B.C. IRRIGATION MANAGEMENT GUIDE

Chapter 7

Editor

Ted W. van der Gulik, P.Eng.

Authors

Stephanie Tam, B.A.Sc.
T. Janine Nyvall, P.Eng.
Lance Brown, Eng Tech

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LIMITATION OF LIABILITY AND USER'S RESPONSIBILITY

The primary purpose of this B.C. Irrigation Management Guide is to provide irrigation professionals and consultants with a methodology to assess the irrigation system performance and manage the system effectively.

While every effort has been made to ensure the accuracy and completeness of these materials, additional materials may be required to complete more advanced assessments. Advice of appropriate professionals and experts may assist in completing assessments that are not covered in this Guide.

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7

IRRIGATION SCHEDULING

This chapter outlines how to determine an irrigation schedule for the peak part of the irrigation season. This basic schedule establishes an irrigation system operating time for each set and an appropriate irrigation interval (the length of time between irrigation applications). Strategies and methods for managing the irrigation scheduling are also discussed in this chapter. There are a number of ways that the system can be operated to match climate conditions. Some farms alter the operating time throughout the season to match climate conditions and crop growth requirements; others keep the operating time the same but change the operation frequency. Either method can be used to ensure that the irrigation application matches the crop water requirements.

During water shortages, it is important to conserve water and stretch water resources to ensure that the supply will be available for the entire growing season. The objective is to ensure the crop has enough water during its growing cycle to maximize yields while not wasting water.

Water efficiency and conservation can be achieved by:

- using more efficient equipment, and ensuring equipment is operating properly
    - repairing leaks in the irrigation system
    - selecting a more efficient irrigation system if possible
    - improving sprinkler irrigation efficiency

- managing water application on farm more effectively
    - finding maximum irrigation set time and only applying as much water as the soil can hold
    - knowing crop's water requirements
    - using soil moisture monitoring device to determine when to irrigate
    - refraining from irrigating during hot windy periods of the day if possible


Water Conservation
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IRRIGATION TIPS TO CONSERVE WATER ON THE FARM

Irrigation Tips to Conserve Water on the Farm

An irrigation schedule matches irrigation water application to the soil and the crop's water needs. The key objective of irrigation scheduling is to reduce water loss due to overland flow or leaching.

Irrigation scheduling requires information on:

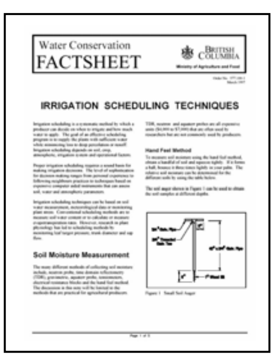
- the soil water holding capacity (AWSC) of the soil
- the amount of evapotranspiration (ET) and precipitation (climate information)
- the application rate of the irrigation system
- irrigation set times

An irrigation schedule can be implemented by using the following practices:

- irrigate according to crop requirements instead of a schedule of convenience or other rigid timetable
- monitor soil moisture
- monitor climate information and be aware of the forecast
- consider recent rainfall events and ET
  - the amount of water to be added to the soil depends on how much has been removed by the crop and added by rainfall since the last irrigation
  - irrigation begins when a significant amount of water has been removed from the soil root zone: 50% for sprinkler systems; and 20 – 30% for trickle systems

Trickle and sprinkler systems are scheduled differently. The goal of a trickle system is to keep the soil moisture at a constant level by applying small amounts of water frequently. With sprinkler systems, the soil is allowed to dry between irrigations, allowing the soil moisture to reach the maximum soil water deficit (MSWD).

7.1 Soil Moisture Monitoring


Water Conservation
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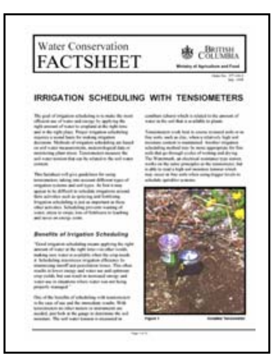
IRRIGATION SCHEDULING TECHNIQUES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IRRIGATION SCHEDULING WITH TENSIOMETERS

The need for irrigation should never be gauged by the moisture content of the soil surface layer alone. It is important to determine the moisture content throughout the root zone to make a wise decision on when to start irrigation. This can be done by using the hand-feel method or moisture monitoring devices, such as tensiometers, electrical resistance blocks, time domain reflectometery (TDR)/time domain transmissivity (TDT), and wetting front sensors.

Irrigation Scheduling Techniques

Irrigation Scheduling with Tensiometers

Hand-Feel Method, Chapter 5

Hand-Feel Method

To measure soil moisture using the hand-feel method, obtain a handful of soil and squeeze tightly. If it forms a ball, bounce it three times lightly in your palm. The relative soil moisture can be determined for the different soils by using Table 7.1.

Table 7.1 Soil Moisture, Appearance and Description Chart

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

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

Soil Moisture Monitoring Devices

Tensiometers

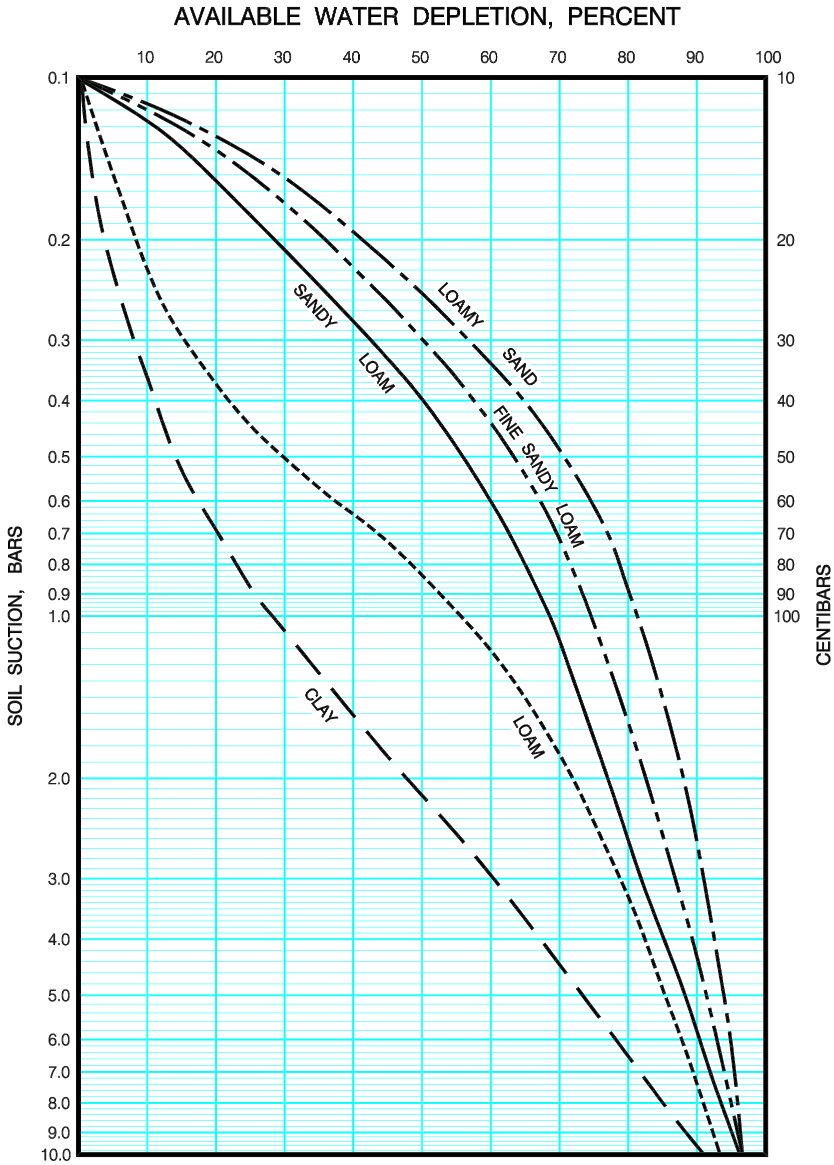


Figure 7.1 Soil Moisture Tension and Available Water

A tensiometer measures the soil water tension that can be related to the soil water content for specific soils. Figure 7.1 shows the relationship between the available depletion and the soil matric potential (soil moisture tension).

The tensiometer is made of a closed tube with a special ceramic tip attached to one end. The tube can be sealed off at the top to create an airtight seal within the tube. As the soil dries and draws water from tube, a vacuum gage registers the amount of suction indicating the level of soil moisture left in the soil (Figure 7.2).

Tensiometers are responsive to soil water tensions of 5 – 70 centibars (cbars).

