Irrigation Systems

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An orchard irrigation system should be able to efficiently meet tree water demands. Efficient irrigation means that most of the applied water goes to the beneficial use of meeting tree water demands while little water is lost to deep percolation (water leaching below the crop root zone) or unused tailwater runoff.

Irrigation systems in prune orchards include *gravity surface systems* and *pressurized systems*. Surface systems include furrow and border check systems in which water is applied to the soil surface at the high end of the field and allowed to move down slope and infiltrate into the soil. Generally these systems do not apply the irrigation evenly and have significant irrigation runoff issues. Surface irrigation systems require a high degree of management to be operated efficiently. Pressurized systems, sprinkler irrigation and microirrigation, provide the operator with the capability to more carefully manage both quantity and timing of irrigation applications.

Many irrigation systems are suitable for use in orchards. There is no *best* system or method because land, water, energy and labor costs—in addition to soil and plant conditions—vary at each site. Irrigation systems are designed and operated to favor optimum crop yield and quality and efficient use of water and energy. However, other considerations may dominate both design and operational decisions. Total cost—which includes initial installation, operation and maintenance—substantially influences the choice of irrigation systems. Other factors to consider in choosing the system best suited to the orchard are soil physical and chemical characteristics, soil type / texture, slope of the land, frost hazard, and the cost and availability of water. Table 1 provides general guidelines and limitations to integrate all these factors in choosing an appropriate irrigation system.

Table 1. FACTORS TO CONSIDER IN SELECTING AN IRRIGATION SYSTEM (LIMITATIONS OF SYSTEMS)

Factors	Sprinkler system Solid set	Surface-flood systems Graded Border	Level Border	Furrow	Microirrigation systems Drip	Micro-sprinkler
Maximum slope (%)						
Irrigation direction	None	0.2-2.0	0.0	1.0-2.0	None	None
Cross-slope	None	0.2	0.2	6.0	None	None
Soil						
Water-intake (in/hr)						
Minimum	0.05	0.30	0.10	0.10	0.02	0.02
Maximum	3.00	2.00	2.00	3.00	None	None
Erosion hazard	Slight	Moderate	Slight	Severe	None	Slight
Saline-alkali hazard	Slight	Moderate	Slight	Severe	Moderate	Moderate
Water						
(TDS)*	Severe	Slight	Slight	Moderate	Slight	Slight
Suspended solids	Moderate	None	None	None	Severe	Severe
Rate of flow	Low	Moderate	Moderate	Moderate	Low	Low
Dissolved iron (1 ppm or greater)	None	None	None	None	Moderate to severe	Moderate
Climatic factors						
Temperature-controlled	Yes	Yes	Yes	Yes	No	No
Wind-affected	Yes	No	No	No	No	Yes
Irrigation efficiency (%)‡	75-85	65-80	70-80	65-80	80-95	80-95

* Total dissolved solids.
† Amortized capital cost plus operation and maintenance cost.
‡ Consumptive use + applied water = irrigation efficiency, assuming good to excellent management and design. High efficiencies in surface irrigation systems requires a tailwater return system.

The following sections provide more information on each type of irrigation system.

MICROIRRIGATION SYSTEMS

Microirrigation systems, surface drip, subsurface drip, and microsprinklers, are seeing increased use in orchards. These systems wet only a portion of the orchard floor. Generally, it is recommended that 40-60% of the orchard floor be wetted for good tree performance. Wetted

soil volume is often a better indicator of adequate wetting by the microirrigation system, but it is difficult to determine wetted soil volume without extensive soil moisture monitoring or excavating a backhoe pit.

Advantages of Microirrigation Systems

1. They provide a high degree of water application uniformity, often the highest of all irrigation systems in use. This means less applied water is required to meet tree evapotranspiration demand (ETc) compared to most surface irrigation systems.
2. They allow excellent control of the amount and timing of irrigation. Small, frequent irrigations can be applied to match the tree's water needs. Runoff is minimized because of the low application rates, and deep percolation losses can also be minimized if the correct amount of water is applied. The frequent irrigation provides an excellent balance between aeration and adequate soil moisture for optimal tree performance.
3. They can easily irrigate irregular terrain.
4. Weed growth is minimized since only a portion of the orchard floor is wetted.
5. Microirrigation systems are well suited to soils that have infiltration problems.
6. Chemigation, injection of fertilizers and other chemicals, is easily accomplished using microirrigation systems. Chemigation is often simpler, more efficient, and safer compared to other methods of chemical application.
7. Microsprinklers can provide limited frost protection.

Disadvantages of Microirrigation Systems

1. High initial cost of the systems.
2. Excellent management is needed to maintain the system since clogging of the emitters by physical particles, organic materials, and/or chemical precipitates may occur.
3. The irrigation water must be pressurized, resulting in energy costs. The required pressures are generally less than those needed for sprinkler systems, but they are higher than those of surface irrigation systems.
4. The system must be run more frequently than surface or sprinkler irrigation systems.
5. Cover crops cannot be grown year-around due to the localized nature of the water applications.
6. The microirrigation system can be damaged by insects and animals.

7 . Low application rate systems requiring long set times have been shown to be associated with increased incidence of brown rot in prune orchards.

