3 Plants, Soil and Water

A trickle irrigation system should be designed to match the anticipated peak water use required by the crop. The system design requirement is established by the plant water requirement. This is the maximum flow rate which the system must be capable of supplying.

A trickle system should never be designed for 24 hours of operation per day. The total system operating time should not exceed 20 hours/day to compensate for a reduction in system flow rate over time. As system flow rates decrease over time, system operating times can then be increased to supply the plant's water needs. This would not be possible if the system was originally designed to operate 24 hours per day.

3.1 Plant Water Requirements

Parameters that must be considered to determine the plant water requirement are shown in Figure 3.1 A trickle irrigation system design must take into account:

Climatic conditions

The peak evapotranspiration rate will normally occur during the hottest period of the growing season. The system design must be based on this peak rate.

Crop maturity

On all crops, plant water requirement will increase with plant growth and leaf coverage. The system design capacity must be based on the irrigation requirements of a mature crop.

Crop type

Water requirements for various plants will vary due to plant size, plant spacing, leaf area and type of leaf surface.

Effective Soil Water Storage

The effective soil water storage is the volume of water stored in the soil which is readily available for use by the plant. It is a function of soil type, plant rooting depth and the plant's ability to extract water from the soil. Section 3.3 provides information on soil and water relationships.

Rooting Depth

Evaluate the plant size and condition and soil type when determining the plant rooting depth. Table 3.2 provides maximum effective rooting depths for various crops. The actual effective rooting depth can vary due to boundary layers in the soil, soil depth, and root stock selection.

