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Vineyard Irrigation Systems

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Adequate quantities of water are essential for rapid vineyard development and crop production. Water deficits early in the growing season reduce vegetative (shoot) growth and can reduce crop yields. Slowed vegetative growth is detrimental in young vines, which need maximum growth to hasten the development of the vineyard canopy. Severe water deficits during the summer and after harvest may disrupt bud development and cause premature leaf drop. Too much water, on the other hand, can cause poor internode spacing and lack of winter hardiness, and can damage roots by depriving them of oxygen and creating conditions that favor the development of soilborne diseases.

Grape growers must determine the amount of irrigation water to apply, when to apply it, and the most efficient application method for a given set of conditions. By knowing when to irrigate and how much water to apply, growers can avoid problems associated with over- or underirrigating. The goal is to keep the root zone moisture at a level that will allow appropriate levels of vine growth and will not reduce crop yields or quality in the current or subsequent years.

Chapter 17, Water Management and Irrigation Scheduling, addresses the amount and timing of water applications. For now, it is important to understand that irrigations should be applied to meet the variable crop requirements over the season, should be distributed evenly to maximize irrigation efficiency and facilitate the vine's uptake of nutrients, and should minimize the effects of soil conditions that could encourage disease. The vineyards may require some water in excess of the crop requirement in order to maintain a favorable salt balance in the root zone. The total irrigation requirement varies depending on soil salinity, water quality, crop tolerance, and the amount of water supplied by rainfall.

SYSTEM DESIGN AND SELECTION

Many irrigation systems are suitable for vineyard use. There is no best system or method because land, water, energy, and labor costs—in addition to soil and plant conditions—vary with each site. Irrigation systems are designed and operated to favor optimum crop yields and quality as well as efficient use of water and energy. At times, however, other considerations may dominate both design and operational decisions. Total cost—which includes initial installation and continuing operation and maintenance—substantially influences the grower's choice of an irrigation system. Other factors to consider are the physical and chemical characteristics of the soil, the uniformity of the soil, the slope of the land, any frost hazard, and the cost and availability of water. The grower must analyze all of these variables before he or she can select the right system (Table 8.1).

An appropriate system is most often a compromise of goals within economic constraints. The selection of an appropriate irrigation system is the first step toward good water management. Good water management favorably influences the yield and quality as well as the mineral nutrition of vines; in addition, it minimizes insect and disease problems and makes weed control easier.

Note that the best-designed and most expertly installed system will not function efficiently without proper management. Effective management includes the use of a water budget, and that means estimating crop water requirements through predictive methods or actual soil-moisture monitoring devices and then evaluating the efficacy of the irrigation after the scheduled amount has been applied.

Table 8.1 Factors to consider in selecting an irrigation system (limitations of systems)

Factor	Sprinkler system (solid set)	Surface flood systems			Low-volume systems	
		Graded border	Level border	Furrow	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 characteristics						
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 characteristics						
TDS*	Severe	Slight	Slight	Moderate	Slight	Slight
Suspended solids	Moderate	None	None	None	Severe	Severe
Rate of flow	Low	Moderate	Moderate	Moderate	Low	Low
Climatic factors						
Temperature-controlled	Yes	Yes	Yes	Yes	No	No
Wind-affected	Yes	No	No	No	No	Yes
System costs						
Capital (*$/acre*)†	700–1,200	500–600	500–600	400–500	700–1,100	800–1,200
Labor	Low	Moderate	Moderate	High	Low	Low
Power	High	Low	Low	Low	Moderate	Moderate
Annual average costs (*$/acre/year*)	200–300	100–200	100–200	200–300	200–300	200–300
Irrigation efficiency (%)‡	75–85	70–80	75–80	70–80	80–95	80–95

*Total dissolved solids
†Amortized capital cost plus operation and maintenance costs
‡Consumptive use + applied water = irrigation efficiency, assuming good to excellent management and design

IRRIGATION STRATEGY

The amount of water that can be applied in a single application via conventional surface irrigation (that is, flood, furrow, or border irrigation) or, to some extent, sprinkler irrigation, depends upon the ability of the soil to absorb water. For minimum disease problems and maximum vineyard life, surface irrigation water should be absorbed by the soil within a maximum of 24 to 48 hours.