Figure 7.2 Tensiometer

Electrical Resistance Blocks

There are a number of electrical resistance blocks available on the market under various trade names. Watermark is one product that has been used in British Columbia (Figure 7.3). Watermarks measure the electrical resistance to current flow between electrodes embedded in a material resembling fine sand surrounded by a synthetic porous material.

Figure 7.3 Electrical Resistance Block

The blocks are installed in the soil in a similar procedure to installing a tensiometer. The blocks must make good contact with the soil, and the pilot hole with the wire leads should be refilled and tamped to prevent surface moisture from collecting around the blocks. Readings are taken by attaching a special resistance meter to the wire leads, setting the soil temperature and pushing a button to initiate current flow.

High resistance readings mean lower block water content; therefore, higher soil water tension. The Watermark will give higher values for dry soil conditions, and low readings for wet conditions, similar to tensiometers. Calibration with the specific soil type must be done to establish the relationship between soil water content and tension.

Watermarks require little maintenance and can be left in the soil under freezing conditions. The Watermarks are responsive to soil water tensions of 40 – 125 cbars, and are therefore well-suited for heavier soils.

Time Domain Reflectometery (TDR)/Time Domain Transmissivity (TDT)

TDR and TDT instruments give accurate readings of volumetric soil moisture. The Moisture Point® (Figure 7.4) uses TDR technology which measures the time a pulse takes to travel along a section of transmission line. The amount of water in the soil is proportional to the time it takes for the propagation of this pulse. The Moisture Point® is easier to use, but is quite expensive for small growers.

Figure 7.4 Moisture Point® Meter

The Gro-Point® (Figure 7.5) uses TDT technology. The TDT signal is simpler to analyze; therefore, the equipment is less expensive. The device can control an irrigation zone through the controller. A desired soil moisture range can be set through a hand-held meter. The irrigation clock controls the irrigation schedule; however, if the soil moisture is in a preset range at the time that the controller indicates it is time to irrigate, the sensor will override the controller and prevent irrigation from occurring. If the soil moisture is less than the preset range, irrigation will continue as normal. The hand held meter can also be used as a sensor to monitor soil moisture.

Figure 7.5 Gro-Point® Sensor

Locations of Soil Moisture Devices

A soil moisture monitoring site should be established in a part of the field that is indicative of the majority of the field conditions. Where two or more predominant soil types are present, more than one soil moisture site should be considered. Ideally, each distinct area will be managed separately.

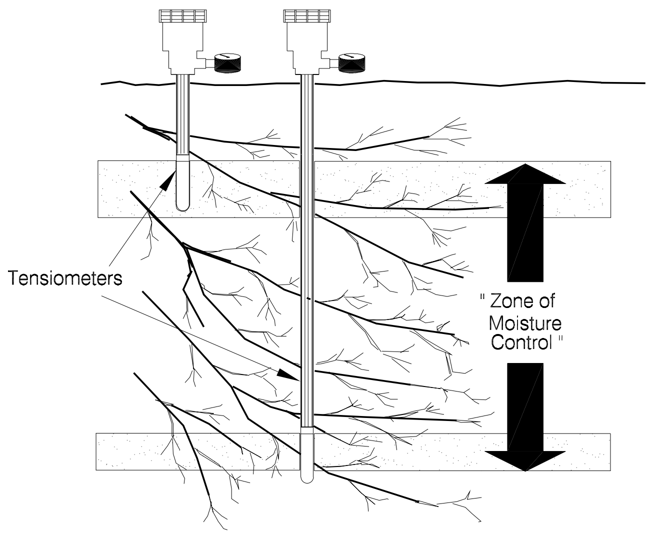


Figure 7.6 Location of Sensor in the Root Zone

Depending on the plant's maximum rooting depth and the soil type present, more than one sensor at a monitoring site may be required. All deep-rooted plants, such as fruit trees, should have two monitoring devices per site – one at 30 cm (12 in.), and the other at 60 cm (24 in.) (Figure 7.6).

The irrigation system should be scheduled using information from a representative area, not just the driest part of the field. Information on the best soil moisture monitoring locations for different system types is provided below.

Sprinkler System

For sprinkler systems on forage crops, the sensors should be located between the first and second lateral sets in the field, half way between sprinkler locations on the lateral. The second irrigation would be scheduled when the soil moisture level at this location has dried to the appropriate value. The number of sensors to be installed will depend on the rooting depth of the crop and the irrigation regime being followed (depth of irrigation).

For horticultural crops, such as apples, grapes and berries, sensors should be placed along the crop row but at a point approximately half way out into the canopy. Select a location that is at the mid-point between two sprinklers. Soil moisture should be monitored at the beginning of the irrigation set, half way in between the first and second laterals.

Trickle System

When operating a trickle system, the soil should be maintained at a higher soil moisture level than for sprinkler systems. Sensors should be placed about half the distance between the emission point and the outer perimeter of the wetted area formed by an emitter. Select a location that is between two emitters and in a region where plant root growth and water uptake are highest (Figure 7.7).

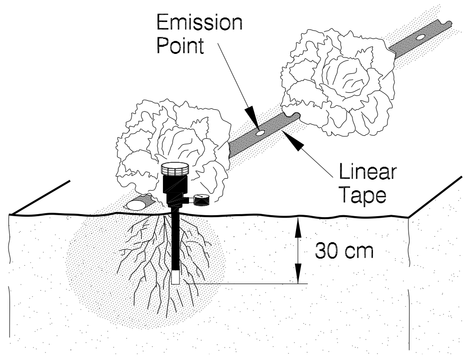


Figure 7.7 Location of Sensor along Drip Line

Other Sensor Location Options

Occasionally, due to improper installation or rocks near the ceramic cup, soil moisture sensors may give a higher reading than anticipated. Installing a second set of sensors near the first set provides a check for discrepancies.

Readings from sensors placed at the ends of laterals can be compared to readings from those in the centre or start of a lateral to determine if pressure readings in the line are affecting the amount of water reaching the crop.

Readings of Soil Moisture Sensors

Sensor reading should be taken every few days immediately after irrigation. As the soil dries, soil tension can change more quickly, and readings should be taken daily.

Soil moisture sensors read either volumetric soil water content as a percentage, or the soil water tension in centibars (cbars).

Volumetric Soil Moisture

Volumetric soil moisture is intuitively easy to understand. If the reading is high, the soil moisture is high. However, for readings to be useful, it needs to be related to some known conditions, e.g., knowing the volumetric soil moisture for the soil when the soil is at field capacity. Field capacity is the starting point for irrigation management decisions. Once field capacity is known, irrigation can be scheduled based on the percentage of field capacity that should be depleted. For trickle systems, the soil moisture should remain at about 75% of this value. For sprinkler systems, irrigation should be started when the moisture reaches 50% of field capacity.

Types of sensors: TDR (Moisture Point®) or TDT (Gro-Point®)

Soil Water Tension

Soil water tension is determined by how tightly water is held within the soil. Drier soils hold water more tightly. As the soil dries, the tension increases and as the soil is wetted the tension decreases.

Chapter 5 explained that different soils have different water holding capacities. Heavier soils hold water tighter and will therefore have a higher tension reading at 50% of field capacity than lighter soils. The tension readings can be converted to the amount of available water that has been depleted using Figure 7.1.

Types of sensors: tensiometer, electrical resistance blocks (Watermark)

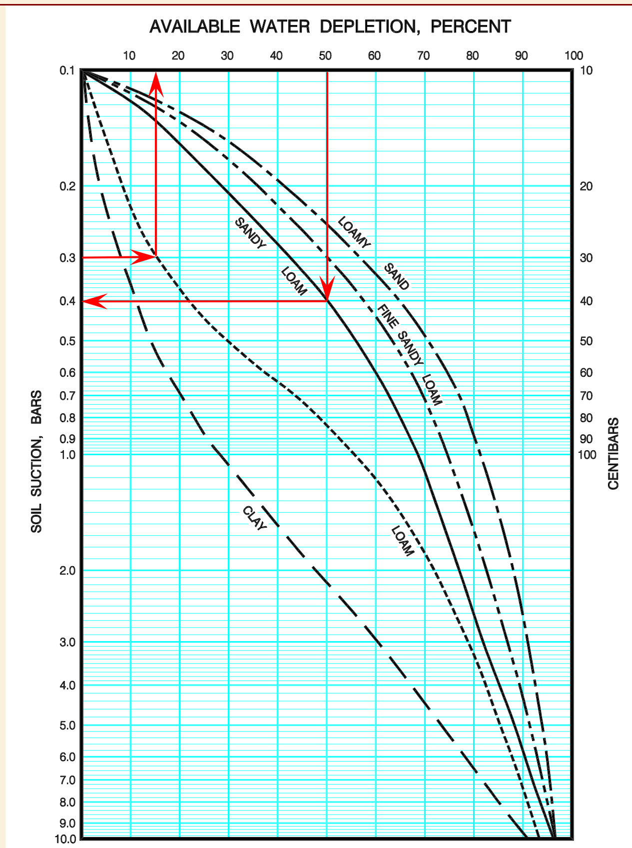
Example 7.1 Determination of Available Water Depletion

Question:

(a) An irrigation system in a sandy loam soil is scheduled to begin irrigation when the available water has been depleted by 50%. What will the reading on the sensor be?