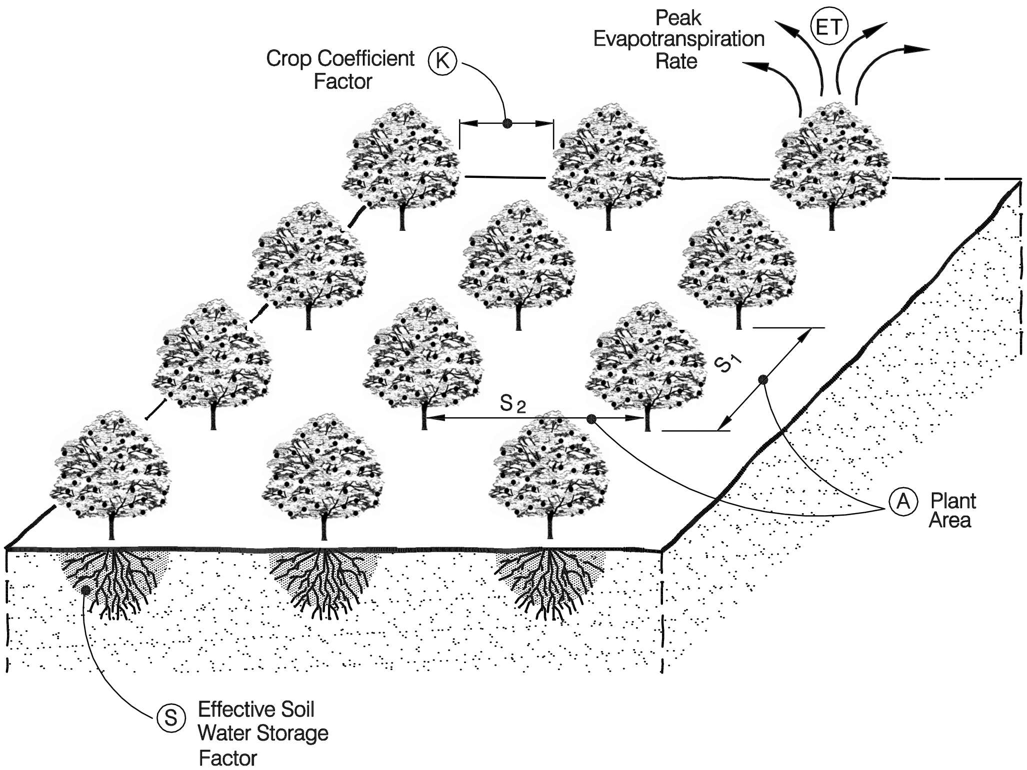


Figure 3.1 *Factors Affecting Plant Water Requirement*

When the effective soil water storage capability is low, the trickle system design capacity must be based on the peak evapotranspiration rates that occurs daily. The soil is not able to store adequate water for future use. However, if the effective soil water storage is high, the plant can draw on the soil water reserve should the trickle irrigation system not supply sufficient water that day.

In these situations the system design capacity can be reduced as the amount of water supplied does not need to match the peak evapotranspiration rates that occur. The amount of reduction will depend upon crop rooting depth, crop type and soil conditions. The soil water storage factor (S) takes this into account in Equation 3.1, the plant daily requirement equation.

The plant water requirement for a trickle irrigation system design is expressed in gallons/plant/day (G/P/D) or litres/plant/day (L/P/D). It is calculated by using Equation 3.1.

Equation 3.1

$$G/P/D = 0.623 \times ET \times S \times A \times K$$

where

G/P/D	=	gallons (U.S.) per plant per day
0.623	=	$\frac{27{,}152 \text{ gal/ac-in}}{43{,}560 \text{ ft}^2\text{/acre}}$
ET	=	Peak evapotranspiration rate for location (in/day) (Table 2.1)
S	=	Effective soil water storage factor (decimal) (Table 3.4)
A	=	Plant area (ft^2) – calculated from plant spacing
K	=	Crop coefficient factor (Table 3.5) (decimal)

Two factors that require further explanation are the effective soil water storage factor (S) and the crop coefficient factor (K).

Calculating the Effective Soil Water Storage Factor (S)

The effective soil water storage capacity of the plant root zone depends upon

(i) the available water storage capacity of the soil (Table 3.1)

(ii) effective rooting depth of mature crops (Table 3.2)

(iii) the availability of the stored water to the crop (Table 3.3)

The availability coefficient shown in Table 3.3 is the allowable depletion of moisture in the soil from field capacity. The soil water storage factor (S) is dependent upon the effective soil water storage capacity and peak evapotranspiration rate (Table 2.1). Soils and crops that produce a high effective storage capacity will have a lower (S) factor as the crop has more water to draw on during peak conditions. Very low effective storage capacity conditions will have a high (S) factor (close to 1.0). The (S) factor increases as the peak evapotranspiration rate increases.

Table 3.1 Guide to Available Water Storage Capacities of Soils

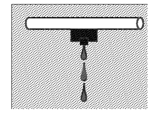
Textural Class	Available Water Storage Capacity (Inches of Water/ Foot of Soil)	Available Water Storage Capacity (Cm of Water/ Metre of Soil)
Sand	1.0	8.3
Loamy Sand	1.2	10.0
Sandy Loam	1.5	12.5
Fine Sandy Loam	1.7	14.2
Loam	2.1	17.5
Silt Loam	2.5	20.8
Clay Loam	2.4	20.0
Clay	2.4	20.0
Organic Soils (muck)	3.0	25.0

Table 3.2 Effective Rooting Depth of Mature Crops Under Trickle Irrigation

Shallow 1.5 ft (0.45 m)	Medium Shallow 2 ft (0.60 m)	Medium Deep 3 ft (0.90 m)	Deep 4 ft (1.2 m)
Cabbages	Beans	Brussels Sprouts	Asparagus
Cauliflowers	Beets	Corn (sweet)	Blackberries
Cucumbers	Blueberries	Eggplant	Grapes
Lettuce	Broccoli	Kiwifruit	Loganberries
Onions	Carrots	Peppers	Raspberries
Radishes	Celery	Squash	Sugar Beets
Turnips	Potatoes	Saskatoons	
	Peas		
	Strawberries		
	Tomatoes		
	Tree Fruits (3' x 10')	Tree Fruits (6' x 13')	Tree Fruits (12' x 18')