Many growers with surface or sprinkler systems allow the root zone moisture to deplete to near 50 percent of the available soil moisture, and then irrigate with enough water to refill most or all of the root zone. Unfortunately, some California soils do not absorb water at a rate sufficient to refill the root zone within 48 hours. To ensure the vine's successful growth and production, growers must use alternate strategies. One strategy would be to use shorter irrigations (to prevent ponding or soil saturation) that are applied more frequently to meet the vine's water requirement.

Another strategy capitalizes on the vine's ability to preferentially use a greater portion of the shallow moisture, if available. For this strategy, start the season with a full moisture profile but meet the early- and midseason requirement by applying frequent irrigations when the soil moisture is well above 50 percent depletion. This preserves deep-profile moisture for later use during high-requirement summer months or during harvest when water infiltration is more difficult.

With any strategy, the total water requirement is met through stored winter rainfall, irrigation, and in-season rainfall. The most effective way to use these water resources is to construct a water budget that includes estimates of crop consumptive water use.

IRRIGATION METHODS

If not constrained by physical limitations, a typical raisin vineyard can use surface, sprinkler, and micro-irrigation (drip and low-volume sprinkler) technologies. Each system can supply water adequately if designed and managed properly. All systems should be designed with the capacity to deliver enough water during the peak use period to meet crop requirement, maintain the salt balance or required leaching fraction, and compensate for system inefficiencies.

Water should be applied as uniformly as possible. This is most important in young vineyards. If irrigation exceeds the basic intake rate of the soil, runoff or saturated conditions will result. With micro-irrigation, the wetted areas should be large enough to provide for optimum nutrient uptake and physiological health.

Soil-controlled water intake. All irrigation methods fit into one of two categories: those for which the soil's rate of water intake is governed by soil conditions, and those for which is it governed by the method of application. With surface irrigation, water is applied to the soil surface and gravity moves the water across the field. The soil conditions control both the rate at which water enters the soil and the uniformity of its distribution down the length of the field. As irrigation begins, water enters the soil at a high rate, primarily because the soil is dry and soil pores are easily accessible. As irrigation proceeds, the infiltration rate declines rapidly. After a few hours, the basic or sustained rate becomes of greatest importance. Figure 8.1 shows the typical relationship between the water's rate of infiltration into the soil and the length of time the soil is under surface irrigation. A soil's water intake characteristics depend on the soil's own physical and chemical composition as well as the chemical composition of the applied water.

To ensure even distribution over the length of the field, you can increase the water on-flow rate to a given furrow or border and thus advance the water quickly down the furrow, making the intake opportunity time more equal over the field. This approach has the disadvantage that excess runoff can result while you wait for the minimum opportunity time to occur when the water is too-slowly absorbed by the soil. Therefore, by increasing the on-flow rate you increase distribution uniformity, but must deal with more runoff. One solution is to recover and recycle runoff water using a tailwater recovery system; another is to reduce the flow to the individual furrow or border check after the water reaches the end of the field. A good rule of thumb is that the water should reach the end of the field in one-half the total irrigation time.

Spatial variability, another component of uneven water intake distribution, is more difficult to address because factors such as soil texture, structure, chemistry, and compaction, and a variety of other poorly understood phenomena, vary widely even in a vineyard that appears to be uniform.

