13

Irrigation Scheduling

This chapter provides information on developing an irrigation schedule for a trickle irrigation system. Good irrigation scheduling makes the most efficient use of water and energy by applying the right amount of water to crops at the right time and in the right place. The goal is to supply the plants with sufficient water while minimizing losses to evaporation, runoff and unnecessary deep percolation. Irrigation scheduling depends on soil, crop, climate, irrigation system and operation factors. Proper irrigation scheduling requires a sound basis for making irrigation decisions. Methods of irrigation scheduling are based on soil water measurements, meteorological data or monitoring plant stress.

Trickle irrigation systems are operated frequently to replenish the water evaporated from the soil and plant surface and transpired by the crop. With proper management less water may be required on an annual basis than for the same crop irrigated by conventional sprinkler or flood systems. Water savings are achievable with trickle irrigation systems because of:

- Reduced losses due to deep percolation with good management.
- High application efficiencies of Trickle Irrigation Systems.
- Decreased evaporation losses by reducing the wetted area. Since a trickle irrigation system applies water directly to the plant roots, the surface area that is irrigated is reduced.

A trickle irrigation system, like any other irrigation system, is designed to match the crop's peak irrigation requirement during the growing season. Plant water requirements throughout the growing season will vary substantially from the peak requirement. To accurately schedule irrigation applications with a trickle system requires monitoring of the soil moisture, measuring climatic conditions or observing plant performance. A grower converting from sprinkler to trickle irrigation may experience difficulty in scheduling the trickle system due to the concept differences between trickle and sprinkler systems. Trickle irrigation systems keep the soils moisture at a constant level while sprinkler systems allow the soil to dry between irrigations. If climatic data or plant observations are used for scheduling it is recommended that growers also use some method of soil moisture measurement to assist in making the correct decisions.

13.1 Measuring Soil Moisture

Simple soil moisture measurement methods that can be used are the hand feel method, tensiometers and gypsum blocks.

Hand Feel Method

Use a soil auger or soil tube to obtain a soil sample. Samples should be obtained starting from a depth of 20 cm to the bottom of the effective crop rooting zone.

To measure soil moisture using the hand feel method, squeeze a handful of soil tightly. If it forms a ball, bounce it three times lightly in your palm. The relative soil moisture can be determined by using the Table 13.1. For a trickle irrigation system the soil moisture should be maintained at 75 - 80% of field capacity.

Table 13.1 Soil Moisture, Appearance and Description Chart

Available Water*	Feel or Appearance of Soil #			
	Sand	Sandy Loam	Loam/Silt Loam	Clay Loam/Clay
Above field capacity	Free water appears when soil is bounced in hand.	Free water is released with kneading.	Free water can be squeezed out.	Puddles; free water forms on surface.
100% (field capacity)	Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand. (1.0)	Appears very dark. Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand. Makes short ribbon. (1.5)	Appears very dark. Upon squeezing, free water appears on soil, but wet outline of ball is left on hand. Will ribbon about 1 inch. (2.0)	Appears very dark. Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand. Will ribbon about 2 inches. (2.5)
75-100%	Tends to stick together slightly, sometimes forms a weak ball with pressure. (0.8 to 1.0)	Quite dark. Forms weak ball, breaks easily. Will not slick. (1.2 to 1.5)	Dark color. Forms a ball, is very pliable, slicks readily if high in clay. (1.5 to 2.0)	Dark color. Easily ribbons out between fingers, has slick feeling. (1.9 to 2.5)
50-75%	Appears to be dry, will not form a ball with pressure (0.5 to 0.8)	Fairly dark. Tends to ball with pressure but seldom holds together. (0.8 to 1.2)	Fairly dark. Forms a ball, somewhat plastic, will sometimes slick slightly with pressure. (1.0 to 1.5)	Fairly dark. Forms a ball, ribbons out between thumb and forefinger. (1.2 to 1.9)
25-50%	Appears to be dry, will not form a ball with pressure. (0.2 to 0.5)	Light colored. Appears to be dry, will not form a ball. (0.4 to 0.8)	Light colored. Somewhat crumbly, but holds together with pressure. (0.5 to 1.0)	Slightly dark, Somewhat pliable, will ball under pressure. (0.6 to 1.2)
0-25%	Dry, loose, single-grained, flows through fingers. (0 to 0.2)	Very slight color. Dry loose, flows through fingers. (0 to 0.4)	Slight color. Powdery, dry sometimes slightly crusted, but easily broken down into powdery condition. (0 to 0.5)	Slight color. Hard, baked, cracked, sometimes has loose crumbs on surface. (0 to 0.6)

* Available water is the difference between field capacity and permanent wilting point.
# Numbers in parentheses are available water contents expressed as inches of water per foot of soil depth.

Tensiometers

Tensiometers give a direct reading of the soil water tension which can be used to determine the soil moisture available in the plant root zone. See Figure 13.1. The tensiometer is made of a closed plastic tube with a ceramic tip attached to one end and a vacuum gage with an air tight seal at the other end. The tube is filled with water and sealed. Installation must be done carefully to ensure that the ceramic tip is in complete contact with the soil. To install, auger or drill a pilot hole to the proper depth, pour a soil-water slurry mix into the hole and push the tensiometer tip into the slurry until it reaches the bottom of the hole.