Table 3.3 Availability Coefficient (Allowable Depletion)

Crop	Maximum Percent (%)
Peas	35
Potatoes	35
Tree Fruits	40
Grapes	40
Tomatoes	40
Other Crops	50



Example 3.1 Determining the Soil Storage Factor (S)

First calculate the effective soil water storage capacity for a high density tree fruit crop (5' x 12') growing in a loam soil with a peak ET value of 0.24 in /day.

From:	Table 3.1 Available Water Storage Capacity for a loam soil	= 2.1 in/ft
	Table 3.2 Rooting depth of tree fruits	= 3 ft
	Table 3.3 Availability Coefficient	= 0.40

Effective soil water storage capacity

= 2.1 in/ft x 3 ft x 0.40

= 2.52 in

The soil water storage factor (S) is interpolated from Table 3.4 using an effective soil water storage capacity of 2.52 inches and a peak ET rate of 0.24 in/day.

From Table 3.4 the effective soil water storage factor (S) would be between 0.80 and 0.75. A factor of 0.80 would be used to ensure system capacity is adequate.

Table 3.4 Effective Soil Water Storage Factor (S)

Effective Soil Water Storage Capacity	Peak Evapotranspiration Rate in/day	S Factor
3.0 inches +	0.30	0.80
	0.25	0.75
	0.20	0.75
2.0 inches	0.30	0.85
	0.25	0.80
	0.20	0.75
1.0 inches	0.30	0.95
	0.25	0.90
	0.20	0.85

Selecting a Crop Coefficient Factor (K)

The crop coefficient factor (K) accounts for the field area that is not utilized by the plants' canopy or root area. The crop coefficient factors listed are for mature crops and can only be used in the design process if actual plantings closely approximate the plant spacings shown in the table. For larger plant spacings the crop coefficient factors may possibly be reduced.

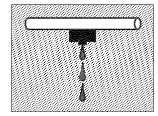
Table 3.5 Crop Coefficient Factor (K)

Plant	Crop Coefficient	Approximate Spacing	
Apples Apricots Cherries Peaches Pears Plums	0.90 0.80 0.90 0.80 0.80 0.80	7' x 12' to 20' x 20'	2 m x 3.6 m to 6 m x 6 m
Tree Fruits - High Density	1.00	3' x 10' to 5' x 12'	0.9 m x 3 m to 1.5 m x 3.7 m
Grapes	0.70	5' x 12'	1.5 m x 3.7 m
Blueberries	0.80	5' x 10'	1.5 m x 3 m
Blackberries	0.60	8' x 10'	2.4 m x 3 m
Kiwi Fruit	1.00	15' x 15'	4.6 m x 4.6 m
Logan Berries	0.60	8' x 10'	2.4 m x 3 m
Raspberries	0.70	2.5' x 10'	0.75 m x 3 m
Strawberries	0.75	1' x 4'	0.3 m x 1.2 m
Tomatoes	0.90	1.5' x 5'	0.5 m x 1.5 m
Vegetables	0.75	1' x 3'	0.3 m x 0.9 m

Calculation of Plant Water Requirement

The amount of water to be applied to a parcel of land by a trickle irrigation system will depend upon climatic conditions, soil characteristics, crop type, and plant spacings. As shown in the following three examples, the plant water requirement varies dramatically depending on location, plant spacing and crop type.

Example 3.2 Calculating Plant Water Requirement for an Apple Crop



An apple crop, planted at 5 ft x 12 ft is being grown in Kelowna in a loam soil. What is the plant water requirement during the peak of the season?