(b) A sensor in a loam soil reads 30 cbars. How much has the available water been depleted?

Answer:



Using Figure 7.1,

(a) Irrigation should start when the sensor reads 40 cbars.

(b) 15% of the available water has been depleted

Scheduling Methods Using Soil Moisture Sensors

Soil moisture monitoring can be used to determine when to begin an irrigation and how long to irrigate, as well as provide a visual reference of soil moisture within the root zone. This method involves preparing a chart with the soil moisture tension readings over a specific period of time.

A sample soil moisture curve for sprinkler systems is shown in Figure 7.8. The chart shows a “saw-tooth” pattern in the soil moisture tension. An upward slope indicates when the soil is dry; and a downward slope indicates when the field is irrigated.

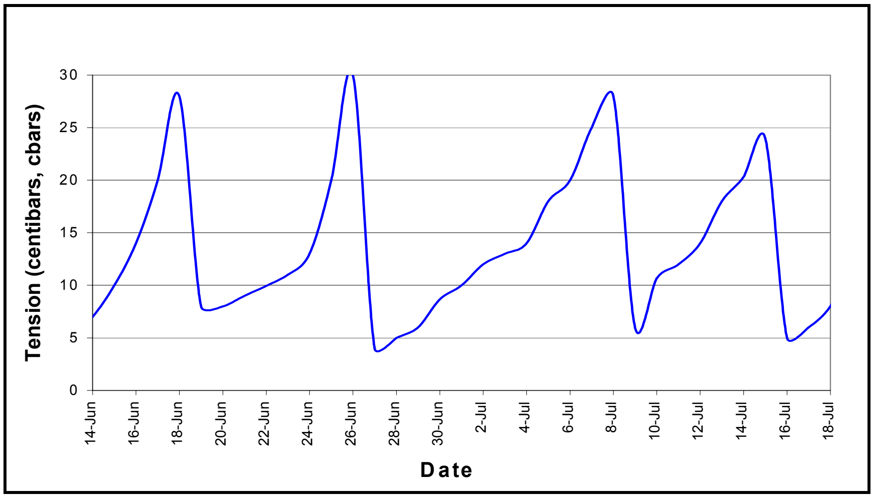


Figure 7.8 Soil Moisture Profile - Tensiometer Drying Curve

Irrigation started when the soil moisture reaches a “trigger level”. Figure 7.1 should be used to determine the trigger level. For very stony soils or crops with shallow rooting depth, a slightly lower trigger level is chosen to allow for some flexibility in management.

Drip/Trickle and Micro-Jet Systems

For drip/trickle and micro-jet systems, the crop is irrigated frequently (often daily), and requires the soil to be maintained at a moisture level about 80-90% of field capacity. Table 7.2 indicates the soil moisture tension reading required to maintain 15% depletion of the available water for various soils.

Table 7.2 Range of Soil Moisture for Drip/Trickle and Micro-Jet Systems

Soil Type	Soil Moisture Tension (cbars)	
	Low (wet)	High (dry)
sand	10	15
loamy sand	10	15
sandy loam	15	20
loam	25	30

For drip systems, the moisture level can be maintained by adjusting the length of time each zone is irrigated on a daily or weekly basis. If the soil is always wet or dry, reduce or increase the amount of time the zone is irrigated to make up for the soil moisture difference.

Sprinkler System

Delaying the start of an irrigation cycle may be the most practical method of scheduling sprinkler irrigation systems that are not automated. If the system is automated, the irrigation set time can be adjusted to match crop water needs.

Trigger Level

For sprinkler systems, it is convenient to maintain a set time of 8, 12 or 24 hours and use a soil moisture trigger level to indicate when irrigation should begin. To trigger an irrigation, 40 – 50% of the available soil moisture should have been removed from the soil. Table 7.3 gives minimum trigger levels for various crop's rooting depths and soil types.

Table 7.3 Soil Moisture Trigger Levels for Sprinkler Systems

Rooting Depth		Soil Type	Trigger Level [cbars]
[ft]	[cm]		
<1	<30	S – LS	15 – 20
		SL – L	25 – 35
2	60	S	20
		LS	25
		SL	30
		L	35
4	120	S	25
		LS	30
		SL	35
		L	40

Place the soil moisture device in the area irrigated by the first lateral as mentioned in the previous section. Turn on the first lateral when the soil moisture reaches the trigger level. The remainder of the crop is irrigated as usual. Wait for the soil moisture to reach the trigger level before beginning the next cycle.

For deep-rooted crops, both the shallow and deep readings should be taken into consideration. Plants obtain not only 40% of the moisture from the top 25% of the root zone, but also significant water from deeper roots. If soil moisture is adequate in a part of the root zone, then the amount of irrigation required to fill up the root zone can be reduced.

Rate of Change in Soil Moisture Readings

Another method of scheduling sprinkler systems is to watch the rate of change in soil moisture readings. As the soil dries, the rate of change in soil moisture readings increases. For example, it may take four days for the soil tension to go from 10 to 15 cbars, but only one day to go from 25 to 30 cbars. A sharp upward slope in the soil moisture curve indicates irrigation should be started soon. If the plot indicates a sharp upward slope, and the forecast is for hot dry weather, irrigation should take place in the next day or two. If the slope is shallow and the weather is cool, irrigation may be able to be held off for a number of days. The shallow soil moisture reading is usually used to determine the trigger level; however, if the crop has deep roots and there is plenty of soil moisture at depth (i.e., low tension readings), irrigation can be delayed past the shallow sensor trigger level. **Monitor soil moisture more frequently at high soil moisture tensions**.

Micro-Sprinkler System

A micro-sprinkler system is designed similar to a sprinkler system but because of the low application rates and frequent irrigations, the soil is not often filled up to field capacity. The soil moisture range available for operation is therefore much smaller. The soil should ***not*** remain as wet as soils being irrigated with drip systems, and should also ***not*** reach sprinkler trigger levels for deep-rooted crops.

For micro-sprinklers on a frequent schedule on a sandy soil, the upper limit of the soil moisture reading range should be about five cbars above that of a drip system (Table 7.2). The lower level remains the same.

When irrigating on a set irrigation interval, change the set time according to the soil moisture. Use the soil moisture readings to determine if the soil is wet or dry. If the soil remains too wet between irrigations, reduce the set time. Likewise, if the plants are becoming stressed, increase the set time. If the soil is constantly wet between irrigations, decrease the irrigation frequency to allow time for the soil to dry out a bit before the next irrigation. Table 7.4 summarizes irrigation scheduling techniques for various irrigation systems.

Table 7.4 Summary of Irrigation Scheduling

Irrigation System	Scheduling Method	Notes
Drip/Trickle/ Microjets	Set Time	▪ Daily irrigation ▪ Change the set time to maintain a constant soil moisture
Sprinkler	Set Time	▪ Monitor deeper soil moisture during irrigation ▪ Reduce or stop irrigation if the soil is wet
	Irrigation Cycle	▪ Monitor soil moisture readings daily or every couple of days ▪ Begin irrigation once the trigger level is reached
Micro-Sprinklers	Set Time	▪ Adjust the operating time of each zone to reflect soil moisture conditions but keep the irrigation interval the same.
	Irrigation Frequency	▪ Maintain the set time and lengthen or shorten the interval to maintain soil moisture at an optimum level

