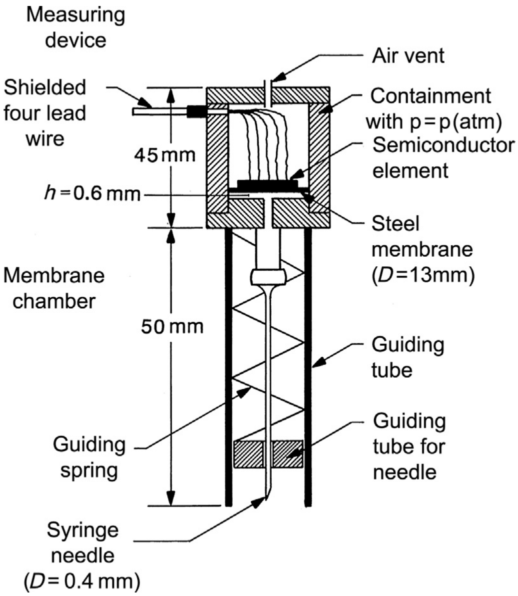


**FIGURE 5.12** Diagram of pressure transducer with attached syringe needle. The needle is shown in the photograph of the Tensimeter™ in Figure 5.9. *From Marthaler et al. (1983). Soil Science Society of America: Madison, Wisconsin. Reprinted by permission of the Soil Science Society of America.*

(see Chapter 6 for a description of a soil moisture characteristic curve). Consequently, as the surrounding soil wets and dries, the sensor also wets and dries. A two-wire lead from the sensor is connected to a meter, which is used to read the sensor resistance. Calcium sulfate is a weakly soluble salt that dissolves in the water in the porous sensor and renders the water conductive. The more water that is in the sensor, the more conductive is the medium between the electrodes. That is, the resistance decreases as the water content increases (International Atomic Energy Agency, 2008). Electrical resistance sensors are widely used to get soil moisture tension. However, for accurate measurements in experimental work, tensiometers should be used rather than electrical resistance sensors. The Tensimeter™ gives a precise, unique reading unlike electrical resistance sensors (Loyd R. Stone, personal communication, June 8, 2013).

## 5.3 TEMPERATURE EFFECTS ON TENSIOMETERS

Temperature affects readings with tensiometers in two ways:

1. Effects of temperature on water in soil.
2. Effects of temperature on the instrument.

Temperature affects the physical properties of water, including density and surface tension (Table 3.1). Therefore, the matric potential (tension) of water in the soil is affected by temperature changes. The major effect of temperature occurs at the soil surface, where temperature changes are greatest. Temperature effects on soil tension account for measurable amounts of water flow (Loyd R. Stone, personal communication, February 1, 1989).

Temperature affects the instrument directly because the mercury is heated (the mercury expands with heating). The metal on the part of the tensiometer that is inserted into the soil can conduct heat from the air to the soil. Plastic instead of metal in the construction of the tensiometer minimizes temperature effects. Tensiometers can be insulated by using shade boxes or temperature effects can be minimized by taking readings early in the morning when the sun is not far up in the sky. Temperature is less of a factor with the Tensimeter™ because it does not have a metal pole (Loyd R. Stone, personal communication, June 8, 2013). Loyd Stone caps his tensiometers that he measures with the Tensimeter™ with a piece of polyvinyl chloride pipe, and this keeps out dew and dust, which plug the needle of the Tensimeter™. It is necessary to keep the needle perfectly clean. However, the soil surface still can heat up and affect readings taken with the Tensimeter™. With the Tensimeter™, Loyd Stone takes his measurements early in the morning to minimize temperature effects.

All tensiometers cannot be used in freezing weather because the water in the tensiometer will freeze and break the tensiometer. But one can bury tensiometers deeply or use methanol—water solutions, which can protect the tensiometers as low as −18 °C (Cassel and Klute, 1986, p. 586). One would need to do a controlled laboratory experiment to determine gradients caused by temperature in the soil and the magnitude of change in soil-water tension with temperature (Loyd R. Stone, personal communication, February 1, 1989). With the dual-probe heat-pulse method (Chapter 9), we can measure soil water content and soil temperature with resolution as fine as measurements 1.5 cm apart (Song et al., 1999). However, tensiometers have not yet been miniaturized enough to measure matric potential at such fine resolution. In the field, one just recognizes that temperature does affect readings with tensiometers and tries to minimize this effect (Loyd R. Stone, personal communication, February 1, 1989), especially in hot, semiarid regions such as Kansas.

## 5.4 APPLICATIONS OF TENSIOMETERS

Tensiometers have five applications (Richards, 1965; Loyd R. Stone, personal communication, June 8, 2013 and July 8, 2013).

1. They are used to determine rooting depth. One can follow readings with time, and the rate of increase in soil tension at any given depth

can be related to the density of the active roots. One can use tensiometers to get water extraction by roots, such as one uses a neutron probes (Frank et al., 2013).