G/P/D = 0.623 x ET x S x A x K (Eq. 3.1)

From:

Table 3.1	Soil Water Storage Capacity	=	2.1 in/ft
Table 3.2	Effective Rooting depth of mature crop	=	3 ft
Table 3.3	Availability Coefficient	=	0.40 (40%)

Effective Soil Water Storage Capacity
= 2.1 in x 3 ft x 0.40
= 2.52 inches

Table 2.1	Peak ET	=	0.24 in/day

Table 3.4 – Based on a 0.24 ET rate and an effective water storage capacity of 2.52 inches an S factor of 0.80 is selected from the table.

Table 3.5	Crop coefficient factor (K)	=	1.00
Plant area (A)	= 5 ft x 12 ft	=	60 ft^2

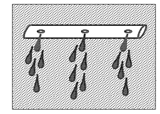
Using Equation 3.1:

G/P/D = 0.623 x ET x S x A x K

G/P/D = 0.623 x 0.24 x 0.80 x 60 x 1.00

= 7.2 gallons per plant per day

Example 3.3 Plant Water Requirements for Strawberries



A strawberry crop, on a 1.0 ft x 4 ft planting is grown in Abbotsford in a sandy loam soil. What is the plant water requirement during the peak of the irrigation season?

From:	Table 3.1 Soil Water Storage Capacity	= 1.5 in/ft
	Table 3.2 Effective rooting depth of mature crop	= 2 ft
	Table 3.3 Availability Coefficient	= 0.50
	Effective soil water storage capacity	= 1.5 in/ft x 2 ft x 0.50
		= 1.5 inches
	Table 2.1 Peak ET rate	= 0.15 in/day
	Table 3.4 Soil water storage factor (S)	= 0.80
	(Based on 1.5 in storage capacity and an ET rate of 0.15 in/day)	
	Table 3.5 Crop Coefficient Factor (K)	= 0.75
	Plant area (A) = 1 ft x 4 ft	= 4 ft^2

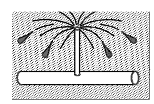
Using equation 3.1:

G/P/D = 0.623 x ET x S x A x K

G/P/D = 0.623 x 0.15 x 0.80 x 4 x 0.75

= 0.22 gallons per plant per day

Example 3.4 Plant Water Requirements for Tree Fruits in Osoyoos



An apple crop, on a 10 ft x 20 ft planting is grown in Osoyoos in a loamy sand soil. What is the plant water requirement during the peak of the irrigation season?

G/P/D = 0.623 x ET x S x A x K

From:	Table 3.1 Soil Water Storage Capacity		= 1.2 in/ft
	Table 3.2 Effective Rooting depth of mature crop		= 4 ft
	Table 3.3 Availability Coefficient		= 0.40
	Effective soil water storage capacity		= 1.2 in/ft x 4 ft x 0.40
			= 2.0 in
	Table 2.1 Peak ET rate		= 0.28 in/day
	Table 3.4 Soil water storage factor (S)		= 0.85
	Based on 2.0 in effective soil water storage capacity and an ET rate of 0.28 in/day.		
	Table 3.5 Crop coefficient factor (K)		= 0.90
	Plant Spacing (A)	= 10 ft x 20 ft	= 200 ft

G/P/D = 0.623 x 0.28 x 0.85 x 200 x 0.90

= 26.7 gallons per plant per day

Comparison of Crop Water Requirements of Various Crops

Due to the variance in water requirements of different crops, a trickle system designed for a certain crop is not necessarily transferable to another crop, even if both crops are grown under the same soil and climatic conditions. A trickle system must be designed for the specific site conditions that exist. This is exemplified in Table 3.6. Note the daily per acre water requirement of various crops at peak conditions, assuming the same soil and climatic conditions, vary from 2830 – 4070 gallons per day per acre. (Plant spacings chosen are typical of the industry). **The water requirements shown in Table 3.6 are for the specific soils and climatic conditions stated.** ***They are to be used for illustrative purposes only.*** The purpose of the table is to indicate that different crops will require various supply rates even when climate and soil conditions remain the same.