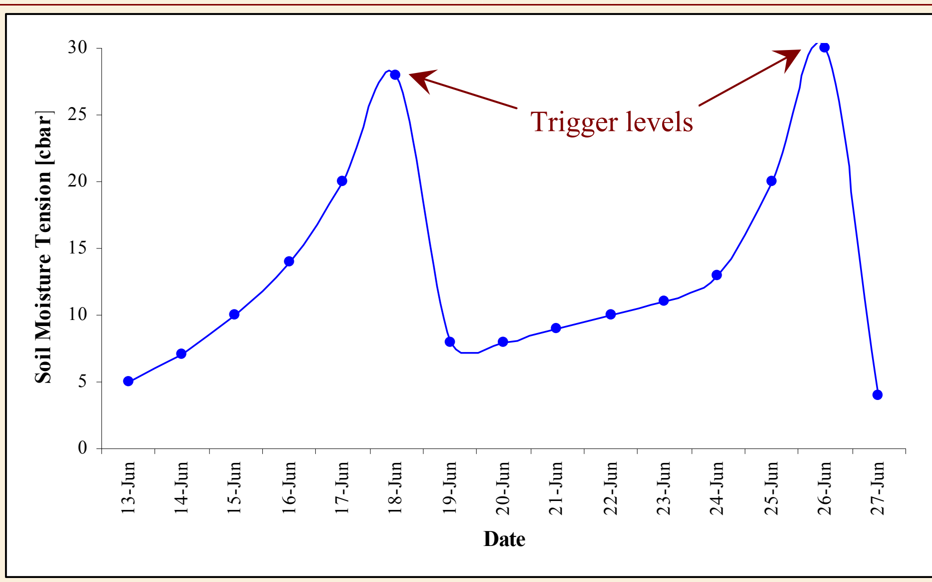
Example 7.2 Irrigation Scheduling Using a Tensiometer

Question: A drip system in a loam soil is scheduled to begin irrigation when the available water has been depleted by 15%, i.e., when the tensiometer reads 30 cbars. Record soil moisture tension readings once a day. Plot the readings against date to illustrate the concept.

Information:

Date	Reading [cbar]	Action
13 Jun	*5*	–
14 Jun	*7*	–
15 Jun	*10*	–
16 Jun	*14*	–
17 Jun	*20*	–
18 Jun	*28*	*Irrigate*
19 Jun	*8*	–
20 Jun	*8*	–
21 Jun	*9*	–
22 Jun	*10*	–
23 Jun	*11*	–
24 Jun	*13*	–
25 Jun	*20*	–
26 Jun	*30*	*Irrigate*
27 Jun	*4*	–

Answer:

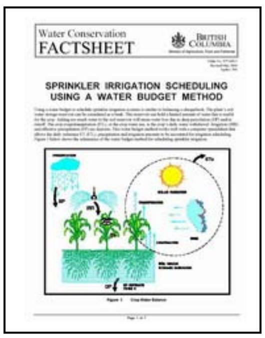


7.2 Climate Monitoring

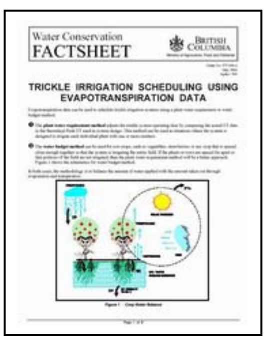
Climate Information on the Internet

Navigating Farmwest.com

1. Choose the climate station closest to you using the series of maps.
2. Choose the time period for the information to be summarized.
3. Access information about the crop's potential evapotranspiration over a given time period and the amount of effective precipitation added to the soil. The moisture deficit for the time period will be calculated for you.
4. Use Water Budget Method to schedule your irrigation. Factsheets on Water Budget Method are accessible through the link "How Does ET Help Me Schedule My Irrigation".


Water Conservation FACTSHEET

SPRINKLER IRRIGATION SCHEDULING USING A WATER BUDGET METHOD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TRICKLE IRRIGATION SCHEDULING USING EVAPOTRANSPIRATION DATA

Farmwest at www.farmwest.com is an agricultural website that provides production and climate information for farmers across B.C. The climate tab contains links to a number of options including evapotranspiration (ET) and precipitation information for irrigation scheduling.

The website allows users to obtain climate information by selecting the climate station closest to their location. A summary page is provided with real-time information on cumulative and daily reference ET (ET_o), precipitation and moisture deficit for any chosen time period up to the previous day.

ET_o on this website is calculated based on a reference grass crop of 10 to 15 cm tall. This ET_o can be adjusted to represent ET for a specific crop by using a crop coefficient.

Although Farmwest reports precipitation, rainfall patterns can vary over a region much more than ET. Having an on-site rain gauge will improve the accuracy of irrigation management using climate data. Farmwest reports effective precipitation as 75% of rainfall over 5 mm. The effective precipitation (EP) shown on Farmwest is always calculated using Equation 3.1. Therefore, during cool wet periods, EP could be low, resulting in a higher moisture deficit than what actually exists. Soil moisture monitoring should be done under these conditions to ensure that irrigation is only applied when necessary.

The five-day forecast on Farmwest is a useful tool for determining how often to monitor the data, and when the next irrigation should take place.

Information from Farmwest is useful when creating an irrigation schedule using climate data.

www.farmwest.com

Sprinkler Irrigation Scheduling Using a Water Budget Method

Trickle Irrigation Scheduling Using Evapotranspiration Data

On-Farm Collection of Climate Information

Having real-time climate data from the immediate area can be a huge benefit, including increased production and water savings. Climate data can help to decide:

- when and how much to irrigate
- when to plant
- when to apply fertilizers
- how to manage pest

The closer the climate station is to the operation, the more reliable the data will be. For example, precipitation varies considerably over an area, and the regional climate station at the nearest airport may not represent rainfall on the farm. The elevation and aspect (the direction the sloping land is facing) also affect temperatures and the amount of ET in the area. A climate station monitors temperature, evaporation and precipitation using one of the methods described below. Such station can be a significant financial investment while manual monitoring is time-consuming. These investments and efforts will be paid back by a number of benefits, e.g., increased farm production.

The climate data does not need to be collected daily. The time interval that is best for collecting information depends on the type of irrigation system, irrigation interval and the current weather. If the weather is cloudy and cool, there will be little change in ET from day to day. However, if it is hot and dry and it has been a few days since the last irrigation, checking ET and the forecast daily would be prudent.

Climate Stations

Figure 7.9 Davis Climate Station

There are many individual climate station packages available that provide information on crop production. Figure 7.9 shows an automatic climate station owned by MAFF in Abbotsford. Many types of weather stations available on the market can be found and compared on the Internet.

Farmwest.com also provides climate information from private climate stations that are linked to the Farmwest network.

www.farmwest.com, Expanding the Farmwest Climate Network

Evaporation Pans

Two types of pans are commonly used. Class A Pan is the standard one used by research facilities and climate stations where a standard method of measurement is essential. Galvanized washtubs are often used in situations where a simpler and less expensive method of collecting ET data is desired.

Class A Evaporation Pan

The Class A evaporation pan (Figure 7.10) is a universally used standard-sized pan with a diameter of 1.2 m and a depth of 250 mm. When installed, it is elevated 150 mm off the ground. The operating water level is 175 – 200 mm deep; therefore, the water level in the pan is kept 50 – 75 mm from the rim.

Figure 7.10
Class A Evaporation Pan

A stilling well located on the side of a Class A pan has a level sensor which is used to record water depths. The measurements can be taken automatically. This pan can be purchased with an automatic refill that fills the pan back to the 200-mm depth when necessary.

Galvanized Washtub

Figure 7.11 Galvanized Washtub

The galvanized washtub (Figure 7.11) is approximately 0.50 m in diameter and 0.25 – 0.30 m in depth. A tub with this depth is most desired. Since the tub is located in the field, a wire cage is placed over the tub to keep away birds and animals.

A ruler is attached to the tub to measure the water level. It is important to measure the water depth at the same place in the tub every time. This is to ensure the differences in water depths in the tub are due to evaporation and rainfall, not irregularities at the bottom of the tub. Mark the inside of the tub to indicate where measurements are to be made.

The water depth in the tub should be maintained between 50 – 75 mm from the rim of the tub. The maximum water depths should be marked on the side of the tub. After each irrigation or if the water level reaches the minimum prior to the next irrigation, the tub should be refilled to the full mark.

Location of Evaporation Pan

The location of an evaporation pan is very important for reliable estimates of evaporation. The tub should be placed near the field, but not on bare ground or next to areas with gravel or black top. These areas increase evaporation due to temperatures that are above normal. The pan should be raised 150 mm above the ground, levelled and firmly supported.

Moreover, the pan should not be placed under trees or near buildings where it will be shaded for part of the day. The vegetation within a 10-m radius of the tub should be kept mowed. An ideal location is a grassed area next to the irrigated area. The irrigation system should not add water to the pan. The conditions should be representative of what the crop is experiencing, taking into account wind, sunlight and temperature. Figure 7.12 shows a pan and a rain gauge located 30 m from the edge of an orchard.

Figure 7.12 Pan Location

Using Pan Data

The pan should be monitored daily or every other day during hot periods, and two or three times a week during cooler periods. Crop coefficients with Class A pans are used to convert ET to crop water use. Reference crop coefficients can also be used to adjust the crop coefficients using Table 3.4 or soil moisture information. Example 7.3 illustrates how data from an evaporation pan are used to determine ET.