When the ceramic tip comes to a moisture equilibrium with the surrounding soil the gauge registers the soil water tension. Soil wetting and drying results in a change in the soil water tension which is measured by the vacuum gauge. The practical operating range of a tensiometer is from 0 to 75 centibars. Zero indicates that the soil is saturated. Readings of 5 - 10 correspond to field capacity for coarse textured soils while readings of 10-15 are at field capacity for fine textured soils. The upper limit of 75 centibars indicates that as much as 80% of the available water has been used for coarse soils but only 25% may have been depleted for the fine textured soils. For drip and trickle systems the soil moisture level is usually kept at a high level, but not at field capacity. Tensiometers are therefore well suited for all types of soils irrigated with a drip system. For optimum irrigation results, tensiometers should read between the 10 - 20 centibar range for most soils.

Figure 13.2 can be used to determine the available depletion based on the soil water tension.

Tensiometers do require supervision and must be correctly installed in order to obtain reliable results. A grower will require two years of experience with these instruments before gaining confidence in the readings. Routine maintenance is critical to ensure successful use. The liquid in the tube must be periodically refilled and the air bubbles removed with the aid of a hand pump.

Figure 13.1 *Tensiometer Installed in Apple Orchard*

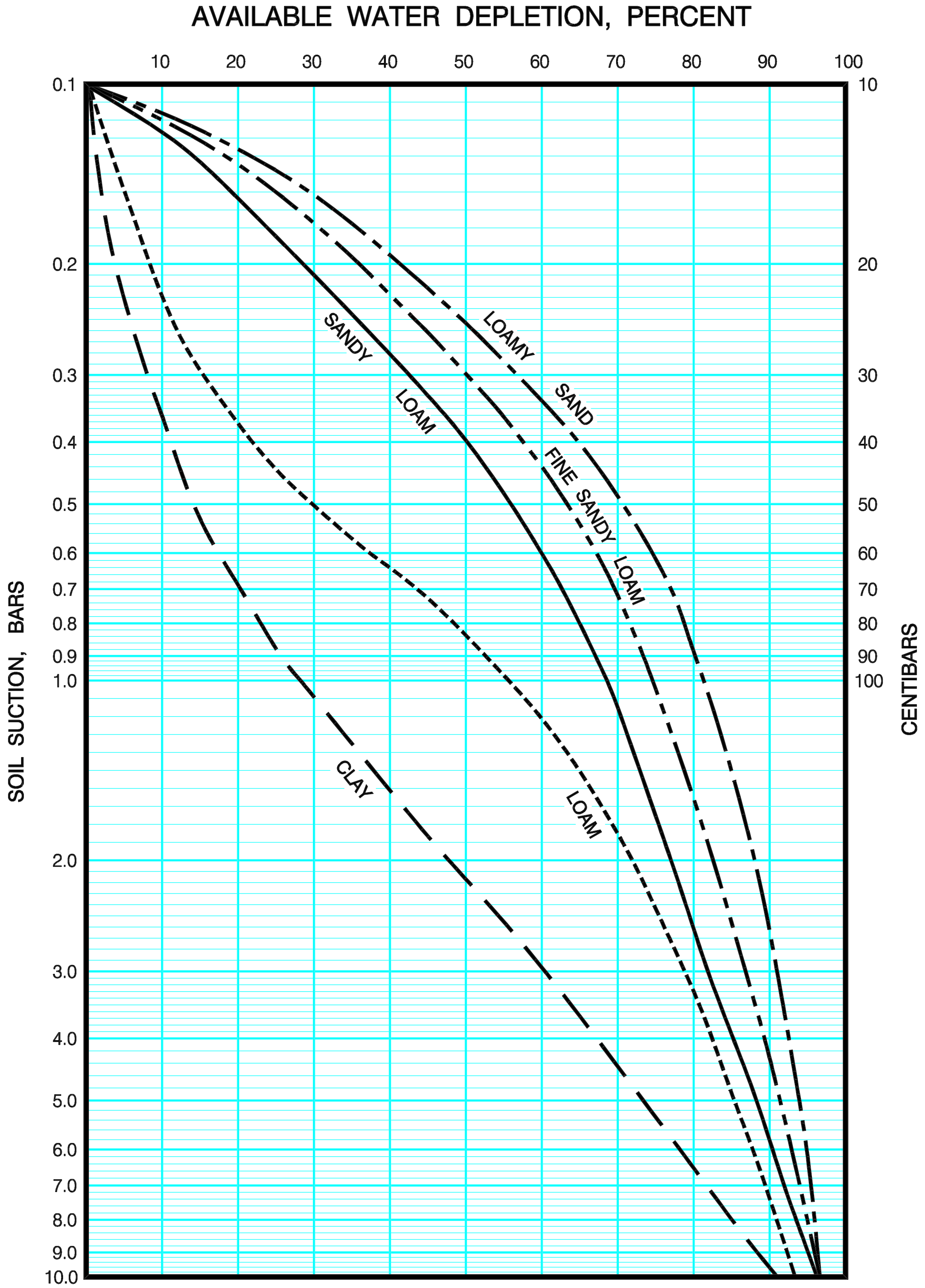


Figure 13.2 *Influence of Available Soil Water on Soil*

Electrical Resistance Blocks

Electrical resistance blocks measure soil water tension in centibars similar to tensiometers readings. Figure 13.2 can be used to determine the available water depletion in %. For drip systems this is usually 20-25 % depletion or 75-80% of field capacity. Resistance blocks are suitable to any depth, stay in position, can be kept in the ground all year, and are easily read. They also have a greater moisture measuring range than tensiometers but this is not usually necessary for drip systems.