Table 3.6 Plant Water Requirements per Acre Based on a Sandy Loam Soil and an ET rate of 0.20 in/day

Crop	Plant Spacing	G/P/D	Plants/Acre	Daily Requirement per Acre gal/ac
Apples	10' x 15'	12.6	290	3660
Grapes	5' x 12'	3.9	726	2830
Raspberries	2.5' x 10'	1.64	1,743	2860
Strawberries	1' x 4'	0.3	10,890	3270
Tomatoes	1.5' x 5'	0.67	5,808	3900

3.2 Calculating Trickle System Design Requirement

Section 3.1 provides information on how to calculate the amount of water a crop requires during peak times if irrigation is applied through a trickle system. However to ensure that the crop receives sufficient water, irrigation system efficiency, distribution uniformity and leaching requirements should be taken into account. Figure 3.2 indicates the considerations that must be taken into account when calculating the amount of water that must be applied by a trickle irrigation system.

Leaching Requirement

Irrigation water contains some salts. To prevent the buildup of salts within the wetted plant root volume, additional irrigation should be applied to ensure salts are leached beyond the plant rooting zone. To ensure that the trickle system has the capacity to apply the leaching requirement it must be added to the design requirement. Table 3.7 provides information on selecting an appropriate leaching factor.

In the drier regions of the province a 5% leaching factor is used for shallow rooted crops (< 2 ft) and 10% for deeper rooted crops (> 2 ft). Lower leaching factor can be used for shallow rooted crops as rainfall is likely to provide some leaching assistance. In the wet coastal regions a leaching factor is not necessary unless fertigation is used. See Table 3.7.

The leaching factor selected is included in Equation 3.2. The trickle system manager must ensure that enough water is applied during the irrigation season to ensure that leaching of salts does occur.

Table 3.7 Leaching Factors for Trickle Irrigation System Design

Region or Special Conditions	Rooting Depth	Leaching Factor
Okanagan, Kootenays, Thompson	< 2 ft > 2 ft	1.05 1.10
South Coastal	all rooting depths	1.00
Fertigation Systems	all rooting depths	1.10

Application Efficiency

The application efficiency takes into account losses due to evaporation during the application process and from the soil surface after application. Not all of the water applied will be available to the plant.

Properly designed and operated trickle irrigation systems are much more efficient than sprinkler irrigation systems. Normal sprinkler irrigation system efficiencies are 65-75% while trickle systems can be as high as 85-95%. Table 3.8 provides information on trickle irrigation system efficiencies for various system types and installation methods.

Mulches and minitunnels are used on row crops to enhance the plant's environment, especially in the early part of the growing season. In the case of minitunnel systems, the plastic cover is quite often removed later in the growing season. Trickle irrigation systems are very compatible with this type of technology and are often used to supply the water and nutrients to the crop. Crop water usage under these types of systems are usually reduced while the minitunnel is in place. However the amount of water saving have not been accurately determined.

The plant water requirement for minitunnel systems should be determined as if the minitunnel is not there, i.e. similar to field conditions. A grower can then be assured that the system capacity will be able to supply enough water during peak conditions. The system operating time must then be adjusted to apply the correct amount of water while the minitunnels are installed.

Plastics and other mulches are usually in place year round once applied. Trickle irrigation systems will be more efficient under a mulch system. A higher application efficiency for trickle irrigation systems operating under a mulch should be used as shown in Table 3.8.

Table 3.8 Trickle Irrigation System Efficiencies

Trickle Irrigation System	Application Efficiency
Spray or Microjet	85%
Drip	90%
Mulch cover such as straw or shavings	93%
Plastic Mulch	95%
Subsurface Drip	95%

Emission Uniformity

There is often confusion between the terms “distribution uniformity (DU)” and “emission uniformity (Eu)”. See sections 4.3 and 4.5 for a more detailed explanation. Emission uniformity assesses the uniformity of a new system and uses the manufacturer’s coefficient for the emitter (Cv) and pressure variation. Distribution uniformity measures the actual performance of the emitters in the field.