Application-controlled water intake. Sprinkler and low-volume methods such as drip and micro-sprinklers use

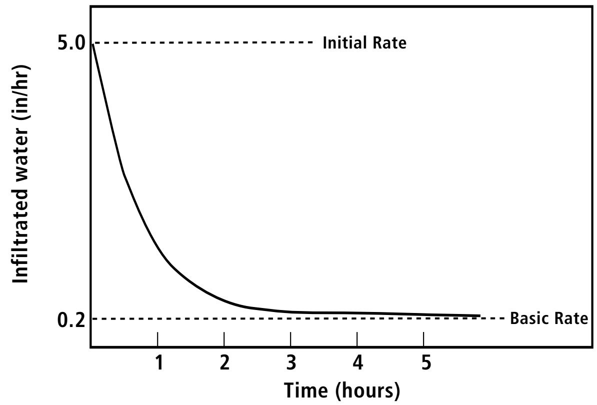

Figure 8.1 Typical water infiltration characteristics

mechanical devices such as nozzles and emitters to control the water application rate. Systems of this type apply water at near to or below the basic infiltration rate (Figure 8.1), reducing the potential for runoff. In general, they apply less water per unit of time than surface systems, and they often require longer or more frequent application periods to meet the vineyard's water requirement. When watering soils that have water infiltration problems or when using systems with high application rates, the irrigation session should end when surface ponding indicates that applied water has exceeded the intake rate. This will reduce runoff and saturated soil conditions. An effective design in an application-controlled irrigation system reduces the effect of variable opportunity time and infiltration rate variability caused by spatial variability.

SURFACE IRRIGATION

The on-farm irrigation efficiency of surface irrigation varies from 40 to 80 percent. Irrigation efficiency is the ratio of the volume of beneficially used water to the total volume of water applied. Higher efficiency can be achieved by adjusting the length of run or stream size or by using a tailwater return system. Water distribution uniformity throughout the length of an individual strip, even when the land is uniform and well graded, rarely approaches 70 percent. If fills from land grading exceed the normal discing depth, uniform water movement may be impaired. Cuts and fills often create compaction and interface problems in a soil profile. Small amounts of water can usually be applied more successfully with furrows than with a border system.

The use of surface irrigation may affect certain pest problems. Field access for cultural operations such as powdery mildew control can be limited after irrigation. Water delivered from canals may contain weed seeds and may contribute to the spread of pathogens through the vineyard as water moves across the soil surface. The major types of surface irrigation are *border* and *furrow* irrigation.

Border Irrigation

Border irrigation has been successfully used in California for many years. It requires relatively level ground (less than 1 percent slope) and relatively large flows of water. Variations on the flood or border system are *square basin, contour basin, contour check,* and *border check*—either level or slightly graded. The width and length of the strips, checks, and basins depend upon slope, soil texture, and the stream sizes or onflow water volume.

Advantages. On relatively flat ground, border irrigation is the least expensive system to install. In a simple system, earthen open ditches with wooden or concrete turnouts deliver water into irrigation checks or strips. A more elaborate system could involve concrete ditches or plastic or fiber pipelines. Labor costs for water control are generally moderate, and maintenance of pipelines and valves is minimal.

Limitations. In a border irrigation system, efficient water application is difficult and deep percolation losses can constitute a serious drawback—especially in permeable soils. Excessive percolation may occur at the upper end of the irrigation run, near the turnouts. Soil variability can also cause uneven percolation and excessive water losses. Large water flows are required. Where water is limited or expensive, other irrigation methods may be preferable. In heavy-textured soils with slow infiltration, the hazard of diseases such as Phytophthora crown and root rot increases with the likelihood of saturated soil conditions. Small or light irrigations are hard to apply, however, but you may be able to overcome this limitation by using alternate-row irrigation.

Furrow Irrigation

Furrow irrigation is a variant of the border system. The furrows are formed in a variety of shapes that allow water to flow downslope. Furrow irrigation is commonly used on lands that do not exceed a 2 percent slope; erosion usually becomes a serious problem on steeper slopes. Water and salt movement characteristics in relation to the location of the vine must also be considered with this method. The water should reach the end of the field in about one-half of the total irrigation time, and you can manipulate that time by controlling the outflow volume, slope, number and shape of furrows, and field length.