8. Drip irrigation systems provided little to no frost protection.

Components and Considerations

The various types of microirrigation systems—microsprinkler, surface drip, and subsurface drip systems—are all made up of the same basic components. Figure1 shows the components of a typical microirrigation system. Generally, a microirrigation system consists of:

- a pump
- a flowmeter
- mainlines and submains
- drip or microsprinkler lateral lines
- valves
- filter(s)
- injection equipment

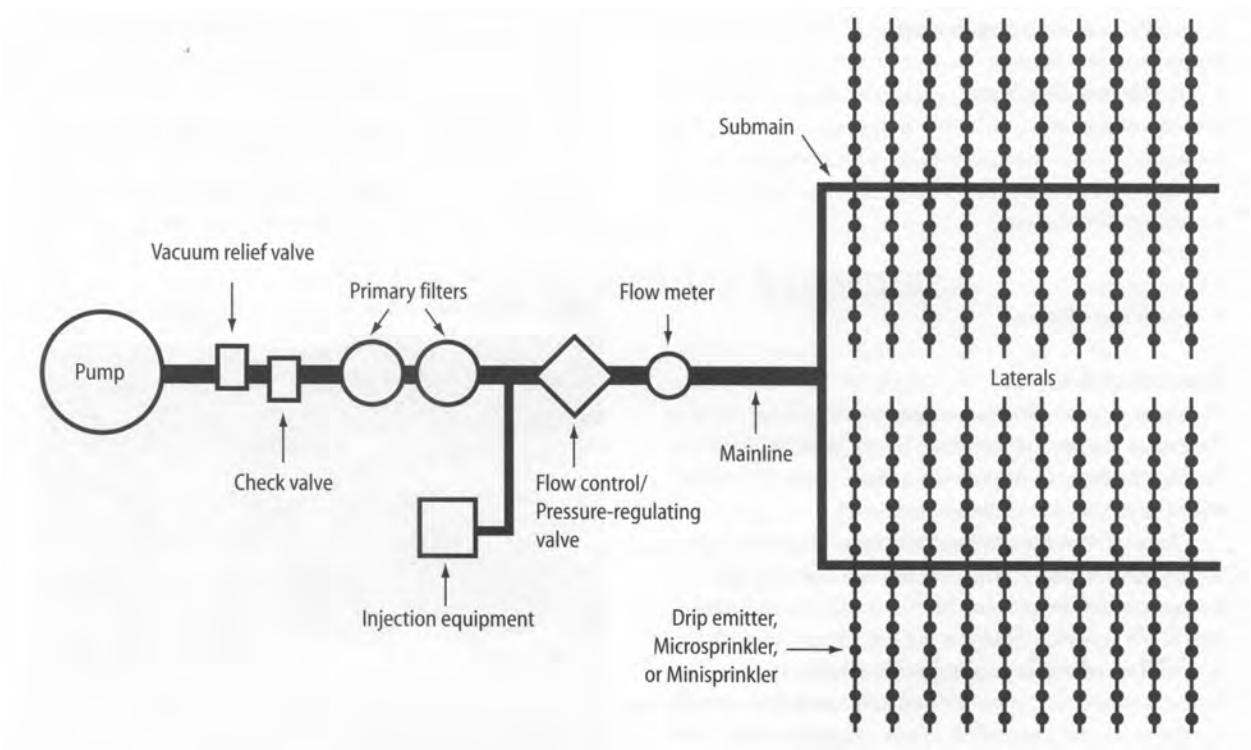

Figure 1. Components of a microirrigation system.

For the most part, microirrigation systems differ only in the emitter spacing, the type of emission device used, and the size of the components. The type of emitter used affects the size of the other components. For instance, microsprinklers, due to their higher application rates, generally require larger filters, mainlines, and submains as compared to drip systems.

In a microirrigation system for trees, the emitter spacing and discharge rate depend primarily on the tree spacing and water needs of the trees. The emission devices must be capable of supplying each tree with enough water during the peak water use periods to satisfy the evapotranspiration (ET) requirement. The peak prune ET for an average year in the Tehama area is 4.25 inches in a 15-day period or 0.28 inches per day (see Chapter XX**).** Frequent irrigation with microsprinklers can cause extended high humidity conditions, which increase the incidence of brown rot. To combat this threat higher output microsprinklers are used which allow a longer dry period between irrigations.

Following is a brief overview of the components and operation of a microirrigation system for trees.

Pumping Plant: It is important to select a pump and motor (or engine) that will deliver the correct pressure and flow rate at the highest possible efficiency. The microirrigation system designer determines the flow rate and pressure to be delivered by the pump, and the pump supplier uses this information to select the most efficient pump for a given system.

Flowmeters: It is very important that a flowmeter be part of the irrigation system. Knowing the flow rate is necessary for determining the amount of water being applied, which, in turn, is critical to efficient irrigation and scheduling. A propeller meter, which displays either the flow rate and/or total water applied, gives an accurate measurement.

Injection Equipment: Microirrigation is well suited to injecting chemicals such as soluble fertilizer. Various types of injection equipment, differential pressure tanks ("batch tanks"), venturi devices, electrically driven or water-driven pumps, and solutionizer machines can be

used, depending on the chemical applied, the accuracy level needed, and the injection rate required.

Valves: Valves are the control mechanisms of microirrigation systems. Several types are common: control valves, air/vacuum relief valves (which allow air to escape when the system is turned on and to enter when the system is shut down), and check valves (which prevent undesirable flow reversal). Pressure-regulating valves are important for maintaining a constant operating pressure in the system.

Filters: Selecting the appropriate filter requires consideration of water quality factors discussed earlier. Particulate matter (such as sand) in the water can be removed with vortex filters (frequently referred to as "sand separators"). Screen, disk, or sand media filters are also effective in removing particulate matter.

Organic matter such as algae or slime can be removed using screen, disk, or sand media filters. Since organic matter can quickly clog a screen or disk filter and is difficult to flush from the screen or disk elements, sand media filters are the usual choice for filtering surface waters containing algae and slime.

Both screen and media filters must be periodically backwashed. The pressure drop across the filter indicates when backwashing is required. Backwashing can be accomplished either manually or automatically, with automatic backwashing taking place either on a defined schedule or when the filter senses a pre-determined pressure drop across the filter and begins the backwash cycle. The water used to backwash is frequently discharged out of the system.