The emission uniformity of a system will be highest when it is new. Over time the system’s emitters will become partially plugged or worn and the Eu will be reduced. The emitter is usually installed in close proximity to the plant to ensure effective water application is achieved. It is important to note that to obtain a good Eu not all the plants need to obtain the same amount of water, only the plants of the same size growing in the same soil.

For the purposes of trickle design an emission uniformity (Eu) of 85 - 90% should be used. Trickle irrigation systems should be designed to operate for only 12 - 18 hours a day, allowing an additional 6 to 12 hours to be available to compensate for system flow deterioration over time.

Trickle System Design Requirement

The trickle system design requirement must take into account the plant water requirement (G/P/D), a leaching factor, an application efficiency and an emission uniformity. The trickle system design requirement is calculated from the formula:

Equation 3.2

$$TC = \frac{G/P/D \times L}{E \times Eu}$$

where	TC	=	trickle system design capacity
	G/P/D	=	plant water requirement
	L	=	leaching factor (Table 3.7)
	E	=	application efficiency (decimal) (Table 3.8)
	Eu	=	emission uniformity (decimal)

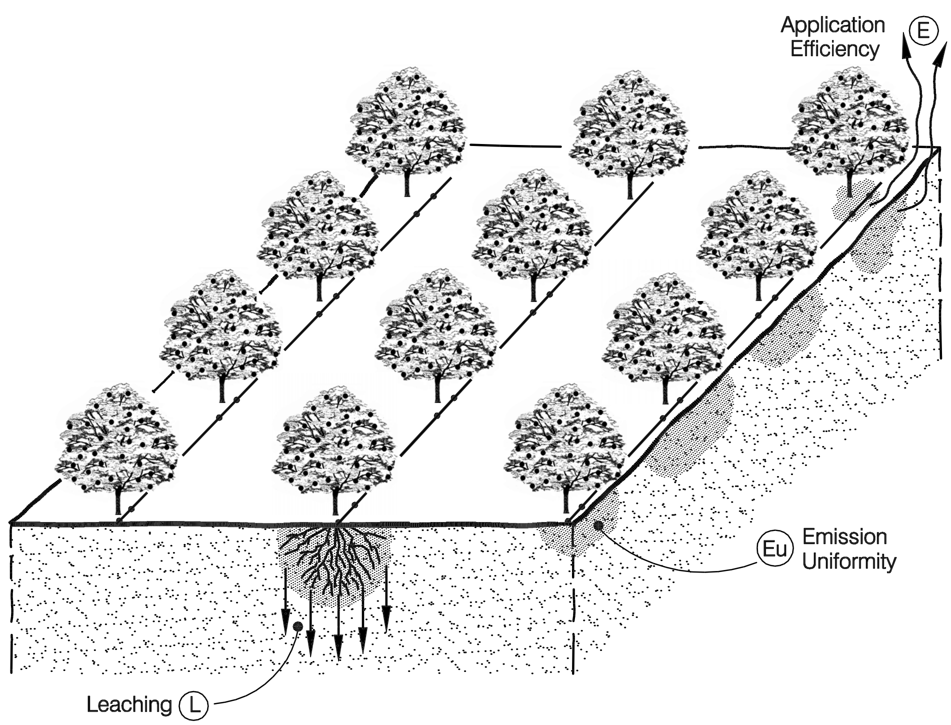
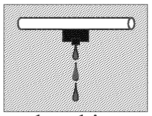


Figure 3.2 *Factors To Determine Trickle System Design Requirement*

The following three examples are used to illustrate other design principles throughout the manual. The symbols in the upper right are used to designate when these examples are continued through the remainder of the manual.