Advantages. The cost of grading lands for a furrow system is minimal, especially when the slope is too great for border irrigation. The system may use pipeline or an open ditch with plastic or tarpaulin dams; siphon pipes deliver water to each furrow. More sophisticated systems use gated pipe or underground pipes and short aboveground pipes that supply water to 12 to 24 furrows each.

Limitations. Furrow irrigation may not be competitive in areas of high-cost water, high water tables, or high soil salinity. Furrow irrigation also requires more labor time and skilled irrigators, which increase labor costs.

SPRINKLER IRRIGATION

Sprinkler irrigation is practiced on unlevel lands or where there are special soil water conditions or management requirements. Soil problems include excessive or inadequate water intake rates, limited water holding capacity, and non-uniform soils. Little new raisin acreage uses sprinkler irrigation. Micro-sprinklers have largely replaced sprinklers, and are now commonly used to ameliorate special soil or water conditions. A limited water supply, the need for frost protection, or irrigation automation may also encourage use of this system. The sprinkler system should be energy efficient, utilizing low-pressure sprinklers and minimizing pumping plant size and friction losses. These systems can be operated as separate irrigation sets or they can apply water over the entire vineyard at one time. Single-set systems (which irrigate the entire vineyard as one set) can be used for frost protection.

Irrigation system selection and design for reduced energy consumption are of increasing importance. Until recently, many systems were designed to operate at high pressures and to complete irrigation quickly, requiring a large pumping unit and large-diameter piping. This kind of system requires a higher capital investment, greater energy consumption, and higher electricity demand charges.

While it supplies the same volume of water, a sprinkler system that is designed to use lower operating pressures can use a smaller pumping plant and thus reduce energy-related costs as well as capital costs. By reducing the operating pressure of the nozzle from 50 to 35 pounds per square inch (psi), a grower can cut energy costs for water pressurization by 30 percent, assuming there are no other head losses. A reduction at the pump from 65 psi down to 50 psi will result in a 23 percent energy cost savings. A reduction in operating pressure can sometimes result in poor distribution, but this problem is of greatest concern only while a vineyard is becoming established. Older vineyards with more extensive root systems are less susceptible to harm from non-uniform sprinkler water distribution patterns.

Sprinkler head and nozzle designs have evolved to improve sprinkler performance at low pressures; consider installing these improved devices. Take care when you consider using a low-pressure system on widely spaced laterals. Lower pressure can result in a smaller coverage diameter for each sprinkler, in turn requiring closer sprinkler spacing that can result in higher overall capital costs. When considering the conversion of a high-pressure system to low-pressure, it is also important that you evaluate all system components for efficiency as well as uniformity. This will ensure savings as well as system efficiency. Sound, efficient design and proper installation are essential for long-term performance.

Advantages. Sprinkler irrigation on rough, irregular land eliminates the cost of expensive land grading and preparations that would be required for surface water distribution. (Extensive grading often exposes subsoils that have physical or chemical deficiencies.) Sprinkling generally avoids the potential for excessive losses from deep percolation or surface runoff. Sprinkler systems are well suited to unlevel lands and lands with low or variable water infiltration characteristics.

A well-designed, well-managed sprinkler system should have a more uniform water distribution pattern than a surface irrigation system, and it should minimize deep percolation and water table buildup. Single-set sprinklers can also be used for frost protection, chemical injection, heat suppression, and spider mite mitigation. The labor requirement for a single-set sprinkler irrigation system is generally lower than for other methods of irrigation.

Limitations. The primary limitations on vineyard sprinkler irrigation are the high initial installation cost and continuing high energy costs, which are reflected in high total annual costs. Sprinklers require a dependable source of electrical power or fuel to generate the water pressure they need in order to operate. Irrigation water must be relatively free of salts, because absorption of salts from water on sprinkled leaves may cause leaf burn. Sprinkling may also limit field access and encourage and spread certain diseases. The system should be designed and operated to minimize this effect.