Resistance blocks also have disadvantages as they are not suitable in gravelly, sandy or peat soils, they require good contact with the soil, require a meter to obtain readings and a chart to interpret the information. Resistance blocks may also deteriorate in acidic soils.

From Irrometer

Figure 13.3 *Electrical Resistance Block*

Watermark is one trade name for electrical resistance blocks. Watermarks measure the electrical resistance to current flow between electrodes embedded in a material resembling fine sand surrounded by a synthetic porous material.

The blocks are installed in the soil in a similar procedure to the tensiometer. The blocks must make good contact with the soil. The pilot hole, with the wire leads, should be refilled and tamped to prevent surface moisture from collecting around the blocks. The Watermark, measuring in centibars, will give higher values for dry soil conditions and low readings for wet conditions, similar to tensiometers.

Watermarks require little maintenance and can be left in the soil under freezing conditions. The Watermark is responsive to soil water tensions of 40 to 125 centibars.

13.2 Soil Moisture Measuring Locations

To be effective the soil moisture should be monitored where the majority of the crop roots are located. The water uptake will be the highest in this region. See Figure 13.5.

Placement of the soil moisture measuring devices is important, both in respect to the depth of the root zone and in respect to the emitter and plant. Depending on the plant's maximum rooting depth and the soil type more than one tensiometer per site may be required. The number of stations required will depend on acreage, exposure, age of planting, the variation in soil types and irrigation system type. See Figure 13.4.

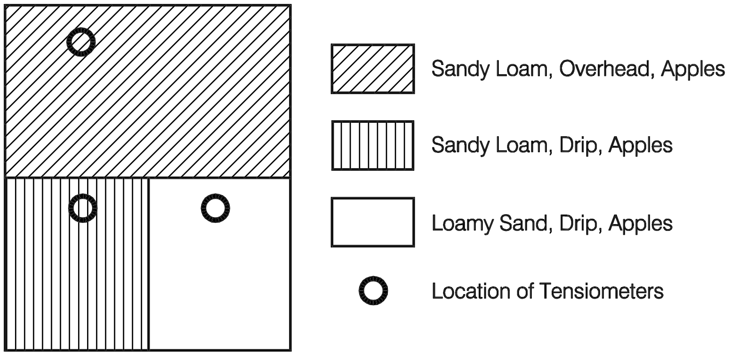


Figure 13.4 *Soil Moisture Monitoring Locations*

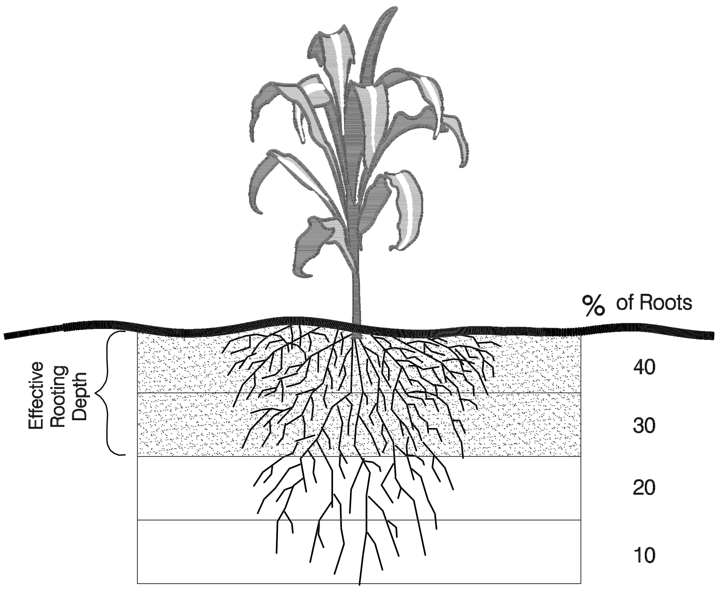


Figure 13.5 *Plant Root Distribution and Water Uptake*

For deep rooted crops (> 0.40 m) tensiometers and watermarks are installed at two different depths to develop a zone of moisture control. See Figure 13.6. One should be at a depth of approximately 25 cm - 30 cm and the other close to the maximum plant effective rooting depth. The instruments should be placed at strategic locations within the plant root zone, and within the wetted zone formed by the emitter. For tree fruits the measuring location should be within the tree drip line and at least 0.30 m from the emitter discharge point.

For shallow rooted crops the devices should be placed centrally to the crop root zone and be located 10 - 15 cm below the soil surface.