Mainlines and Submains: Main and submain pipes, usually made of PVC, deliver water to the lateral lines and emitters. The mains and submains must be sized carefully, with the cost of the pipe balanced against pressure losses caused by elevation differences across the orchard and friction as water moves through the pipe. A qualified microirrigation system designer should design the system.

Lateral Lines: Emitters are attached to tubing, or lateral lines, usually made of polyethylene. The length and diameter of the lateral lines to be used also depend on economics, balancing the tubing cost against pressure loss along the lateral. If the lateral lines are too long or the wrong diameter, the emitters may discharge water at different rates, resulting in non-uniform irrigation.

Emitters: The many different types of microirrigation emitters available can be grouped generally into above- or below-ground drippers and microsprinklers. Choosing which microirrigation emitter to use is dependent on some physical issues such as soil type and water quality, but also on some personal preferences of the manager. The following is a brief discussion of the pros and cons of each type of microirrigation emitter.

Surface drip: Surface drip irrigation, along with microsprinkler irrigation, is one of the most commonly-used microirrigation systems in tree crops. The drip emitters can either be "punched-in" to the drip tubing or formed integrally in the drip hose ("in-line" emitters) at a specific spacing by the manufacturer. Both single and double drip lines per tree row systems are used. Double drip lines are usually chosen to achieve a greater wetted area in the orchard and/or to increase the application rate of the drip system. Increasing the wetted area is frequently an issue in orchards with sandy soils that don't "sub" (move water laterally) well. Increasing the application rate of a drip system requires fewer operating hours to satisfy tree water needs. This gives the manager more time when the drip system is not operating to accommodate other orchard cultural practices such as spraying or mowing. A higher application rate may also allow the manager to more easily irrigate using off-peak power rates. Double-line drip systems are initially more expensive than single-line drip systems.

Subsurface drip: Orchard subsurface drip systems are most often in-line drippers in hard drip tubing, due to their longevity. Drip tape products are seldom used in orchard applications. Both single-line and double-line subsurface drip systems have been used successfully. Subsurface drip systems' installation depth is usually 10" to 24". The deeper depths are chosen to minimize surface wetting and rodent damage, but they make installation and repairs more difficult. Advantages of subsurface drip systems include reduced weed growth since the soil surface usually stays dry, reduced irrigation system damage during harvest or other cultural practices,

and the ability to irrigate almost anytime, even right up to harvest. The major disadvantages of subsurface drip are the difficulty in detecting clogging problems, rodent damage, the hazard of root intrusion into the emitters, and the crimping of the buried hose as primary roots expand. Root intrusion problems may be mitigated by using drip products with herbicide-impregnated emitters, but these products are more expensive.

Microsprinklers: Advantages of microsprinklers compared to drip systems include a larger wetted area, often a higher application rate, less susceptibility to particulate clogging since the flow path is larger, and easier visual inspection for clogging problems. While wetting a larger area may be a benefit for tree growth, it is a disadvantage due to increased weed growth. Another disadvantage of microsprinklers is a problem with insects entering or laying eggs in the microsprinkler orifice and causing them to clog. To prevent this, some microsprinklers have a "bug cap" which closes the orifice when the microsprinkler is not operating.

Operation and Maintenance

Microirrigation systems can apply irrigation water quite efficiently, but only if they are operated and maintained properly. Irrigation scheduling, determining when to irrigate and how much water to apply, is critical to operating the system efficiently. Effective irrigation scheduling requires knowing how much water the tree is using or has used since the last irrigation (the evapotranspiration or ET of the tree) and the application rate (how much water the irrigation system applies in a given period of time). Determining the application rate of a microirrigation system can be confusing at times so a procedure is discussed at the end of this section. Irrigation scheduling and application rate determine how long the microirrigation system should be run.

A virtue of a microirrigation system is its ability to deliver a uniform amount of water to each location it serves so that water is applied evenly over the field. But, because of pressure differences throughout the system and variability in emitter manufacture, even new systems may not apply water completely evenly. A carefully designed system can use pressure regulators in mains, submains, laterals or hoses or pressure-compensating emitters to overcome pressure differences and variation in emitter discharge rates.

While a well-designed system can deliver water with a high degree of uniformity, the system must be properly maintained to keep the application uniform. The principal cause of non-uniformity in microirrigation systems is emitter clogging by particulate or organic matter, lime precipitates, or iron precipitates. The following is a brief summary of the maintenance/clogging issue for microirrigation systems.

Particulate (silt and sand particles) clogging can be a problem with both groundwater and surface water sources, but it can often be prevented by good filtration. The microirrigation emitter manufacturers frequently specify a filtration level for their emitters.

Biological clogging is caused by bacterial slimes, algae, etc. which are either present in the irrigation water or may be growing in the irrigation system. Biological clogging is more frequently a problem with surface water supplies than when groundwater is used, but groundwater can have biological clogging problems associated with iron bacterial slimes. Maintenance practices to minimize biological clogging include injection of a biocide, such as chlorine, and good filtration. Serious biological clogging problems may require continuous chlorine injection at 2-5 ppm chlorine, measured at the end of the lateral line. Less severe problems may require only periodic chlorine treatments at 10-20 ppm every few weeks.

The chemical precipitate clogging hazard can often be anticipated by an irrigation water analysis. For example, irrigation water with a pH of 7.5 or higher and a bicarbonate level of 2 meq/l or greater has an increased hazard for calcium carbonate precipitate clogging. Waters with iron levels of 0.5–1.0 ppm or higher are at risk of iron precipitate clogging. Calcium carbonate precipitate clogging can be prevented or mitigated by lowering the water pH to 7.0 or less by injecting acid. Iron precipitate clogging is usually handled by storing the water in a reservoir, in which the iron precipitate is allowed to settle, prior to withdrawing the irrigation water. For more information see “Microirrigation of Trees and Vines” and “Maintaining Microirrigation Systems”.

