Using tensiometers for scheduling irrigations of coastal vegetables

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Because cool season vegetables are sensitive to water stress, small depletions in soil moisture can slow crop growth. Tensiometers are useful for determining when a vegetable crop has depleted soil moisture to the point that irrigation is needed. Unlike other methods, tensiometers provide a direct measure of soil water tension, which is expressed in units of either kiloPascals (kPa) or centibars (cbar). Since 1 kPa equals 1cbar, these units are often used interchangeably. A high tension means that the crop needs more force or energy to pull water held in soil pores. As a reference, 1500 cbars is considered the permanent wilting point for plants and 0 cbars corresponds to saturated soil conditions. At moderate tensions (30 to 40 cbars), growth of leafy vegetables such as lettuce and spinach slows. Vegetable yields can be maximized by irrigating to maintain soil moisture tension less than these tension thresholds (Table 1).

An advantage of tensiometers compared to other methods of monitoring soil moisture is that a tension reading is less affected by site-specific factors such as soil texture or salinity. A reading of 40 cbars has the same physiological meaning to a plant whether it is in a sandy or clay textured soil. In contrast, the readings from volumetric soil moisture sensors corresponding to moisture stress are dependent on soil texture. A crop may need to be irrigated at volumetric moisture content of 25% in a field with sandy loam texture soil but need to be irrigated at 35% in a field with a clay loam texture soil. Since cool season vegetables are sensitive to water stress, they need to be irrigated after small depletions in volumetric soil moisture (usually a depletion of 3 to 5%). Many volumetric soil moisture sensors are only accurate to ± 2 or 3% without calibration, so a single reading may not be sufficiently accurate to determine if irrigating is necessary.

Tensiometers are fairly low tech in that they consist of a water filled shaft fitted with a porous ceramic cup at the lower end and a vacuum gauge and reservoir of water at the top end (Figure 1). Water added to the tensiometer should be degassed by first boiling the water and then allowing it to cool to room temperature. It is important that the tensiometer has no air leaks or it will not accurately reflect the true tension of the soil. When installed in the field, water passes freely through the ceramic cup into the soil creating a vacuum in the tensiometer that equals the soil water tension. It is also important to properly install the tensiometer in the field to achieve good contact between the ceramic cup and soil: using a soil probe, make a pilot hole of a diameter equal to the tensiometer and a few inches shallower that the depth of installation. Add a slurry of soil and water into the hole and push the tensiometer to the desired depth. The soil slurry assures the hydraulic integrity between the ceramic cup and soil. Formation of air gaps between the ceramic cup and the soil will lessen the accuracy of tensiometer readings. After a day of equilibration the tension reading should accurately reflect the tension of the soil.

Some users have expressed a lack of confidence in the tensiometer readings, unsure if low readings reflect moist conditions or are an artifact of a leaky seal. The main cause for faulty readings are vacuum leaks or because the soil became drier than 80 cbars. Tensiometers generally leak air through the ceramic cup or cap when the soil moisture tension reaches more than 70 or 80 cbars. This is because water begins to vaporizes at 80 cbars of negative pressure so the hydraulic continuity between the water column in the tensiometer and the soil breaks down. Tensiometers may not be appropriate for tree, vine, and agronomic crops that are grown under relatively drier conditions than cool season vegetables. For leafy greens, celery, and cole crops, however, soil moisture tensions are infrequently greater than 60 cbars. One can also have confidence that the tensiometer is free of air by testing it before installation. Wrapping an absorbent towel around the ceramic cup should cause the vacuum gauge to rise above 30 cbars within a few minutes. Further exposing the ceramic cup to dry conditions should increase the vacuum reading above 70 cbars. Remember to refill the reservoir with degassed water after testing is completed. Periodic maintenance should be made on tensiometers installed in the field. Check the level of water in the shaft and refill the tensiometer with degassed water at least once per month. Also check that rubber stoppers or gaskets form secure seals.

Another advantage of tensiometers compared to volumetric soil moisture sensors is that they are relatively inexpensive ($70 – $120 per tensiometer) and the vacuum gauge can be read in the field by an irrigator. Some tensiometers have an option for connecting them to dataloggers so that moisture data can be collected continuously (Figure 2). and in some cases viewable through an internet service. The datalogger option increases the cost of the tensiometer but is very useful for checking that the instrument is working properly. Some higher cost tensiometers products can also automatically refill with water.

For those wanting to measure soil water tension at 70 cbars or greater, several indirect methods are available including electrical resistance blocks (granular matrix and gypsum), or volumetric or thermocouple sensors embedded in a porous matrix material (delta-T EQ2, Campbell sci. 229-L, respectively). While these methods can be used in tree and vine crops where soil tensions are relatively higher than in vegetables, they are usually not as accurate as tensiometers at less than 40 cbars of tension. However, these sensors require less maintenance than tensiometers, and in some cases, such as granular matrix blocks, are cheaper.