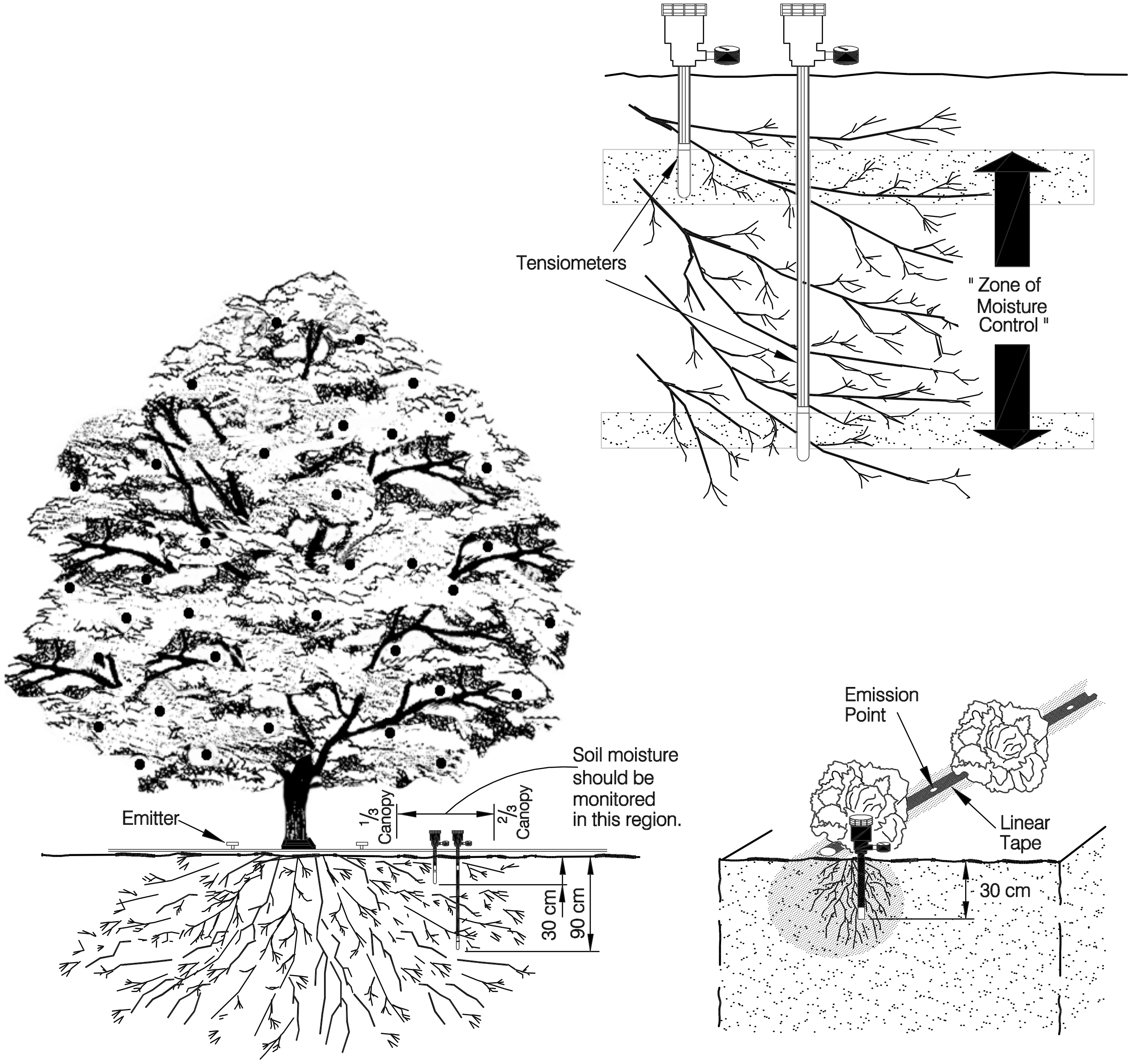


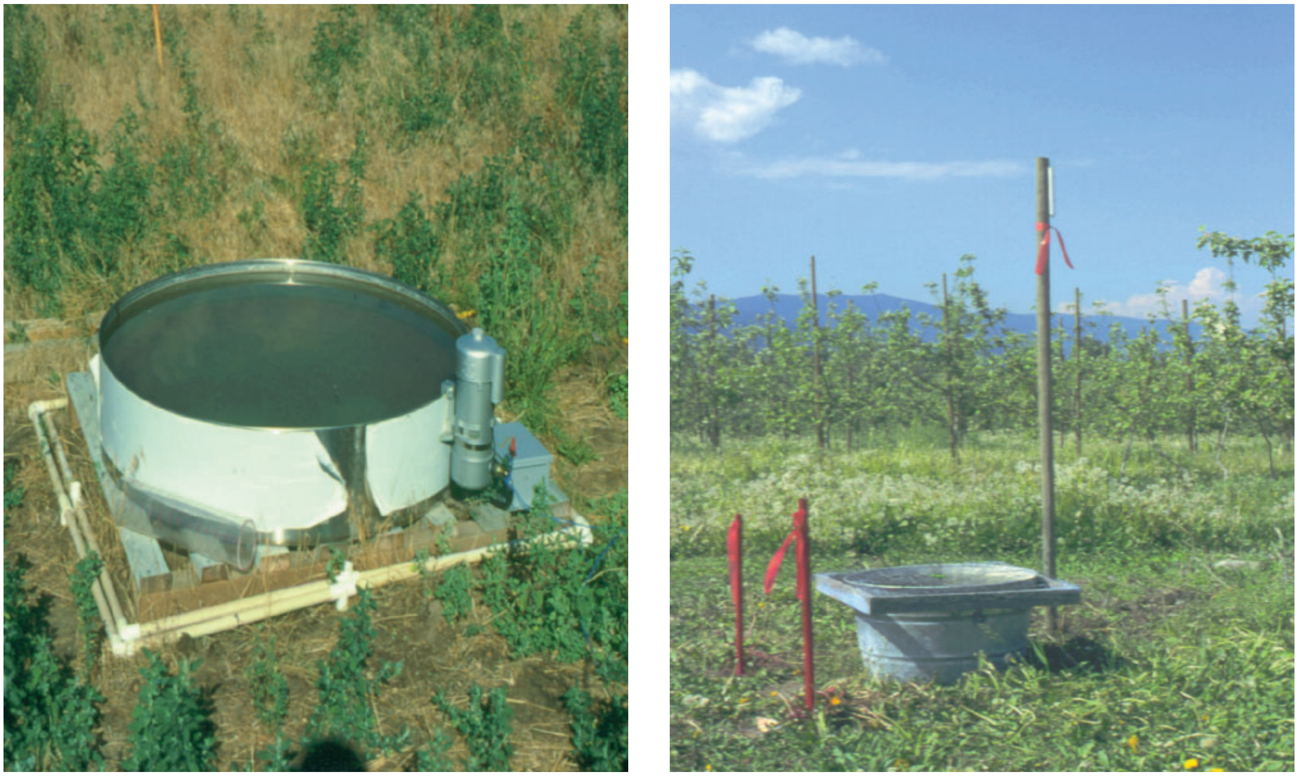
Figure 13.6 *Moisture Sensor Placement*

13.3 Collecting Meteorological Data

Water budgets can be developed using meteorological data. This method involves monitoring the additions and losses to the crop area and maintaining a favourable soil water level. The most important component of water budgeting is to accurately determine the crop water use or evapotranspiration (ET).

Daily ET can be calculated using information from sensors that collect radiation, wind, temperature and relative humidity data. While the calculation method is often employed where weather stations have been established, (usually around research stations) more often ET information is gathered by using evaporimeters.

Two types of evaporimeters are the evaporation pan and the atmometer. The Class A Pan evaporimeter is a common device used by most research facilities. These pans are quite large and can be fully automated by connecting to a data logger for data retrieval. Simple washtubs can be easily set up and used as a pan to collect ET data as shown in Figure 13.7. An evaporation pan should be monitored weekly.



Class A Pan **Wash Tub Evaporimeter**

Figure 13.7 *Evaporation Pans*

For an evaporation pan to work effectively, the pan should be located in an area that is exposed to full sun and wind. Figure 13.8 shows the ideal dimensions for an evaporation pan and the best location with respect to the crop.