The microirrigation system should be flushed regularly with mainlines, submains, and lateral lines all being flushed until the water runs clear. Fine particles passing the filters and any contaminants from the microirrigation system tend to accumulate at the end of the lateral lines and flushing removes them before they clog emission devices. Begin flushing on a 3 to 4 week interval. Adjust the flushing frequency depending on how dirty the system is: if flushing a lateral line clean takes more than a minute, consider flushing more frequently. If flushing a lateral line clean happens quickly (less than a minute), you can probably go longer between flushing events.

Irrigation Uniformity

How uniformly or evenly water is applied is also important to good irrigation water management. An irrigation system with uniform water application means each tree will receive nearly the same amount of water during an irrigation event. Uniformity can be measured as Distribution Uniformity (DU) or estimated if no measurements have been made. When dealing with microirrigation systems, Distribution Uniformity is often referred to as Emission Uniformity. A well designed and maintained microirrigation system typically has a DU of 85-90%. Non-uniform water distribution occurs from three main causes: emitter manufacturing variability, irrigation system pressure changes due to friction losses and elevation changes, and emitter clogging.

A field evaluation of a microirrigation system, in which a sampling of emitter discharges are measured, is the preferred method of determining the Distribution Uniformity. In some areas, mobile irrigation evaluation teams are available to do such evaluations. In most locales, there are consultants who will do such field evaluations. If a field evaluation has not been done, an assumption of the orchard's Distribution Uniformity will need to be made when determining the irrigation schedule. An example will be done below.

Determining the Application Rate of a Microirrigation System

Determining the application rate of microirrigation systems can be confusing because irrigation scheduling and tree water use information is usually presented in inches per day (in/day), while

discharge from microirrigation emitters is measured in gallons per hour (gph). The following may be helpful in determining required operating times for microirrigation systems.

The water use of the tree and the application rate of the emission device(s) determine how long drip and microsprinklers should be operated.

Drip Emitters and Microsprinklers

Step 1 in determining the required operating time is to convert the tree water use (ET) information (usually available in inches per day) to gallons per day of tree water use. The following formula may be used (or see Table 2):

Water use by the tree (gal/day)	=	Tree spacing (ft^2)	x	Tree water use (in/day)	x	0.623

Example: Tree spacing = 20 ft. × 20 ft. = 400 ft^2
Tree water use = 0.25 in./day (assumed)

Water use by the tree (gal/day) = 400 ft^2 x 0.25 in/day x 0.623
= 63 gal/day

Step 2 is to determine the application rate of the irrigation system in gallons per hour (gal/hr). For both drip emitters and microsprinklers, this requires determining: (1) the number of emission devices per tree, and (2) the discharge rate per emission device (gal/hr/emitter):

Application rate (gal/hr)	=	Number of emission devices per tree	×	Discharge rate per emission device (gal/hr/emitter)

Example: Drip emitters: 5 drip emitters per tree
Discharge rate per emitter: 1 gal/hr

Application rate (gal/hr.): = 5 emitters/tree x 1 gal/hr per emitter
= 5 gal/hr. per tree

Example: Microsprinklers: 1 microsprinkler per tree
Discharge rate per microsprinkler: 12 gal/hr.

Application rate (gal/hr): = 1 microsprinkler/tree x 12 gal/hr per microsprinkler
= 12 gal/hr. per tree

Step 3 is to determine the irrigation system operation time in hours per day. This requires using the tree water use (determined in Step 1), and the application rate (determined in Step 2). The following formula may be used (or see Table 3):

$$\text{Net hours of operation per day} = \frac{\text{Tree water use (gal/day)}}{\text{Application rate (gal/hr)}}$$

Example:

Drip emitters*:* Tree water use (gal/day) = 63 gal/day (Step 1)
Application rate (gal/hr) = 5 gal/hr (Step 2)
Net hours of operation per day = 63 gal/day ÷ 5 gal/hr
= 12.6 hrs/day

Microsprinklers*:* Tree water use (gal/day) = 63 gal/day
Application rate (gal/hr) = 12 gal/hr
Net hours of operation per day = 63 gal/day ÷ 12 gal/hr
= 5.3 hrs/day

Table 3 gives the same hours of operation for these examples.

Step 4 accounts for the microirrigation system uniformity, quantified as Distribution Uniformity or Emission Uniformity (same numerical value). Irrigation non-uniformity means that some areas of the orchard are receiving less water than others. To ensure that most of the orchard is adequately irrigated, additional water beyond that calculated in Step 1 needs to be applied. Therefore, the operation times calculated in Step 3 will need to be longer to apply more water. The irrigation system operation time, accounting for irrigation uniformity, can be calculated as follows:

$$\text{Gross hours of operation per day} = \frac{\text{Net hours of operation per day}}{\text{Distribution Uniformity (\%)}} \times 100$$

Example:

Drip emitters*:* Net hours of operation per day = 12.6 hrs/day (Step 3)
Distribution Uniformity (assume a well-designed, well-maintained system) = 85%
Gross hrs of operation per day = (12.6 hrs/day ÷ 85) x 100 = 14.8 hrs/day

Microsprinklers*:* Net hours of operation per day = 5.3 hrs/day (Step 3)
Distribution Uniformity (assume a well-designed, well-maintained system) = 85%
Gross hrs of operation per day = (5.3 hrs/day ÷ 85) x 100 = 6.2 hrs/day

An alternative method of determining the depth of applied water (inches) is to monitor the flow meter (if available) at the pump. The following formula can then be used:

$$\text{Applied depth of water (inches)} \quad \frac{\text{Pump discharge (gpm)} \times \text{Irrigation time per set (hrs)}}{449 \times \text{Acres irrigated per set}}$$

For flow meters without an instantaneous, gpm readout, use the flow meter's totalizing readout. Keep track of the total flow change during a recorded period of time to determine the average gpm flow rate. This is often more accurate than using the instantaneous flow meter indicator.