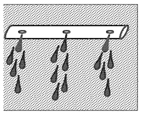
Example 3.2 Calculating Plant Water Requirement for an Apple Crop (Continued)



A point source drip system is used to irrigate a high density apple (5’ x 12’ spacing) orchard in Kelowna. An Eu of 90% is used. The trickle system design requirement (TC) will therefore be:

From Table 3.7	L	= 1.10
From Table 3.8	E	= 0.90
	Eu	= 0.90
	G/P/D	= 7.2 (calculated previously)
	TC	$= \frac{7.2 \text{ G/P/D} \times 1.10}{0.90 \times 0.90} = 9.8$ G/P/D

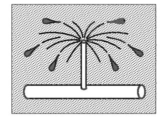
Example 3.3 Plant Water Requirements for Strawberries (Continued)



A linear tape system under plastic mulch is used to irrigate a strawberry crop in Abbotsford. The Eu for this system is 80%. The trickle system design requirement (TC) will be:

From Table 3.7	L	= 1.0
From Table 3.8	E	= 0.95
	Eu	= 0.80
	G/P/D	= 0.22 (calculated previously)
	TC	$= \frac{0.22 \text{ G/P/D} \times 1.0}{0.95 \times 0.80} = 0.29$ G/P/D

Example 3.4 Plant Water Requirements for Tree Fruits in Osoyoos (Continued)



A microjet system is used to irrigate an apple crop in Osoyoos in loamy sand soil. Due to the sloping terrain the system will be designed to an Eu of 0.85. The trickle system design requirement (TC) will be:

From Table 3.7	L	= 1.10
From Table 3.8	E	= 0.85
	Eu	= 0.85
	G/P/D	= 26.7 (calculated previously)

$$TC = \frac{26.7 \text{ G/P/D} \times 1.10}{0.85 \times 0.85} = 40.7 \text{ G/P/D}$$

3.3 Soils

An understanding of soils is imperative to ensure that enough water is applied to each plant. The lateral movement of water in the soil is determined by the soil texture and rate of irrigation application. The effective wetted soil volume that can be achieved by each emitter will determine the emitter spacing and the number of emitters per plant. Establishing an irrigation schedule requires knowledge of soil water holding capacity and allowable depletion. Chapters 5, 6 and 13 provide additional information on emitter selection, placement and scheduling using soil texture information. Chapter 15 provides information for landscape drip systems.

Soil Texture

Soil texture is defined in terms of the size distribution of the mineral components in the soil. Soil particles are grouped into four particle sizes: clay, silt, sand and gravel. Table 3.9 outlines the size range of particles in each of these groups.

Soil texture refers to the relative percentage of sand, silt, and clay sized particles in the soil material. It is generally estimated in the field with the hand feel method as explained in Table 13.1. If the composition of sand, silt and clay are known the soil texture can be determined from the textural triangle in Figure 3.3.

It is often convenient to place soil textures or types into four main groups and describe the important properties that are common to each group as in Table 3.10. Soil texture is a permanent soil characteristic and will not change unless a large quantity of material with another texture is added.

Table 3.9	Soil Particle Size and Characteristics	
Particle	**Size**	**Properties**
Gravel	2 mm - 7.5 cm	Rounded, coarse rock fragments. Single grained and loose.
Sand	0.05 mm - 2.0 mm	Somewhat rounded, single grained and loose. Can be felt as grit.
Silt	0.002 mm - 0.05 mm	Rounded, generally forms clods, easily broken, floury when dry, soapy or buttery, but not sticky when moist or wet.
Clay	Less than 0.002 mm	Flat particles, forms hard clods when dry, sticky and plastic when moist or wet.