➔ **Conversion of Crop Coefficients, Section 7.3**

Example 7.3 Determining Evaporation Using an Evaporation Pan

Worksheet 20 Determining Evaporation Using an Evaporation Pan

Information: Recording information from an evaporation pan. The maximum water depth is 200 mm, and the minimum before refill is 175 mm. Readings are taken two or three times a week.

Date	Water Depth [mm]	Evaporation [mm]	Moisture Deficit per Day [mm/d]
July 07, refill	*205*	*–*	*–*
July 10	*184*	*21*	*7*
July 12	*175*	*10*	*5*
July 12, refill	*198*	*–*	*–*
July 14	*185*	*13*	*6.5*

Sample Calculations – for period between July 07 to Jul 10:

Number of days between July 07 and July 10 = *3* [1] d

Evaporation between July 07 and July 10

= Water Depth on July 07 – Water Depth on July 10

= *205* [2] mm – *184* [3] mm

= $\boxed{21}$ [4] mm

Evaporation per Day = $\frac{\text{Evaporation}}{\text{No. of Days}}$

= $\frac{21 \text{ [4] mm}}{3 \text{ [1] d}}$

= $\boxed{7}$ [5] mm/d

Rain Gauges

Rain gauges are required to monitor the amount of precipitation that falls in the evaporation pan and on the irrigated field. The measured rainfall is subtracted from the water level reading in the pan to determine the amount of moisture evaporated.

Figure 7.13
Automated Rain Gauge

Rain gauges can be automated (Figure 7.13) or manual (Figure 7.14). The automated type measures rainfall automatically using a tipping bucket. These rain gauges require a datalogger to keep track of the rainfall, and are used at the packaged climate stations.

The manual type should be read and emptied after every rainfall event. To prevent the water from evaporating before a reading is taken, the gauge should be seeded with a few drops of light mineral oil. The mineral oil will create a floating layer on the surface of the rainwater.

Figure 7.1
Manual Rain Gauge

Atmometers

Figure 7.15 Atmometer

Atmometers, like evaporation pans, provide a direct reading of ET with no calculations involved. An atmometer (Figure 7.15) measures the amount of water evaporated through a porous ceramic surface. A reservoir of distilled water is supplied to the ceramic cup through a small suction tube. The water level can be read manually from a plastic tube on the side of the atmometer or automatically with a datalogger that keeps track of water removed from the reservoir.

The type of fabric covering the ceramic cup changes the evaporation rate. Unless there is clear information on what type of reference crop the atmometer reading represents, it should not be assumed that the atmometer readings are the same as ET_o or pan ET (ET_p). The crop coefficients need to be adjusted using soil moisture information to be able to calculate actual crop water use.

➔ **Conversion of Crop Coefficients, Section 7.3**

7.3 Crops and the Climate

The reference evapotranspiration (ET_o) is a measurement of the water use for that reference crop. For ET_o, grass is the reference crop. However, other crops may not use the same amount of water as grass due to changes in rooting depth, crop growth stages and plant physiology. The crop coefficient (K_c) takes into account the crop type and crop development to adjust the ET_o for that specific crop. The crop coefficient may change throughout the irrigation season depending on the development stage of the crop (Table 7.6).

Crop Water Use

To determine crop water use or crop evapotranspiration (ET_c), the ET_o is multiplied by the crop coefficient (K_c) (Equation 7.1).

Equation 7.1 Crop Evapotranspiration (ET_c) *Worksheet 21*

$$ET_c = ET_o \times K_c$$

where ET_c = crop evapotranspiration or crop water use [mm]
ET_o = reference ET [mm] (available from Farmwest.com)
K_c = crop coefficient from Table 7.5

If ET_o and/or K_c are obtained from other sources, make sure the values have been developed for the same reference crop.

Conversion of Crop Coefficients

To convert the crop coefficient for grass to a crop coefficient based on alfalfa or pan, use the factors shown in Table 7.5. ET collected from a pan or other sources can be converted to ET_o to be used in Equation 7.1 and with the K_c given in Tables 7.6 and 7.7.

➔ **Example 7.4**

Table 7.5 Conversion of Crop Coefficients or Other ET Sources to Grass Reference ET_o

K_c (alfalfa) =	K_c (grass) x 0.83
K_c (pan) =	K_c (grass) x 0.80
K_c (alfalfa) =	K_c (pan) x 1.04
ET_o =	ET_r (alfalfa) x 0.83
ET_o =	ET_p (pan) x 0.80

The factors shown are for semi-arid, moderately windy conditions. The values will be 10% less for humid and calm conditions, and 10% more for arid windy conditions. For most B.C.'s summer conditions, the factors in this table can be used.

Crop Water Use and Growth Stages

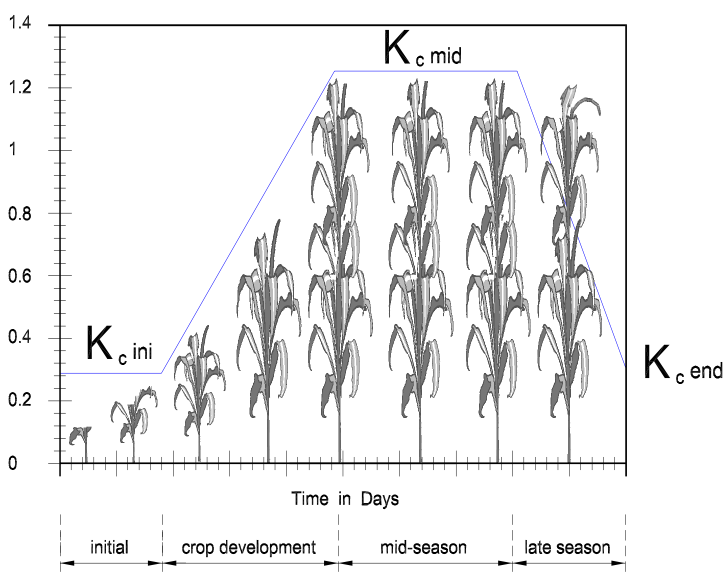


Figure 7.16 Crop Coefficients and Crop Development Stages

Crop growth periods can be divided into four distinct growth stages – **initial**, **crop development**, **mid-season**, and **late season** (Figure 7.16). The length of each of these stages depends on the climate, latitude, elevation and planting date. Local observations are best for determining the growth stage of the crop and which K_c values to use.

Annual Crops

During germination and establishment of annual crops, most ET occurs as evaporation from the soil surface. As the foliage develops, evaporation from the soil surface decreases and transpiration increases.

Perennial Crops

For perennial crops, a similar pattern may occur as the plant starts to leaf out, grow new shoots and develop fruit. The percentage of canopy cover determines ET rate. Maximum ET occurs when the canopy cover is about 60–70% for tree crops and 70–80% for field and row crops. The maximum canopy cover often coincides when sun radiation and air temperature are highest, leading to maximum ET during mid-season.

During the crop development stage, no K_c values are set. If irrigation is done during this period, choose a K_c value between $K_{c,ini}$ and $K_{c,mid}$. A similar approach should be taken during late season to obtain a K_c value between $K_{c,mid}$ and $K_{c,end}$. However, this time period may be much shorter and a jump directly from $K_{c,mid}$ to $K_{c,end}$ could be taken.

Table 7.6 provides a description of the various growth stages of plants. These stages can be used to select an appropriate K_c from Table 7.7.

Table 7.6 Stages of Crop Development

Stage	Indicators	Crop Coefficient
Initial	Planting date (or the start of new leaves for perennials) to 10% ground cover	$K_{c,ini}$
Crop Development	10% ground cover to effective full cover, about 60 – 70% coverage for tree crops and 70 – 80% for field and row crops	$K_{c,ini}$ – $K_{c,mid}$
Mid-Season	Effective full cover to maturity, indicated by yellowing of leave, leaf drop, and/or browning of fruit. This stage is long for perennials but relatively short for vegetable crops that are harvested for their fresh fruit.	$K_{c,mid}$
Late Season	Maturity to harvest – K_c could be high if the crop is irrigated frequently until fresh harvest, or low if the crop is allowed to dry out in the field before harvest.	$K_{c,mid}$ – $K_{c,end}$

Selection of a Crop Coefficient

The crop coefficients based on a grass ET_o in Tables 7.6 and 7.7 is a general guideline for B.C. The crops should be of average height, well-watered and well-managed.

Vegetable and Berry Crops

Table 7.7 provides K_c for forage vegetable and berry crops at different growth stages during the growing season. Crop coefficients for many vegetables may not be available, but they may be roughly estimated at the peak time of year using the ratio of bed width to canopy cover (Figure 7.17 and Equation 7.2). Comparing K_c of other crops similar in nature may also be useful.