Frequency of Irrigation

Determining how often to irrigate with a microirrigation system considers a combination of microirrigation system capacity concerns and soil/tree parameters. During peak ET periods, most drip irrigation systems are designed to operate daily to meet ET demands. Microsprinkler systems, which generally have a higher application rate than do drip systems, are usually operated with multiple days between irrigations. Frequently, 3 or 4 days between irrigations is common for microsprinkler systems during peak ET periods. Microsprinkler irrigation duration should be more than just a few hours. Short irrigation events with microsprinklers result in only the surface soil being wetted. Particularly in young orchards, this shallow water may be lost to

evaporation and not be available for tree uptake. Deeper penetration of irrigation water is desirable and this is often achieved by longer irrigation events. Soil moisture monitoring is helpful both before and after irrigation.

Table 2. Prune water use (gallons/day) for various plant spacing and tree water use (in/day).

Tree spacing (ft^2)	Tree Water Use (in/day)						
	0.05	0.1	0.15	0.2	0.25	0.3	0.35
100	3.1	6.2	9.4	12.5	15.6	18.7	21.8
150	4.7	9.4	14.0	18.7	23.4	28.1	32.7
200	6.2	12.5	18.7	24.9	31.2	37.4	43.6
250	7.8	15.6	23.4	31.2	39.0	46.8	54.5
300	9.4	18.7	28.1	37.4	46.8	56.1	65.5
350	10.9	21.8	32.7	43.6	54.5	65.5	76.4
400	12.5	24.9	37.4	49.9	62.3	74.8	87.3
450	14.0	28.1	42.1	56.1	70.1	84.2	98.2
500	15.6	31.2	46.8	62.3	77.9	93.5	109.1

Tree spacing (ft^2) = row spacing (ft) × tree spacing with the row (ft)

Table 3. Hours of operation per day for various application rates (gal/hour) and tree water use (gal/day).

Tree Water Use (gal/day)	**Application Rate (gal/hr)**										
	1	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
5	5.0	2.5	1.3								
10	10.0	5.0	2.5	1.7	1.3	1.0					
15	15.0	7.5	3.8	2.5	1.9	1.5	1.3	1.1			
25		12.5	6.3	4.2	3.1	2.5	2.1	1.8	1.6	1.4	1.3
50			12.5	8.3	6.3	5.0	4.2	3.6	3.1	2.8	2.5
75			18.8	12.5	9.4	7.5	6.3	5.4	4.7	4.2	3.8
100				16.7	12.5	10.0	8.3	7.1	6.3	5.6	5.0
125				20.8	15.6	12.5	10.4	8.9	7.8	6.9	6.3
150					18.8	15.0	12.5	10.7	9.4	8.3	7.5

SPRINKLER IRRIGATION SYSTEMS

Sprinkler irrigation can be an excellent method of irrigating tree crops. Solid-set sprinklers and hand-move sprinklers are the most common types of sprinkler systems used in prunes. When properly designed, sprinkler systems can apply water uniformly and when properly managed, they can be efficient.

Advantages of Sprinkler Systems

1. Sprinkler systems can apply water uniformly when they are well designed. This ensures that each tree receives nearly the same amount of water.
2. Permanent set sprinkler systems can be easily operated, lending themselves well to automation if desired.
3. Sprinkler systems are full coverage irrigation systems. This takes advantage of the full orchard soil volume to store soil moisture and allows use of a cover crop throughout the season.
4. Permanent set sprinkler systems are the best of all irrigation systems in providing frost protection.
5. Permanent set sprinklers systems require less maintenance compared to microirrigation systems.

Disadvantages of Sprinkler Systems

1. Wetting the entire orchard floor requires more extensive weed control as compared to microirrigation systems.
2. During orchard establishment, when trees are not at full canopy, irrigation efficiency may be reduced due to evaporation from bare soil surfaces.
3. Hand-move sprinkler systems require significant labor to move pipelines.
4. High volume sprinkler irrigation systems have been shown to be associated with increased incidence of brown rot in prune orchards.
5. Permanent set sprinkler systems can be the most expensive of all irrigation systems used in orchards.

Operation of Sprinkler Irrigation Systems

To be efficient, sprinkler irrigation systems must be operated on the correct irrigation schedule. This means that the correct amount of water is applied when the tree needs it. To accomplish this, information on tree water needs (see Chapter XX) and on the sprinkler application rate is required. Tree water needs, often referred to as the tree evapotranspiration (ET), are most often provided in inches of water use per day (in/day) and are available from a variety of sources. Sprinkler application rate is determined in inches of applied water per hour (in/hr). The tree ET (in/day) and the sprinkler application rate (in/hr) are in similar units so it is easy to determine the hours of application required to replace the soil water used by the trees since the last irrigation.

The following provides further information on sprinkler application rate and application uniformity.

Application Rate

The sprinkler system application rate, usually measured in inches per hour (in/hr), is determined from the sprinkler nozzle size, the system's operating pressure, and the spacing of the sprinklers. The discharge rate (gallons per minute - gpm) of a sprinkler head is determined by the first two of the above factors - sprinkler nozzle size and the operating pressure at the sprinkler.

Table 4 shows the sprinkler discharge (gpm) for various nozzle sizes and operating pressures. The nozzle size is frequently engraved on the side of the nozzle or it can be determined by testing the opening with drill bits of known size. The operating pressure can be determined by placing a pitot tube (available at most irrigation supply stores) screwed on to a pressure gauge into the water stream just outside the nozzle opening.

The sprinkler discharge rate can also be quickly determined by using a short length (approximately 4 ft.) of garden hose, a 5-gallon bucket, and a stop watch. By placing the hose over the nozzle and directing the water into the bucket, and then timing how long it takes water to fill the bucket; the discharge rate from the sprinkler can be determined.