Tensiometers should be placed in the field at several locations (at least 3) and preferably include the top, middle and bottom regions of a field. The locations might also be chosen to reflect zones of different soil textures or growth patterns in the crop. Care should be taken to install the tensiometers in a consistent pattern on the beds at each location. A good rule of thumb is to install the tensiometers in the plant row, where roots are concentrated, and taking up the most water. Tensiometers installed at least at 2 depths are preferable for each location. The shallowest depth should be a third to a half of the depth of the effective root zone and the second depth should be just below or at the effective rooting depth (Table 1). Depths of 8 and 18 inches has worked well for lettuce. During the first 30 days of the crop, the 18 inch depth remains close to saturation. After 30 days, moisture decreases at the 18 inch depth between irrigations as roots grow deeper. For vegetables grown longer periods than lettuce or have deeper root systems, such as broccoli or cabbage, 12 and 24 inches may be more appropriate depths to monitor soil moisture.

Tensiometers provide guidance as to when to irrigate rather than how much to irrigate. This is because tension measurements measure potential water stress that the plant is experiencing but do not measure the volume of water removed from the soil. The volumetric water removed from the soil for a given tension will vary among soil types depending on the bulk density and porosity. Table 2 illustrates the relationship between tension and volumetric water content for 4 soil textures and Table 3 shows how much water is removed between almost saturated conditions (10 cbars) and tensions ranging from 20 and 60 cbars for these same 4 soil textures. Perhaps the best method to infer how much water your crop depleted since the last irrigation is to use reference evapotranspiration data as a cross-check.

In summary, tensiometers provide a good method of directly measuring soil water tension for crops that are well-watered such as leafy greens and cole crops. An additional advantage of tensiometers is that they do not need to be calibrated for different soil types and the same tension threshold can be used on a range of soil textures to decide when to irrigate. Tensiometer readings are also easy for irrigators to understand and use, requiring no electricity or electronic devices to function, though they do have the option to be interfaced with datalogging equipment. Finally, tensiometers may require more servicing than other devices for measuring soil moisture. They will work most reliably if installed correctly and if they are serviced regularly.

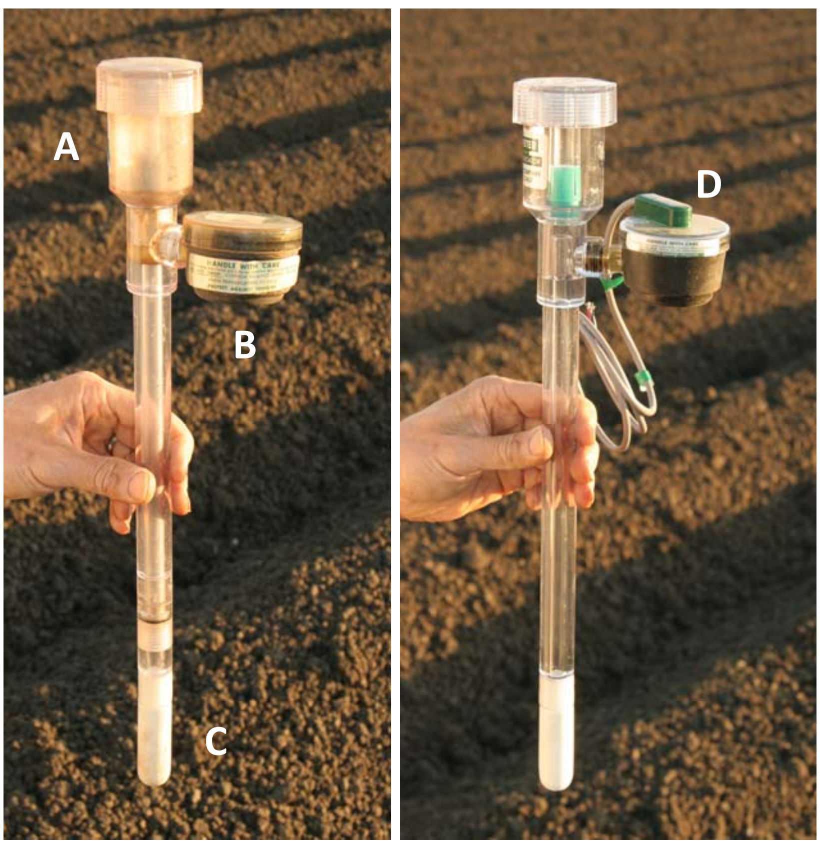

Figure. 1. Tensiometer components: A. Reservoir and cap, B. vacuum gauge, C. ceramic cup, and D. vacuum gauge with electronic output signal.