2. They are used for timing of field irrigations. It is time to irrigate when tensiometer readings reach a prescribed value for a soil depth where feeder root concentration is greatest. The duration of irrigation is judged with tensiometers that measure soil tension at a second or greater depth. If tension readings at this second depth are low (high matric potential), an irrigation of short duration is indicated. Conversely, if they are high, irrigation water should be allowed to run until readings are low.
3. They are used to determine timing of greenhouse irrigations for potted plants and greenhouse beds. Under these conditions, only one depth is read.
4. The water table level is determined using tensiometers. If using a mercury manometer, one first zeros the scale of the manometer, which can be carried out by filling the instrument with mercury and water in advance of installation. With the instrument supported in the same orientation that it will have in the field, and with the cup immersed in a container of water, the position that the mercury level attains in the manometer is then marked as the zero setting for the scale. If a reading on this mercury tensiometer in the field is below zero, it is evidence that a water table occurs above the depth of the cup. The negative reading in millibars is equivalent to the distance in centimeters from the water table to the cup depth. Similarly, as described above, one could determine the water table level with a vacuum gauge tensiometer or a Tensimeter™. The depth measured may not necessarily be the depth of the water table (rarely in Kansas), but it could be a perched water table or a flooded condition, which has caused the reading associated with the submergence potential. But the reading will be temporary, and, when water infiltrates (e.g., after a flooding operation is stopped), the reading goes from a submergence potential (positive) to a matric potential (negative).
5. The hydraulic gradient is determined from measurements using two tensiometers. (See Chapter 7 for the definition of the hydraulic gradient.) If one knows the hydraulic gradient, one knows which way water is moving in the soil. The use of two tensiometers at two different depths is the only way to determine the direction of movement of water in the soil (up or down). This knowledge is necessary if one wants to leach out salts or determine the water balance. Two typical depths of installation of tensiometers are at 4.5 and 5.5 feet (1.4 and 1.7 m) because these depths are below the root zone (Darusman et al., 1997a). By reading the tensiometers, one can

determine if the soil is wetting up or draining. This knowledge is critical in water-balance studies because one needs to know the drainage component. In semiarid Kansas, the goal is to minimize drainage to improve irrigation efficiency (Darusman et al., 1997b; Stone et al., 2008).

## 5.5 APPENDIX: BIOGRAPHY OF L.A. RICHARDS

Lorenzo Adolph Richards, known as "L.A." or "Ren," was born on April 24, 1904, in Fielding, Utah. At Utah State College, he received his B.S. degree in 1926 and his M.A. in 1927; in 1931, he received the Ph.D. in Physics from Cornell University. He is best known for the "Richards's equation" (Richards, 1931), which is widely used in numerical simulations (computer models) for water flow in unsaturated soils. He was an assistant at Utah State from 1924 to 1927, an assistant at Cornell from 1927 to 1929, an instructor at Cornell from 1929 to 1935, and a research physicist at Battelle Memorial Institute in Ohio in 1935. He then moved to Iowa State College, where he was an assistant and associate professor of physics and a research assistant and associate professor of soil between 1935 and 1939. He left Iowa State to become senior soil physicist at the U.S. Salinity Laboratory in Riverside, California, where he stayed from 1939 to 1942. He was a National Defense Research Fellow and Group Leader at the California Institute of Technology from 1942 to 1945 (Cattell, 1961). He then returned to the Salinity Laboratory, where he was the chief physicist from 1945 to 1966. He married Zilla Linford of Logan, Utah, in 1930, and they had three children: L. Willard Richards; Paul L. Richards; and Mary Armstead (American Society of Agronomy, 1993). Paul Richards is a professor of Physics at the University of California at Berkeley, specializing in infrared and millimeter wave physics, and he is a member of the National Academy of Sciences and the American Academy of Arts and Sciences.

L.A. Richards received many awards, including honorary Doctor of Science degrees from the Israel Institute of Technology in Haifa in 1952, and later in life, from his alma mater, Utah State University. He was the Fellow of the American Society of Agronomy and won its Stevenson Award in 1949. He was the president of the Soil Science Society of America (1952) and the American Society of Agronomy (1965). In recognition of his military contributions during World War II, he received the U.S. Department of Navy Ordnance Development Award in 1945 and the Presidential Certificate of Merit in 1948. He received the USDA Superior Service Award in 1959 and honorary membership in the International Society of Soil Science in 1968. In 1981, the American Geophysical Union organized a symposium on the impact of the Richards's (1931) equation, to honor the fiftieth anniversary of his influential publication in *Physics*

(American Society of Agronomy, 1993). He was a long-time member of the American Geophysical Union.

His research interests were in soil physics, retention and flow of water in soil, vacuum tube circuits, rocket ordnance, diagnosis and improvement of saline and alkali soils, the relation of soil water to plant growth, and measurement of aqueous vapor pressure at high humidity (Cattell, 1961). His brother, Sterling Jacob Richards (born 1909; Cattell, 1961), also made contributions in soil physics but was not as famous as his older brother.

L.A. Richards made continuous improvements in the design and operation of the instruments used to provide a quantitative understanding of the energy status of water in the soil. His children helped him build his equipment to provide money to put them through college. They formed a company called Lark (L.A. Richards Kids). Richards (1965, p. 157) cites Lark Instruments in Riverside, California, as a supplier of tensiometers at the time. L.A. Richards initiated and edited the influential 1954 USDA Agricultural Handbook No. 60 entitled, *Diagnosis and Improvement of Saline and Alkali Soils*, a publication still in use today (United States Salinity Laboratory Staff, 1954). He died of Alzheimer's disease on March 12, 1993, in Carmel, California at the age of 88 (American Society of Agronomy, 1993).

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