For example, if it takes 100 seconds to fill the 5-gallon bucket, the sprinkler discharge rate is 3 gallons per minute (gpm).

300 ÷	Time to fill a 5-gallon bucket (seconds)	=	Sprinkler discharge rate (gpm)

$$300 \div 100 \text{ seconds} = 3 \text{ gpm}$$

Table 4. Sprinkler discharge rate (gallons per minute - gpm) for various nozzle sizes (inches) and pressures (psi).

	Nozzle Size (in)										
psi	**3/32**	**7/64**	**1/8**	**9/64**	**5/32**	**11/64**	**3/16**	**13/64**	**7/32**	**15/64**	**1/4**
20	1.17	1.60	2.09	2.65	3.26	3.92	4.69	5.51	6.37	7.32	8.34
25	1.31	1.78	2.34	2.96	3.64	4.38	5.25	6.16	7.13	8.19	9.32
30	1.44	1.95	2.56	3.26	4.01	4.83	5.75	6.80	7.86	8.97	10.21
35	1.55	2.11	2.77	3.50	4.31	5.18	6.21	7.30	8.43	9.69	11.03
40	1.66	2.26	2.96	3.74	4.61	5.54	6.64	7.80	9.02	10.35	11.79
45	1.76	2.39	3.13	3.99	4.91	5.91	7.03	8.30	9.60	10.99	12.50
50	1.85	2.52	3.30	4.18	5.15	6.19	7.41	8.71	10.10	11.58	13.18
55	1.94	2.64	3.46	4.37	5.39	6.48	7.77	9.12	10.50	12.15	13.82
60	2.03	2.76	3.62	4.50	5.65	6.80	8.12	9.56	11.05	12.68	14.44
65	2.11	2.88	3.77	4.76	5.87	7.06	8.45	9.92	11.45	13.21	15.03
70	2.19	2.99	3.91	4.96	6.10	7.34	8.78	10.32	11.95	13.70	15.59
75	2.27	3.09	4.05	5.12	6.30	7.58	9.08	10.66	12.32	14.19	16.14

Whether the sprinkler operating pressure and Table 4 are used or the bucket / stopwatch method, measurements should be taken at various locations within the orchard. As pressure varies within the orchard, so will the sprinkler discharge. It will be a management decision whether to select irrigation set times to adequately irrigate the orchard section(s) receiving the least water, or to irrigate based on the orchard's average sprinkler discharge rate.

Determining the application rate (in/hr) is easy once the discharge rate of the sprinkler (gpm) and the sprinkler spacing are known. The following equation can be used:

$$\text{Application Rate (in/hr)} = \frac{96.3 \text{ x Sprinkler Discharge (gpm)}}{\begin{pmatrix}\text{Sprinkler Spacing} \\ \text{Along Row (ft.)}\end{pmatrix} \text{ x } \begin{pmatrix}\text{Sprinkler Spacing} \\ \text{Across Row (ft)}\end{pmatrix}}$$

For example, if the sprinkler discharge rate is 1.0 gpm and the sprinkler spacing is 48 ft. along the tree row and 20 ft. across the tree row, the application rate is 0.1 in/hr.

$$\text{Application Rate} = 96.3 \text{ x } 1.0 \text{ gpm} \div (48 \text{ ft. x } 20 \text{ ft.}) = 0.1 \text{ in/hr}$$

Table 5 can also be used to determine the sprinkler system application rate. The sprinkler area in square feet (ft^2) is determined by multiplying the sprinkler spacing along the row (ft.) times the sprinkler spacing between rows (ft.). For the previous example, the sprinkler area would be 20 ft. x 48 ft. = 960 ft^2. Looking in Table 2 under 960 ft^2 and a sprinkler discharge rate of 1.0 gpm, gives the same sprinkler application rate of 0.1 in/hr.

Table 5. Average application rate for various sprinkler discharge rates(gpm) and areas of coverage (ft^2).

	Sprinkler Discharge Rate (gpm)							
Sprinkler Area (ft^2)	**0.75**	**1.00**	**1.25**	**1.5**	**1.75**	**2.00**	**2.25**	**2.5**
500	0.14	0.19	0.24	0.29	0.34	0.39	0.43	0.48
550	0.13	0.18	0.22	0.26	0.31	0.35	0.39	0.44
600	0.12	0.16	0.20	0.24	0.28	0.32	0.36	0.40
650	0.11	0.15	0.19	0.22	0.26	0.30	0.33	0.37
700	0.10	0.14	0.17	0.21	0.24	0.28	0.31	0.34
750	0.10	0.13	0.16	0.19	0.22	0.26	0.29	0.32
800	0.09	0.12	0.15	0.18	0.21	0.24	0.27	0.30
850	0.08	0.11	0.14	0.17	0.20	0.23	0.25	0.28
900	0.08	0.11	0.13	0.16	0.19	0.21	0.24	0.27
950	0.08	0.10	0.13	0.15	0.18	0.20	0.23	0.25
1000	0.07	0.10	0.12	0.14	0.17	0.19	0.22	0.24
1050	0.07	0.09	0.11	0.14	0.16	0.18	0.21	0.23
1100	0.07	0.09	0.11	0.13	0.15	0.18	0.20	0.22
1150	0.06	0.08	0.10	0.13	0.15	0.17	0.19	0.21
1200	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
1250	0.06	0.08	0.10	0.12	0.13	0.15	0.17	0.19
1300	0.06	0.07	0.09	0.11	0.13	0.15	0.17	0.19
1350	0.05	0.07	0.09	0.11	0.12	0.14	0.16	0.18
1400	0.05	0.07	0.09	0.10	0.12	0.14	0.15	0.17
1450	0.05	0.07	0.08	0.10	0.12	0.13	0.15	0.17
1500	0.05	0.06	0.08	0.10	0.11	0.13	0.14	0.16
1550	0.05	0.06	0.08	0.09	0.11	0.12	0.14	0.16
1600	0.05	0.06	0.08	0.09	0.11	0.12	0.14	0.15