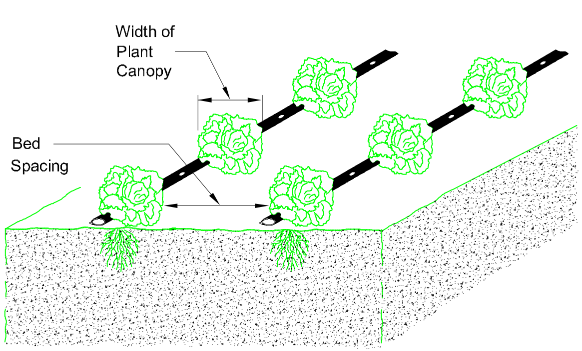


Figure 7.17 Vegetable Canopy Measurement

Equation 7.2 Crop Coefficients for Vegetable Crops *Worksheet 21*

$$K_c = \frac{W_p}{W_b}$$

where
K_c = crop coefficient
W_p = width of plant canopy [mm]
W_b = bed spacing [mm]

Table 7.7 Crop Coefficients for Forage, Vegetables and Berries

Crop	$K_{c,ini}$	$K_{c,mid}$	$K_{c,end}$	Crop	$K_{c,ini}$	$K_{c.mid}$	$K_{c,end}$
alfalfa	0.40	1.20	1.15	**onions**	0.70	1.05	0.95
asparagus	0.30	0.95	0.30	**pasture (grass)**	0.40	1.00	0.85
beans, green	0.50	1.05	0.90	**peas**	0.50	1.15	1.10
beets	0.50	1.05	0.95	**potato**	0.50	1.15	0.75
blueberries	0.40	1.00	0.75	**pumpkin**	0.50	1.00	0.80
broccoli	0.70	1.05	0.95	**radish**	0.70	0.90	0.85
cabbage	0.70	1.05	0.95	**raspberries**	0.40	1.20	0.75
carrots	0.70	1.05	0.95	**small vegetables**	0.70	1.05	0.95
cauliflower	0.70	1.05	0.95	**spinach**	0.70	1.05	0.95
cranberries	0.40	0.90	0.50	**strawberries**	0.40	1.05	0.70
celery	0.70	1.05	0.95	**squash**	0.50	0.95	0.75
cereal	0.30	1.15	0.25	**sweet corn**	0.30	1.15	0.40
corn	0.30	1.15	0.40	**sweet peppers**	0.70	1.05	0.85
cucumber	0.60	1.00	0.75	**tomato**	0.70	1.05	0.80
green ions	0.70	1.05	0.95	**tubers**	0.50	1.05	0.95
lettuce	0.70	1.00	0.95	**watermelon**	0.40	1.00	0.75

Alfalfa and Other Forage Crops

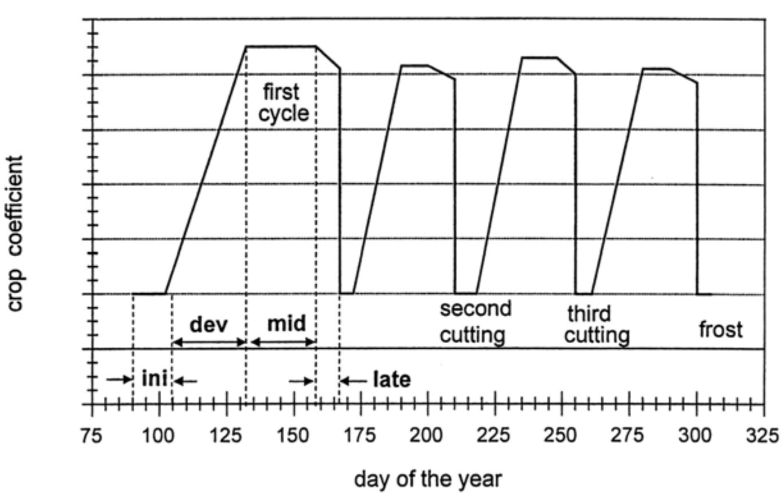


Figure 7.18 Growth Cycle for Forage Crops with more than One Cut (FAO, 2000)

Many forage or hay crops are harvested several times during the growing season. These crops therefore have a new growth stage cycle for each cut. Instead of one K_c curve for the entire season as in Figure 7.16, these crops have a series of curves to make up for the entire growing season (Figure 7.18). Immediately after a cut, K_c reverts to $K_{c,ini}$ and $K_{c,end}$ ends at the next harvest date.

The growth stages for the second and third cuts may be shorter than the first or the fourth one because the heat units available during the warmer summer months speed up the growth. Growth during the early spring and fall would be shorter. The crop coefficients for forage crops are shown in Table 7.7.

Apples and Grapes

Crop coefficients for tree fruits and grapes have been segregated into months as shown in Table 7.8. The absence of a cover crop will lower the crop coefficients shown. The cover crop draws water from the soil storage reservoir; therefore, increasing water use. If there is no cover crop or grass between the tree or plant rows, the crop coefficients will be about 10% lower in May, September and October, and 20% lower in June, July and August.

Table 7.8 Crop Coefficients for Tree Fruits and Grapes

Crop	May	Jun	Jul	Aug	Sep	Oct
Apples, Cherries and Pears with Cover Crops*						
Lower Mainland and Vancouver Island	0.70	0.90	1.00	1.00	0.95	0.75
Okanagan and Thompson	0.85	1.15	1.25	1.25	1.20	0.95
Kootenays	0.80	1.10	1.20	1.20	1.15	0.70
Apricots, Peaches and Other Stone Fruit with Cover Crops*						
Lower Mainland and Vancouver Island	0.90	1.00	1.00	1.00	0.95	0.80
Okanagan and Thompson	0.80	1.10	1.20	1.20	1.15	0.90
Kootenays	0.70	1.00	1.05	1.10	1.00	0.80
Grapes						
Lower Mainland and Vancouver Island	0.55	0.65	0.65	0.65	0.65	0.50
Okanagan and Thompson	0.50	0.70	0.80	0.85	0.80	0.70
Kootenays	0.45	0.70	0.85	0.90	0.80	0.70
* No cover crop, reduce values by	10%	20%	20%	20%	10%	10%

Example 7.4 Crop Water Use in Vernon

Worksheet 21 Crop Water Use

Question: The ET_p measured from an evaporation pan in a cabbage field in Vernon is 12 mm for three days in May (early season). The crop dimensions measured at this point of the season are: canopy width = 200 mm, bed spacing = 500 mm. What is the actual crop water use?

Information:

	Value	Ref	Unit
Evaporation	*12*	1	mm
Factor to convert ET_p (pan) to ET_o (grass) from Table 7.5	*0.80*	2	
Method 1. For crops listed in Table 7.7 or 7.8			
Crop coefficient (K_c) from Table 7.7 or 7.8	*0.70*	3	
Method 2. For other vegetable crops			
Width of planting canopy (W_p)	*200*	4	mm
Bed spacing (W_b)	*500*	5	mm

Calculations:

Step 1 Calculate grass reference evapotranspiration (ET_o)

$$ET_o = ET_p \times \text{Factor}$$

= *12* [1] mm x *0.80* [2]

= *10* [6] mm

Step 2 Method 2 is used to check the K_c value from Table 7.7.

Equation 7.2

$$K_c = \frac{W_p}{W_b}$$

= *200* [4] mm / *500* [5] mm

= *0.40* [7]

K_c calculated from Equation 7.2 is less than the value in Table 7.7. For this situation, the K_c value determined here is used instead of the one from Table 7.7 as it is deemed more accurate.

Answer:

Step 3 Calculate crop evapotranspiration (ET_c)

Equation 7.1

$$ET_c = ET_o \times K_c$$

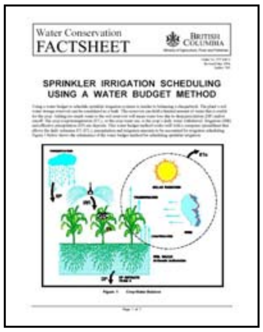
= *10* [6] mm x *0.40* [3 or 7]

= *4.0* [8] mm

ET trigger levels can also be determined by calculating the cumulative ET between irrigations where the soil moisture has reached the designated soil moisture trigger level. The cumulative ET is calculated from the first day of the last irrigation to the date the trigger level was reached. Although using ET calculations are a good guide for irrigation scheduling, it is important to monitor soil moisture as well.