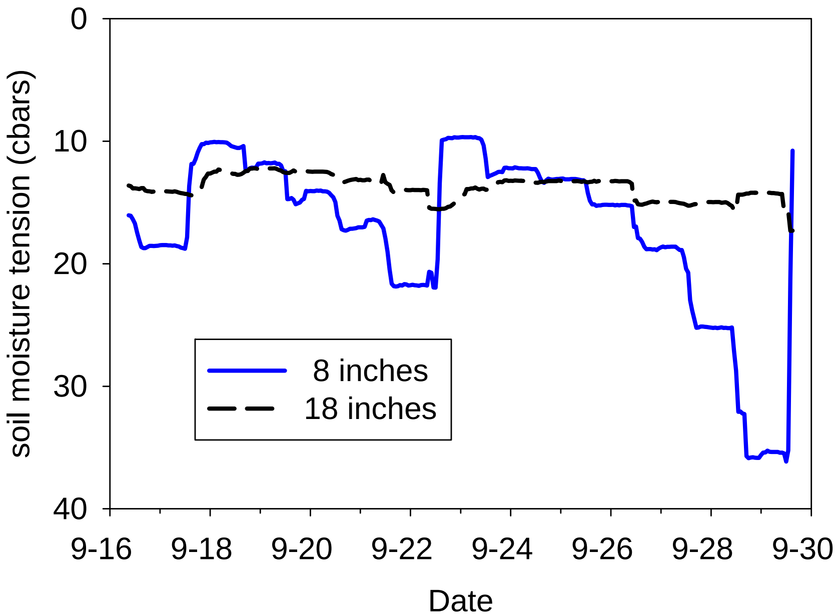

Figure 2. Soil moisture tension at 8 and 18 inch depths in iceberg lettuce during the last 2 weeks of the crop. Tension was measured with irrometer tensiometers interfaced to a datalogger using the irrometer electronic gauge.

Table 1. Effective rooting depth, and recommended maximum soil moisture tension and tensiometer depths for coastal vegetables.

Vegetable crop	effective rooting depth[1] at crop maturity	Irrigation criteria: average soil moisture tension in root zone		recommended tensiometer depths
		establishment	post-establishment	
	inches	------------ cbars -------------		inches
Artichokes				
annual	12 to 18	20 to 30	30 to 45	8 and 18
perennial	18 to 24	--	40 to 50	12 and 24
Asparagus	24 to 36	20 to 30	45 to 60	12 and 24
Carrots	12 to 18	15 to 25	25 to 35	8 and 18
Celery	12 to 18	15 to 25	20 to 30	8 and 18
Cole				
broccoli	18 to 24	20 to 30	30 to 45	12 and 24
cauliflower	18 to 24	20 to 30	30 to 45	12 and 24
cabbage (red and green)	18 to 24	20 to 30	30 to 45	12 and 24
brussels sprouts	18 to 24	20 to 30	30 to 45	12 and 24
Lettuce				
iceberg	12 to 18	15 to 25	25 to 35	8 and 18
romaine	12 to 18	15 to 25	25 to 35	8 and 18
leaf	8 to 12	15 to 25	20 to 30	8 and 18
spring mix	8	15 to 20	20 to 30	8
Bell pepper (drip)	12 to 18	15 to 25	25 to 35	8 and 18
Spinach				
bunch	12	15 to 20	20 to 30	8 and 18
baby and teen	8	15 to 20	20 to 30	6 to 8
Fresh market tomato (drip)	18 to 24	20 to 30	45 to 60	8 and 18

1. typical depths that contain 80% of roots in a deep, uniform, well drain soil profile

Table 2. Volumetric water content of 4 soils at tensions ranging from 10 to 60 cbars.

	soil moisture tension (cbar)					
texture	10	20	30	40	50	60
	------------------- volumetric soil moisture (%) ----------------					
sandy loam	22.8	20.8	19.6	18.8	18.1	17.6
silt loam	30.2	28.4	27.4	26.6	26.0	25.6
clay loam	32.6	31.1	30.2	29.6	29.1	28.7
clay	42.0	40.8	40.1	39.6	39.2	38.8

Table 3. Volume of water depleted from 4 soils for tensions ranging from 20 to 60 cbars. Assume saturated conditions correspond to 10 cbars unless otherwise notes.

	soil moisture tension (cbar)				
texture	20	30	40	50	60
	--- inches of water removed per foot of depth[1] ---				
sandy loam	0.24	0.38	0.49	0.56	0.63
silt loam	0.22	0.34	0.43	0.50	0.56
clay loam	0.18	0.29	0.37	0.43	0.48
clay	0.29	0.38	0.44	0.49	0.53

1. assume 5 cbars corresponds to saturation for the clay soil and 10 cbars corresponds to saturation for the other soils.