When designing a sprinkler irrigation system, it is often difficult to choose an application rate. A major objective is to minimize runoff from the orchard. Ideally, water should soak in near where it lands. The infiltration rate of the soil is not easy to determine since it changes during an irrigation and may change across the season. During an irrigation event, the infiltration rate initially starts out at the highest rate and decreases during the irrigation until a relatively constant, final infiltration rate is reached (see fig. 2). This final infiltration rate should

be equal to or greater than the sprinkler application rate so that no runoff occurs. Often the best guidance for choosing a sprinkler application rate can be made by seeing what has worked on other orchards in the area with similar soil conditions, slope, management, etc.

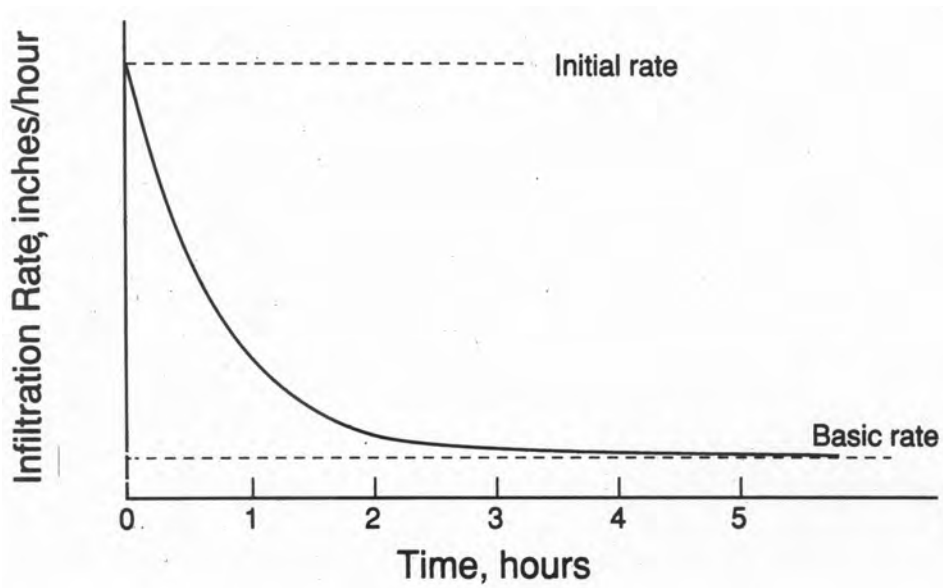

Fig. 2. Typical infiltration rate curve showing high infiltration rate at the beginning of the irrigation decreasing to a lower, constant final infiltration rate.

When designing a sprinkler irrigation system, it is preferable to have the application rate chosen correctly at the design stage, but nozzle sizes can be retrofitted if needed. It is important to remember though that it is better to over-estimate the application rate and later decrease nozzle sizes. This is because underground piping, pump sizing, etc. are all based on the flow rate of the system. If larger sprinkler nozzles are later retrofitted to the system, it is likely that the piping and pump capacity will be too small; resulting in inadequate pressure in the retrofit system.

An alternative method of determining the depth of applied water (inches) during an irrigation is to monitor the flow meter (if available) at the pump. As mentioned earlier in this chapter, the following formula can then be used to estimate the applied water using flow meter readings:

$$\text{Application Rate (in/hr)} = \frac{\text{Pump discharge (gpm)}}{449 \text{ x Acres being irrigated}}$$

For flow meters without an instantaneous, gpm readout, use the flow meter's totalizing readout. Keep track of the total flow change during a recorded period of time to determine the average gpm flow rate. This is often more accurate than using the instantaneous flow meter indicator.

Determining Irrigation Set Time

Once the sprinkler system application rate has been determined, the irrigation set time (hrs.) can be chosen in order to replace the soil water depleted since the last irrigation plus any irrigation inefficiencies. The soil water depletion can be estimated by evapotranspiration (ET) techniques or by soil moisture monitoring (see Chapter X). Since no irrigation is 100% efficient, additional irrigation water would need to be applied to ensure adequate irrigation. Efficiencies of 75-85 % are desirable for solid-set sprinkler systems.

The *Desired Irrigation Amount (inches)* is therefore:

$$\text{Desired Irrigation Amount (in)} = \text{Soil Moisture Depletion (in)} \div \text{Irrigation Efficiency (\%)} \times 100$$

and

The *Irrigation Set Time (hrs.)* is :

$$\text{Irrigation set Time (hrs)} = \text{Desired Irrigation Amount (in)} \div \text{Sprinkler Application Rate (in/hr)}$$

For example:

Given: Interval since last irrigation = 10 days
Estimated soil moisture depletion = 2.0 inches (from ET information)
Sprinkler application rate = 0.1 in/hr
Irrigation Efficiency = 80%

$$\text{Desired irrigation amt.} = 2.0 \text{ in.} \div 80 \times 100 = 2.5 \text{ in}$$

and

$$\text{Irrigation set time} = 2.5 \text{ in.} \div 0.1 \text{ in/hr} = 25 \text{ hrs}$$

Irrigation Uniformity

How uniformly or evenly water is applied is also important to good irrigation water management. A sprinkler irrigation system that is uniform in water application means that each tree will receive the same amount of water during an irrigation event. No tree will get too much water or too little water. Potential irrigation efficiency can be estimated by measuring the Distribution Uniformity of a sprinkler system. Irrigation uniformity is quantified by field-measured catch can tests. Mobile irrigation evaluation teams or private consultants can perform this test.