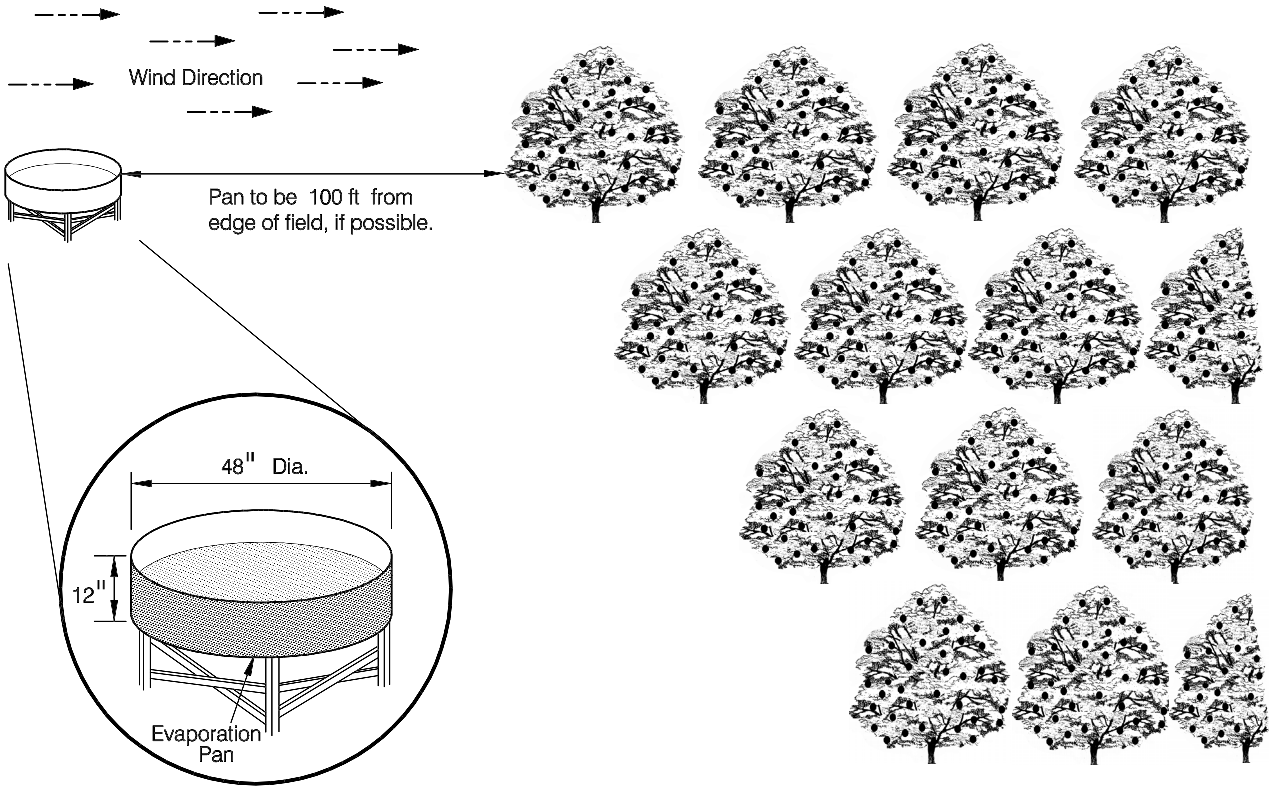


Figure 13.8 *Evaporation Pan Dimensions and Field Location*

An atmometer has a porous ceramic surface covered by a special cloth. See Figure 13.9. Water evaporated from the surface can be read manually or electronically by a data logger. The advantages of an atmometer is they can easily be installed in any location and can be automated with a 12 volt battery.

Figure 13.9 *Atmometer*

Evaporimeter data cannot be correlated to crop water use directly. Crop coefficients (K_c) or pan adjustment factors are used to adjust the collected ET data for growth stage and seasonal changes. Table 13.2 provides crop coefficients for various crops at the peak of the growing season using a Class A pan. The adjustment factors vary with climatic zones. Lower values should be used for humid conditions while higher values are for drier regions. The values must also be lowered for conditions early or later in the growing season. See Table 13.3. Also the type of evaporimeter that is used may affect the pan adjustment factor that should be applied. The coefficient for pans with a smaller surface may be different than that of a Class A pan, which have a larger surface area. For calculated ET values the adjustment factors (crop coefficients) may again be different.

Note: “Crop coefficient” is the terminology often used for the factor to adjust evaporation pan data. In this manual there is also a crop coefficient term used in Chapter 3, to calculate the crop’s peak water use for design purposes. The crop coefficient factor (K) in Chapter 3 is used to adjust the peak ET used in the formula to calculate G/P/D.

The crop coefficient used in Chapter 13 (K_c) is used to adjust the actual ET measured from an evaporimeter in the field for the crop type that is present. In effect, (K) and (K_c) could be the same however a conservative approach is taken for design purposes. The crop coefficient used in Chapter 3 is therefore higher for some crops than the values used in this chapter for scheduling purposes. The reason is that the system must be designed so it is capable of supplying enough water during the peak climatic conditions that are expected.

Table 13.2 Average Pan Evaporation Adjustment Factors for Various Crops at Peak Conditions

(humid areas use the lower values, dry windy areas use the higher values)

Crop		Pan Factor K_c	Crop		Pan Factor K_c
Apple	(with cover crop) (w/o cover crop)	0.9 - 1.0 0.80 - 0.90	Onion	(green)	0.80 - 0.95
Apricot	(with cover crop) (w/o cover crop)	0.90 - 0.95 0.70 - 0.85	Peach	(with cover crop) (w/o cover crop)	0.90 - 0.95 0.70 - 0.85
Asparagus	(after full fern)	0.90 - 0.95	Peas		0.80 - 1.00
Cherry	(with cover crop) (w/o cover crop)	1.0 - 1.2 0.90 - 0.95	Pear	(with cover crop) (w/o cover crop)	0.90 - 1.10 0.75 - 1.00
Grape	(with cover crop) (w/o cover crop)	0.80 - 1.00 0.70 - 0.75	Potato		1.00 - 1.10
Hops	(after reaching top wire)	1.40 - 1.60	Raspberry		1.00 - 1.2
Mint		0.95 - 1.00	Strawberry		0.40 - 0.50
Onion	(dry)	0.70 - 0.95			

NOTE: Given crop factors are for full cover conditions. Over irrigation will occur when used for early- and late-season conditions, but should be used as a rough guideline as to the *minimum* interval between irrigations early and later in the season.

Table 13.3 provides an example of actual data collected from a research station. Note the range in adjustment factors that can occur during a growing season. The range will be different from one season to the next and different areas of the province.