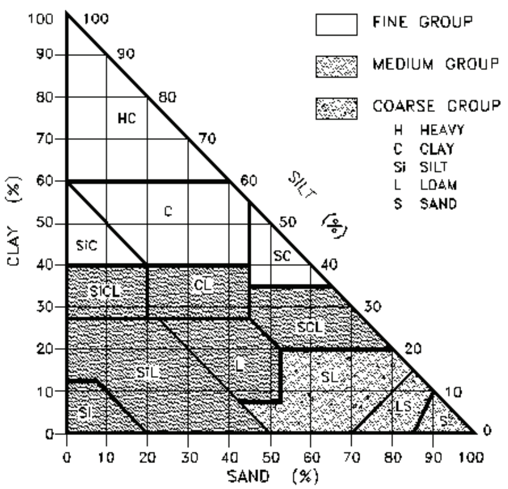


Figure 3.3 *Soil Texture Diagram*

Soil and Water

The following terms explain mechanisms by which water is transported and held by the soil.

Hygroscopic Moisture is water held tightly by soil particles and is not normally available to the plant.

Capillary Moisture is the water held in pore spaces by the surface tension between the water and soil particles. Capillary moisture is the primary source of water for plants.

Gravitational Water is the water that moves freely through the soil under the influence of gravity. After a soil has been saturated gravitational water moves downward leaving the soil at field capacity.

Field Capacity is the water left in the soil after the influence of gravity. A soil that has been saturated by rainfall or irrigation is usually at field capacity if allowed to drain for 24 hours. The soil will lose very little water after it has drained to field capacity except to evaporation and transpiration by the plant.

Permanent Wilting Point is the soil moisture content at which the plant will wilt and often die.

Available Soil Moisture is the difference between the amount of water in the soil at field capacity and the amount at the permanent wilting point. The total available water holding capacity of a soil is determined by multiplying the plant rooting zone depth by the soil holding capacity values shown in Table 3.1.

Allowable Depletion

Maximum allowable depletion is the amount of available water that can be removed from the soil before the plant is stressed. The availability coefficient in Table 3.3 can be used to calculate the maximum amount of water that should be removed from a soil at field capacity for agricultural crops.

Drip irrigation systems are designed and operated to keep the soil moisture content at a level above the maximum allowable depletion by using frequent applications of irrigation. An allowable depletion of 25% should be used for agricultural drip systems and 30 % for landscape systems.

Allowable depletion is used to determine an irrigation interval. Section 13.4 provides further information for agricultural drip irrigation system scheduling. Section 15.4 provides information on landscape drip irrigation system scheduling.

Table 3.10 Physical Characteristics of Soil Textural Groups

Soil Textural Group	Soil Textures and Types	Characteristics
Coarse to Moderately Coarse	Gravel Sand Loamy Sand Sandy Loam Fine Sandy Loam	Loose and friable when moist or wet. Loose to soft when dry. Very high proportion of large pores. Low water-holding capacity. Good bearing strength and trafficability when wet. Tends to form weak clods when cultivated. Easy to maintain good tilth.
Medium	Very Fine Sandy Loam Loam Silty Loam Silt	Slightly sticky and plastic when wet. Friable to firm when moist, soft to slightly hard when dry. Moderately easy to maintain good tilth. Moderately good trafficability and bearing strength when wet. Tends to form small to medium, slightly firm clods when cultivated. High proportion of medium to small pores, high water-holding capacity and available water.
Moderately Fine to Fine and Very Fine	Sandy Clay Loam Clay Loam Silty Clay Loam Sandy Clay Clay Silty Clay Heavy Clay	Sticky and plastic when wet. Friable to firm when moist, hard to very hard when dry. High proportion of small pores. Moderately difficult to maintain good tilth. Poor trafficability when wet. Tends to form large, firm clods when cultivated. High water-holding capacity, but less available water than medium-textured soils.
Organic Soils	Muck and Peat	Variably sticky, usually non-plastic, friable, slightly firm when dry. Very high water-holding capacity. Poor trafficability when wet. Tends to form small to medium clods when cultivated. Easy to maintain good tilth.