A single sprinkler head does not apply water evenly over the area it wets. Fig. 3 shows the pattern of water distribution for a typical impact sprinkler head. Note how some areas get more water applied to them than do others. In order to make the water application more uniform, the patterns from adjacent sprinklers are overlapped. This is illustrated in fig. 4. This overlapping of sprinkler patterns is advantageous because it makes the water application more uniform, but it has the disadvantage of increasing the application rate. To see this, examine Table 5. For a particular sprinkler discharge rate, say 1.5 gpm, as the sprinkler area decreases (closer sprinkler spacing); the application rate increases. Thus, closing up the sprinkler spacing may increase irrigation uniformity, but it can also increase the application rate to the point where runoff may become a problem. A second obvious disadvantage of closing up sprinkler spacing is the added cost of more sprinkler heads and the increased size of pipe supplying the sprinklers. Design of a good sprinkler system is therefore a "balancing act" of choosing an acceptable application rate and achieving good irrigation uniformity.

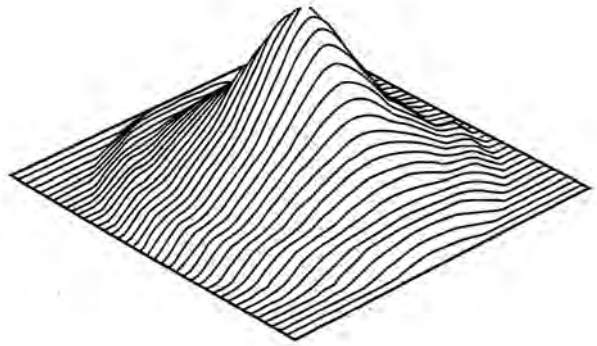

Fig. 3. Typical distribution pattern of a single impact sprinkler. The sprinkler head located in the center of the plot.

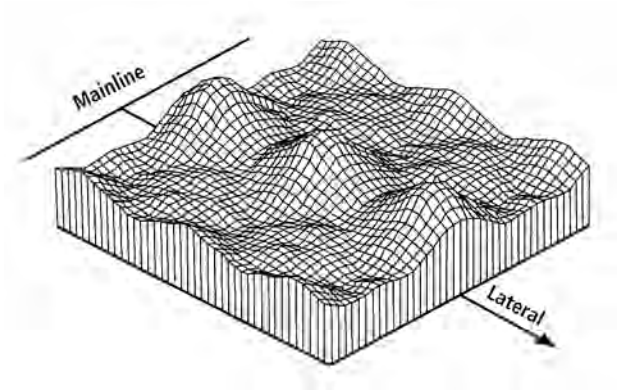

Fig. 4. Water distribution pattern for overlapped impact sprinklers. Sprinkler heads located along lateral line.

SURFACE IRRIGATION

Surface irrigation systems, border flood irrigation and furrow irrigation, while the simplest irrigation systems with regard to hardware, are the most complicated irrigation system to manage properly.

Advantages of Surface Irrigation Systems

1. Surface irrigation systems have the lowest energy demands of all irrigation systems. If water is delivered from an irrigation district, little to no pumping energy is required. Groundwater sources require energy to obtain the water but little additional pressure is needed for the surface irrigation system.
2. Maintenance of the surface irrigation system is minimal although delivery and runoff ditches may need to be created and/or maintained.

Disadvantages of Surface Irrigation Systems

1. Irrigating efficiently and uniformly is difficult with surface irrigation systems.
2. Runoff from surface irrigation systems can be a problem due to water quality issues and the need to manage runoff water.
3. Weed control can be an issue.
4. Land must be relatively flat.
5. Initial land preparation costs may be significant.

6. Infiltration rate and other factors affecting surface irrigation performance change during the season. This complicates irrigation scheduling and makes it difficult to apply the desired irrigation amount.

Operation of Surface Irrigation Systems

In general, the objective of any flood irrigation is to have water infiltrating for the same length of time at all parts of the field. This is difficult to accomplish because the water is introduced at the head of the field so water infiltrates there for the entire irrigation duration. It takes time for water to flow down the field, called the advance time; and this advance time is time those portions of the field don't have water on them as compared to the head of the field. This lesser time water is in contact with the soil means lesser infiltration of water into the soil.

For furrow irrigation, the head of the field almost always has greater water applied to it than the tail of the field. The exception is if water is allowed to pile up at the end of the field. Then the part of the field which gets the least water applied to it is frequently at approximately the 2/3 to 3/4 the distance down the field.

With border irrigation, many variations exist depending on the border length, slope, and operation. In general, it is advantageous to keep borders as short as practical to keep irrigation uniformity high. The tradeoffs to short borders are increased labor and pipeline costs.

An additional difficulty in managing surface irrigation systems is measuring the water going on the orchard. If water supplies are from a pump, a flow meter such as a propeller meter can be installed in the outlet pipe. Following the manufacturer's recommended installation criteria is important for accurate measurements. If water supplies are from an open ditch, etc., water measurement is difficult. Consulting the irrigation district may help in getting a good estimate of the flow rate to the orchard.

The following formula may be used to determine the average amount of water applied to an orchard.

Flow in cubic feet per second (cfs)	x	Irrigation Time (hours)	=	Area Irrigated (acres)	x	Depth of Water (inches)

Note: If your flow meter reads in gallons per minute (gpm) rather than in cubic feet per second (cfs), the conversion is as follows:

1 cfs = 449 gpm

The Depth of Water applied in the above formula should be the amount of water used by the orchard since the last irrigation and can be estimated by the orchard evapotranspiration (see Chapter XX). Remember that some additional water should be applied since no irrigation

system is 100% efficient. The efficiencies of flood irrigated orchards generally are lower than those that are sprinkler irrigated. If there is no irrigation evaluation information available on the orchard of concern, an irrigation efficiency estimate of 65 to 75% is realistic.

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