Table 13.3 Pan Evaporation Adjustment Factors Throughout the Growing Season

Crop Type	May	June	July	Aug	Sept
Peaches (with cover)	0.64	0.84	0.92	0.92	0.80
Apples (with cover)	0.68	0.92	1.00	1.00	0.96

13.4 Trickle Irrigation Scheduling

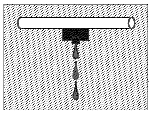
Trickle irrigation systems are designed to be able to supply the anticipated peak water use required by the crop. As calculated in Chapter 3, a peak ET rate is used to determine the design system supply rate, capable of delivering enough water to the crop at the peak time of year. Irrigation scheduling is a process that determines how much water to apply during non peak conditions. A schedule provides information on the timing and duration of application. Care should also be taken to not exceed the water holding capacity of the soil. This minimizes leaching of excess water and loss of nutrients.

Climatic Moisture Deficit Scheduling

Evaporation data can be used to develop an irrigation schedule but soil moisture information should also be used. The soil moisture data will help to make adjustments to the crop coefficients used with the ET data. If the crop coefficient is too low the soil moisture will be depleted over time. When the soil moisture readings stabilize at the desired level and the amount of water being applied is based on ET data, a crop coefficient can be established with confidence. Example 13.1 provides the methodology for using ET data.

For Example 13.1 it is also possible to adjust the irrigation schedule weekly. In this case the average ET per day for the week should be calculated and used to adjust the schedule for the following week. The average ET per day in Example 13.1 is 5.6 mm. Using the same calculation as in Example 13.1 the irrigation schedule would be altered to irrigate for 8.4 hours per day for the next seven days. The weekly adjustment ensures the soil moisture depleted the previous week is replaced. While not as effective as altering the schedule daily, a weekly schedule will adjust the watering time as the climate and crop change through the growing season.

Example 13.1 Using ET Data to Develop an Irrigation Schedule



The point source emitter example used in this manual has an apple crop with a cover crop on a 5 ft x 12 ft spacing in Kelowna on a loam soil. The particulars for this system at a peak ET rate of 0.24 in/day (6.1 mm/day) are as follows:

Trickle System Capacity (TC) = 9.8 gpd
Emitters per plant = 2
Emitter flow rate = 2 L/hr
Water supplied per plant = 4 L/hr or 1.06 gph
Number of zones = 2
Maximum zone operating time = 9.2 hours / day

Assume ET data has been collected from a pan for the week of July 20th to July 26th as shown below. From Table 13.2 and Table 13.3 the adjustment factor (K_c) for apples during the peak time of the year is 1.0.

If the trickle system is fully automated and the operating time can be easily adjusted, the daily ET values can be used to establish the operating time for each day. If the system runs 9.2 hours a day during the peak of the season when the ET is 6.1 mm, then if the ET is only 5.2 mm the operating time will be:

For July 20th, the zone operating time = $\frac{9.2 \text{ hours}}{6.1 \text{ mm}} \times 5.2 \text{ mm} \times 1.0 = 7.8 \text{ hours}$

The daily ET is multiplied by the adjustment factor (K_c). In this case the factor is 1.0 so there is no effect.

The same calculation can be made for each day. The trickle system is therefore replenishing the amount of water used by the crop the previous day.

Pan Data

July	Daily ET mm	Zone Operating Time hrs
20th	5.2	7.8
21st	4.8	7.2
22nd	6.1	9.2
23rd	7.8	11.8
24th	5.5	8.3
25th	4.8	7.2
26th	4.9	7.4
Total ET for week	39.1 mm	
Average ET per day	5.6 mm	8.4 hours per day

Determining an Irrigation Interval

The trickle irrigation concept is to apply enough water to replenish the crop water requirement on a daily basis. However, soil type, soil drainage conditions, crop rooting depth and climate should be taken into account before deciding on a trickle irrigation schedule. In some cases it may be advantageous to run the system for a longer period of time but less frequently, every two or three days instead of every day.

The least expensive trickle system would be designed with continuous water application. System flow rates would be reduced thereby reducing pipe sizes and minimizing control and zone valves. Continuous operation, however, leads to several problems, including excessive algae buildup, overwatering which induces leaching or runoff and, waterlogging, which can be detrimental to several crops. It is recommended that each zone be operated intermittently and not operated for more than 12 hours per day. This criteria should be used in determining the number of emitters per plant. See Section 5.4 for additional information on selecting the number of emitters per plant.

Short irrigation intervals are required in regions where evapotranspiration rates are high, the available water storage capacity of the soil is low, water quality is poor (saline) or if plants are shallow rooted. Longer irrigation intervals can be used if evapotranspiration is low, the available water storage capacity of the soil is high, water quality is good, or plants are deep rooted.

The irrigation interval can be checked or determined by using ET data and calculating an effective soil water holding capacity. The volume of water per cubic foot of soil must be determined. Table 13.4 can be used as a guide to determine the volume of water per square foot of soil. *Interpretive skills are required to determine the effective rooting depth and width of lateral water movement. Field checking is a must as water movement in the soil is not easily predictable.* Example 13.2 illustrates how to determine an irrigation interval by taking the soil water holding capacity into account.