7.4 Irrigation Scheduling of Sprinkler Systems

Water Budget Method


Water Conservation
FACTSHEET
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SPRINKLER IRRIGATION SCHEDULING
USING A WATER BUDGET METHOD

Sprinkler irrigation can be scheduled using a water budget method which is similar to balancing a chequebook. The plant's soil water storage reservoir can be considered as a bank. This reservoir can hold a limited amount of water that is useful for the crop. Adding too much water to the soil reservoir will mean water loss due to deep percolation (DP) and/or runoff. The crop evapotranspiration (ET_c), or the crop water use, is the crop's daily water withdrawal. Irrigation (IRR) and effective precipitation (EP) are deposits. This water budget method works well with a computer spreadsheet that allows the daily reference ET (ET_o), precipitation and irrigation amounts to be accounted for irrigation scheduling. This method can be done daily or over a time period.

Sprinkler Irrigation Scheduling Using a Water Budget Method

Equation 7.3 Current Soil Water Content *Worksheet 22*

$$CSWS = PSWS + EP + IRR - ET_c - DP$$

where
CSWS = current soil water storage (today) [mm]
PSWS = previous soil water storage (yesterday) [mm]
EP = effective precipitation since yesterday [mm]
IRR = irrigation since yesterday [mm]
ET_c = crop evapotranspiration [mm]
DP = deep percolation, water lost beyond the root zone [mm]

The water budget equation does not provide a factor for runoff as good irrigation management practices should eliminate runoff. Deep percolation (DP) is also assumed to be zero in most cases as it is difficult to measure and should be minimal if good irrigation practices are followed. If leaching is desired in some instances, then the amount of irrigation applied would need to exceed the soil water storage capacity.

Soil Water Capacity and Deficit

Measuring the existing soil moisture can be difficult. It is therefore easier to start the water budget after a thorough irrigation or rainfall that fills the entire root zone. The water budget would then start with a full storage value equal to the maximum soil water storage (SWS). If the soil is not full, the actual soil moisture may be determined using tensiometers or other soil moisture monitoring devices. The current soil water storage (CSWS) of the current day will be the previous soil water storage (PSWS) of the following day. Irrigation should start once the CSWS reaches the maximum soil water deficit (MSWD) – the maximum amount of water that can be depleted without stressing the plant.

Soil Moisture Monitoring, Section 7.1
Historical Climate Information for Irrigation Planning, Chapter 3
Soil Water, Chapter 5

Effective Precipitation (EP)

Precipitation data can be collected with an on-site rain gauge as described previously in this chapter, or obtained from climate stations. Daily climate data in real-time can be obtained from www.farmwest.com for various climate stations throughout B.C.

Dry Climate

In dry climate during the irrigation season, rainfall of less than 5 mm does not add any moisture to the soil reservoir as most of it is evaporated before entering the soil. Therefore, if rainfall is less than 5 mm, the effective precipitation (EP) is zero. If rainfall is over 5 mm, only 75% of it will be considered as EP. Refer to Equation 3.1 in Chapter 3.

➔ **Climate Information, Chapter 3**

Wet Climate

In wetter climates or periods of the year when there are many days of rainfall in succession, the summation of the total amount of rainfall can be added without using equation 7.1. For example:

Day	Rainfall [mm]
1	10
2	5
3	2*
4	7

* Not included in the summation as it is considered as a trace amount (<3 mm)

The total EP for this wet period would be 22 mm, the summation of all the rainfall events except for Day 3. Days with only a trace of rainfall (<3 mm) during a wet period would not be added.

Net Depth of Irrigation Water Applied (IRR)

The application rate and the length of time the irrigation system runs determines the net depth of irrigation water applied (IRR). Combining Equations 6.3 and 6.5 in Chapter 6 gives Equation 7.4 which determines the amount applied by a sprinkler irrigation system.

➔ **Assessment of Sprinkler Systems, Chapter 6**

Equation 7.4 Net Depth of Irrigation Water Applied (IRR)

$$IRR = \frac{227 \times Q \times T \times AE}{S_1 \times S_2 \times 100\%}$$

where
IRR = net depth of irrigation water applied [mm]
Q = sprinkler flow rate [US gpm]
T = irrigation time [hr]
AE = application efficiency [%]
S_1 = sprinkler spacing along lateral [m]
S_2 = lateral spacing [m]

Crop Evapotranspiration (ET_c)

Crop evapotranspiration (ET_c) can be determined by using Equation 7.1 with reference evapotranspiration (ET_o) and crop coefficient (K_c) being known. Daily ET_o rates are available at www.farmwest.com for various climate stations throughout B.C.

➔ **Climate Monitoring, Section 7.2**

➔ **Crops and the Climate, Section 7.3**

www.farmwest.com

> ***NOTE:*** ***Irrigation scheduling using the water balance method is based on estimation and should therefore be checked with soil moisture periodically. It is important to monitor soil water content in the field and compare the calculated soil water content to the actual measured water use once a week or every other week, and correct the calculated water balance when necessary.***

Example 7.5 Sprinkler Irrigation Scheduling – *Daily*

Worksheet 22 Sprinkler Irrigation Scheduling Using Water Budget Method

Question: The soil has a maximum soil water storage capacity of 110 mm. The maximum soil water deficit is 55 mm. Therefore, when 55 mm of moisture has been depleted from the soil, a total of 55 mm can be added by the irrigation system. At the beginning of the season, it has been determined that the soil reservoir is full, storing 110 mm of water. For the month of May, the crop irrigated has a crop coefficient of 0.75. Determine when the field should be irrigated.

Information:

Maximum soil water storage (SWS) capacity	*110*	mm
Maximum soil water deficit (MSWD)	*55*	mm
Crop coefficient (K_c)	*0.75*	

Analysis:

Nomenclature:

PSWS	=	Previous Soil Water Storage
EP	=	Effective Precipitation
IRR	=	Net Depth of Irrigation Water Applied
ET_o	=	Reference Evapotranspiration
K_c	=	Crop Coefficient
CSWS	=	Current Soil Water Storage

All units are in millimetres (mm) except for Date and K_c.

Date	PSWS	+	EP	+	IRR	–	ET_o	x	K_c	=	CSWS
May 1	*110*	+	*0*	+	*0*	–	*4.0*	x	*0.75*	=	*107*
May 2	*107*	+	*0*	+	*0*	–	*4.2*	x	*0.75*	=	*104*
May 3	*104*	+	*10*	+	*0*	–	*1.0*	x	*0.75*	=	*110*[1]
May 4	*110*	+	*0*	+	*0*	–	*3.8*	x	*0.75*	=	*107*
May 5	*107*	+	*0*	+	*0*	–	*4.0*	x	*0.75*	=	*104*
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
May 15	*59*	+	*0*	+	*0*	–	*4.5*	x	*0.75*	=	*56*[2]
May 16	*56*	+	*0*	+	*55*	–	*4.0*	x	*0.75*	=	*108*

[1] Even though the total water storage would be 113 mm, the maximum soil water storage can only be 110 mm. The rest of the water is therefore assumed to be lost due to deep percolation and/or runoff.

[2] The maximum depletion of 55 mm is reached, so irrigation should start.

Example 7.6 Sprinkler Irrigation Scheduling – *Over a Time Period*

Worksheet 22 Sprinkler Irrigation Scheduling Using Water Budget Method

Question: Use the same information as Example 7.5 except that the crop irrigated has a crop coefficient of 0.80 in June. Determine when the field should be irrigated.

Analysis:

Nomenclature:

PSWS = Previous Soil Water Storage
EP = Effective Precipitation
IRR = Net Depth of Irrigation Water Applied
ET_o = Reference Evapotranspiration
K_c = Crop Coefficient
CSWS = Current Soil Water Storage

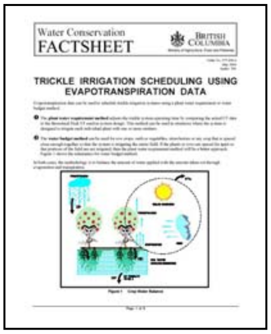
All units are in millimetres (mm) except for Date and K_c.

Date	PSWS	+	EP	+	IRR	–	ET_o	x	K_c	=	CSWS
June 2		+		+		–		x		=	*110*
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
June 12	*110*	+	*10*	+	*0*	–	*60*	x	*0.80*	=	*72*
There are still 17 mm of soil moisture before the MSWD is reached. Check the forecast and monitor ET_o and EP. If the forecast is for hot weather, check in the next three to four days. If the forecast is for cool weather, check in the next five to seven days.											
June 16	*72*	+	*0*	+	*0*	–	*15*	x	*0.80*	=	*60*[1]
June 17	*60*	+	*0*	+	*55*	–	*4.5*	x	*0.75*	=	*110*[2]

[1] The maximum depletion of 55 mm is very close, so irrigation should start.

[2] Even though the total water storage would be 118 mm, the maximum soil water storage can only be 110 mm. The rest of the water is therefore assumed to be lost due to deep percolation and/or runoff.

7.5 Irrigation Scheduling of Trickle Systems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TRICKLE IRRIGATION SCHEDULING USING EVAPOTRANSPIRATION DATA

Evapotranspiration data can be used to schedule trickle irrigation systems using a plant water requirement or water budget method. In both cases, the methodology is to balance the amount of water applied with the amount taken out through evaporation and transpiration.

Trickle Irrigation Scheduling Using Evapotranspiration Data

Plant Water Requirement Method

The plant water requirement method adjusts the trickle system operating time by comparing the actual ET data to the theoretical peak ET used in system design. This method can be used in situations where the system is designed to irrigate each individual plant with one or more emitters. The system operating time is determined by using a ratio of the peak design ET rate and the actual ET_c rate (Equation 7.5).

Equation 7.5 Zone Operating Time – Plant Water Requirement ***Worksheet 23***

$$Zone\ Operating\ Time = Maximum\ Zone\ Operating\ Time \times \frac{ET_c}{Peak\ ET}$$

Units:

Zone Operating Time	[hr/day]
Maximum Zone Operating Time	[hr/day]
ET_c	[mm]
Peak ET	[mm]

It is usually more convenient to adjust the irrigation schedule weekly. In this case the average daily ET_o for the week should be calculated and used to adjust the schedule for the following week. The weekly adjustment ensures the soil moisture depleted in the previous week is replaced. While not as effective as altering the schedule daily, a weekly schedule will adjust the irrigation schedule as the climate and crop change throughout the growing season. When performing a weekly adjustment, visit www.farmwest.com for a five-day forecast on daily ET_o.

Example 7.7 Trickle Irrigation Scheduling in Osoyoos

Worksheet 23 Trickle Irrigation Scheduling Using *Plant Water Requirement Method*

Question: A trickle system is irrigating an apple field in Osoyoos on a loam soil. The peak design evapotranspiration rate is 7.1 mm/day. Each plant has two emitters running at a flow rate of 2 L/hr per emitter. The design zone operating time is 10 hr/day. The plant water requirement is 40 L/day with a crop coefficient of 0.95 in July. The actual daily reference evapotranspiration data from July 20th to July 26th are collected from www.farmwest.com and shown in the table below. Determine the operating time for the next seven days.

Information:

Maximum zone operating time	10	1	hr/day
Peak ET	7.1	2	mm

Analysis:

Date	Daily ET_o [mm]	x	K_c	=	ET_c [mm]		Operating Time [hr/day]	
July 20	6.2	x	0.95	=	5.9	3	8.3	4
July 21	7.0	x	0.95	=	6.7	3	9.4	4
July 22	7.1	x	0.95	=	6.7	3	9.5	4
July 23	7.5	x	0.95	=	7.1	3	10	4
July 24	6.9	x	0.95	=	6.6	3	9.2	4
July 25	6.5	x	0.95	=	6.2	3	8.7	4
July 26	7.4	x	0.95	=	7.0	3	9.9	4
Weekly Total	48.6		–		46.4		–	
Average	6.9		–		6.6		9.3	

Sample Calculations (July 20):

Equation 7.5

$$\text{Zone Operating Time} = \text{Maximum Zone Operating Time} \times \frac{ET_c}{\text{Peak ET}}$$

$$= 10 \ [1] \ \text{hr/day} \times \frac{5.9 \ [3] \ \text{mm}}{7.1 \ [2] \ \text{mm}}$$

$$= 8.3 \ [4] \ \text{hr/day}$$

Answer:

An average operating time of 9.3 hr/day can then be used for the next seven days.

Water Budget Method

The water budget method can be used for row crops, such as vegetables, strawberries or any crop that is spaced close enough together so that the system is irrigating the entire field. If the plants or rows are spaced far apart so that portions of the field are not irrigated, then the plant water requirement method will be a better approach. ***This method should only be used with row crops that are spaced close together.***

The water budget method for trickle systems is basically the same as that for sprinkler systems except that a desired soil moisture range is set, and the operating time is determined using Equation 7.6.

Equation 7.6 Zone Operating Time – Water Budget Requirement

Worksheet 24

$$T = \frac{S_1 \times S_2 \times IRR \times 100\%}{Q \times AE}$$

where
T = irrigation time [hr]
IRR = net depth of irrigation water applied [mm]
Q = emitter flow rate [L/hr]
S_1 = emitter spacing along line [m]
S_2 = line spacing [m]
AE = application efficiency [%]

Trickle irrigation systems normally keep the soil moisture at a level higher than sprinkler systems to reduce stress on the plants. The maximum allowable depletion for trickle system scheduling is therefore less. The maximum allowable depletion should not exceed 25% of the maximum soil water capacity.

Example 7.8 Trickle Irrigation Scheduling

Worksheet 24 Trickle Irrigation Scheduling Using *Water Budget Method*

Question: A trickle irrigation system is irrigating vegetables with emitters spaced 0.3 m apart in a row, with the rows being 0.4 m apart. The crop is growing in a loam soil, and has a rooting depth of 0.4 m; therefore, the soil water storage (SWS) capacity is 70 mm. The crop coefficient is 0.80 in June and 0.95 in July. Each emitter has a flow rate of 1.0 L/hr. The system has an application efficiency of 92%

Information:

	Value	#	Unit
Emitter spacing (S_1)	0.3	1	m
Row spacing (S_2)	0.4	2	m
Maximum soil water storage (SWS) capacity	70	3	mm
Emitter Flow Rate (Q)	1.0	4	L/hr
Application efficiency (AE)	92	5	%

Calculation:

(a) The maximum soil water deficit (MSWD) for trickle systems is 25% of the SWS; therefore,

MSWD = 70 [3] **mm x 25%**

= 17.5 [6] mm

= **Net Depth of Irrigation Water Applied (IRR)**

(b) **Irrigation should start when the balance reaches:**

= 70 [3] mm – 17.5 [6] mm

= 52.5 [7] mm

(c) **Determine operating time**

Equation 7.6

$$T = \frac{S_1 \times S_2 \times IRR \times 100\%}{Q \times AE}$$

$$= \frac{0.3\ [1]\ \text{m} \times 0.4\ [2]\ \text{m} \times 17.5\ [4]\ \text{mm} \times 100\%}{1.0\ [4]\ \text{L/hr} \times 92\ [5]\ \%}$$

= 2.3 [8] hr

(d)

<u>Nomenclature:</u>

PSWS	=	Previous Soil Water Storage
EP	=	Effective Precipitation
IRR	=	Net Depth of Irrigation Water Applied
ET_o	=	Reference Evapotranspiration
K_c	=	Crop Coefficient
CSWS	=	Current Soil Water Storage

All units are in millimetres (mm) except for Date and K_c.

Date	PSWS	+	EP	+	IRR	–	ET_o	x	K_c	=	CSWS
June 24	*70*	+	*0*	+	*0*	–	*5*	x	*0.80*	=	*66*
June 25	*66*	+	*0*	+	*0*	–	*4.8*	x	*0.80*	=	*62.1*
June 26	*62.1*	+	*15*	+	*0*	–	*2*	x	*0.80*	=	*70*[1]
June 27	*70*	+	*0*	+	*0*	–	*4.2*	x	*0.80*	=	*66.6*
June 28	*66.6*	+	*0*	+	*0*	–	*6.6*	x	*0.80*	=	*61.3*
June 29	*61.3*	+	*0*	+	*0*	–	*5.4*	x	*0.80*	=	*57*
June 30	*57*	+	*0*	+	*0*	–	*5.3*	x	*0.80*	=	*52.8*[2]
July 1	*52.8*	+	*0*	+	*17.5*	–	*5.2*	x	*0.95*	=	*65.3*
July 2	*65.3*	+	*0*	+	*0*	–	*6.0*	x	*0.95*	=	*59.6*
July 3	*59.6*	+	*0*	+	*0*	–	*6.5*	x	*0.95*	=	*53.4*[2]
July 4	*53.4*	+	*0*	+	*17.5*	–	*5.6*	x	*0.95*	=	*65.6*
July 5	*65.6*	+	*4*	+	*0*	–	*4.5*	x	*0.95*	=	*65.3*

[1] Even though the total water storage would be 75.5 mm, the maximum soil water storage can only be 70 mm. The rest of the water is therefore assumed to be lost due to deep percolation and/or runoff.
[2] The desired depletion of 55 mm is reached, and is close to the maximum allowable deficit (52.5 mm), so irrigation should start.