Table 13.4 Volume of Water Held by Various Soils

Textural Class	Volume of Water	
	Gallons / Cubic Foot	Litres / Cubic Metre
Sand	0.62	83
Loamy Sand	0.75	100
Sandy Loam	0.94	126
Fine Sandy Loam	1.06	142
Loam	1.31	175
Silt Loam	1.56	209
Clay Loam	1.50	200
Clay	1.50	200
Organic Soils (muck)	1.87	250

Example 13.2 Irrigation Schedule Considering Soil Holding Capacity

The linear tape example used in this manual has a strawberry crop on a 1 ft x 4 ft planting in Abbotsford on a sandy loam soil. The particulars for this system at a peak ET rate of 0.15 in/day (3.8 mm/day) are as follows:

Trickle System Capacity (TC) = 0.29 gpd
Line source orifice spacing = 12 in
Line source flow rate = 0.22 gpm / 100 ft
Row length = 400 ft
Number of zones = 8
Maximum zone operating time = 2.2 hours/day

The first step is to calculate the volume of water that must be replenished in the effective crop rooting zone by taking into account an allowable moisture depletion. Since the objective of a drip system is too keep the soil moisture at a high level, the maximum allowable depletion should not exceed 25%. See Section 3.3.

From:

Table 3.2 The rooting depth of strawberries is 2 ft. While this is the effective rooting depth, the critical zone of moisture control is generally in the top half of the root zone. See Figure 13.5. The critical rooting depth is therefore taken to be 1 ft.

Table 5.3 The lateral spread of water from the emitter for a shallow rooted crop in a sandy loam soil is 1.25 ft. This value is for rooting depths less than 2 ft. However, since the critical rooting depth in this case is much less, only 1 ft, a distance of 0.75 ft will be used for the lateral spread from the emitter. The total wetted width is therefore 2 x 0.75 ft = 1.5 ft.

The effective soil volume in the crop row is:

Soil Volume = row length x the critical rooting depth x lateral water movement
= 400 ft x 1 ft x 1.5 ft = 600 ft^3.

The amount of water stored in this soil volume is:

From Table 13.4 A sandy loam soil can store 0.94 gallons / ft^3
Allowable depletion is 25%

Water volume = 600 ft^3 x 0.94 (gallons / ft^3) x 0.25 = 141 gallons

The time it takes to apply this amount of water by the line source system can now be calculated. The flow rate of the tape used is 0.22 gpm / 100 ft. The 400 ft section therefore has a supply rate of 0.88 gpm.

(Continued)

Example 13.2 Irrigation Schedule Considering Soil Holding Capacity *(Continued)*

$$\text{Maximum Application Time} = \frac{141\ \text{gallons}}{0.88\ \text{gallons/ min}} = 160\ \text{mins} = 2.67\ \text{hours}$$

Assume ET data has been collected for the week of June 18th to June 24th as shown below. From Table 13.2 the crop coefficient (K_c) for strawberries during the peak of the growing season is 0.50. Therefore the values collected need to be adjusted. The average adjusted ET for strawberries for the week is 1.8 mm per day.

June	Daily ET mm	Adjusted ET*
18th	4.5	2.25
19th	3.8	1.9
20th	4.0	2.0
21st	3.7	1.85
22nd	2.9	1.45
23rd	3.1	1.55
24th	2.6	1.3
Total ET for week		12.5 mm
Average ET per day		1.76 mm
Zone operating time per day		1.05 hours

*Pan Adjustment Factor K_c = 0.50 for strawberries

$$\text{The daily operating time is} = \frac{2.2\ \text{hours}}{3.8\ \text{mm}} \times 1.8\ \text{mm} = 1.05\ \text{hours}$$

For the climatic conditions of June 18th to the 24th the system should be operated for 1.05 hours per day. However, using the maximum application time of 2.67 hours based on the soil water storage, a longer irrigation interval can be determined.

$$\text{Irrigation interval} = \frac{\text{maximum application time}}{\text{daily operating time}} = \frac{2.67\ \text{hours}}{1.05\ \text{hrs/day}} = 2.5\ \text{days}$$

The grower could therefore operate for 2.67 hours every 2.5 days or 2.1 hours every other day without exceeding the soil water storage.

Table 13.5 provides a guide to the maximum irrigation intervals that should be used in British Columbia based on the ET value, soil type and crop rooting depth. Checking soil water movement in the field and performing the calculation used in example 13.2 will provide better guidance. The longer intervals can only be used if the soil has sufficient water storage and the system is capable of replenishing the soil storage during a 12 hour application.

Additional irrigation scheduling information is available from the Ministry of Agriculture and Food.

Table 13.5 A Guide to Maximum Irrigation Intervals for Trickle Irrigation Systems

ET		Rooting Depth	Maximum Irrigation Interval (days)			
in/day	mm/day	ft	Coarse Sand	Sandy Loam	Loam	Clay
0.30	7.6	2	1	1	1	1
		4	1	1	2	2
0.26	6.6	2	1	1	1	2
		4	1	1	2	3
0.22	5.6	2	1	1	1	2
		4	1	2	3	3
0.18	4.6	2	1	1	2	3
		4	2	2	3	4
0.14	3.6	2	1	2	3	4
		4	2	3	3	6