MICRO-IRRIGATION

Micro-irrigation includes drip (trickle) and low-volume sprinklers (micro-sprinklers). This irrigation method relies on the frequent application of low volumes of water to a limited soil volume. Water is applied at a point source near a vine through small tubes or mechanical devices called *emitters*. Drip irrigation emitters can be aboveground or buried.

Micro-irrigation techniques have largely replaced sprinkler systems as a way to overcome soil variability, unequal opportunity time, and topographic difficulties. Micro-irrigation systems can be used to apply small amounts of water without disrupting vineyard access and they provide a high degree of control over vine water status. Micro-irrigation systems provide better water distribution and better control of irrigation time, both of which are preferred when using advanced irrigation scheduling.

The volume of soil wetted around the vines by micro-irrigation is smaller than for other irrigation methods. Not everyone agrees, but it has been suggested that mature vines require that 40 to 60 percent or more of the soil volume be wetted (young vines require less). Soils without adequate capillary water movement may require more points of emission in order to achieve the required wetted volume. Large, mature, wider-spaced vines may require as many as three drip emitters each on loamy soil. Micro-sprinkler and similar systems distribute the water over a larger surface area than drip emitters, and so require fewer emitters per vine.

Compared to other systems, a properly managed micro-irrigation system can achieve substantial water savings. The amount of savings depends on the type of system used for comparison, its design, and its level of management. However, there may be some savings due to potential reductions in deep percolation and in evaporation during irrigation and from the soil surface after irrigation. The amount of savings is greatest in young vineyards before the full canopy develops.

Advantages. Most micro-irrigation installations can help overcome water-supply shortages, high irrigation water costs, poor, excessive, or variable water infiltration, and the irrigation problems posed by growing a vineyard on a steep slope. Such systems interfere little with tillage and can be highly automated, so labor requirements are low. Water savings usually result from reduced runoff, reduced deep percolation, and reduced evaporation.

Water savings. The water consumed by the vines in a well-irrigated vineyard is the same, regardless of which irrigation system is used to apply it. Irrigation methods differ significantly in the volume of water they apply, however. Since micro-irrigation systems—and, to some extent, sprinkler systems—distribute water relatively evenly, less water needs to be applied.

Micro-irrigation methods wet less surface area, and so reduce the volume of water lost to evaporation from the soil surface. Estimates of water savings due to reduced evaporation range from 5 to 15 percent depending on frequency of application and climatic severity. Buried drip systems lose very little water to evaporation or weed growth.

Because less soil surface is wetted by micro-irrigation, total weed growth may be reduced even if weeds grow vigorously near emitters. Weeds are often difficult to mow or cultivate near emitters, and may require herbicides for effective control.

The water requirements of a developing vineyard are less than those of a mature vineyard. The root systems do not quickly develop to utilize water applied in the middles. This water is left to evaporate, deep-percolate, or support the growth of weeds. Until canopies are fully developed (i.e., until they provide at least 70 percent land surface shading at maximum yearly canopy extension), micro-irrigation systems can save significant amounts of water over full-coverage systems.

Increased usability of high-salt water. With proper micro-irrigation techniques, water containing relatively high levels of salts can be used successfully. Salts may accumulate at the periphery of the root zone, however, posing a hazard if they are not removed by rainfall or a planned leaching program. During droughts or periods of saline waters use, monitor salt buildup in the soil and conduct an appropriate leaching program.

Energy savings. Micro-irrigation systems typically operate at pressures near 15 psi (measured at the emitter). Compared to high-pressure (50 psi) and low-pressure (35 psi) sprinkler systems, the energy requirement for water pressurization of a micro-irrigation system is about one-third less. Additionally, since micro-irrigation systems apply the same amount of water over a longer period of time, both pump size and pipe size can be smaller. This reduces to some extent the capital investment and energy demand. Micro-irrigation systems lend themselves to automation and, when properly designed, can deliver adequate water during periods of all-peak electric power.

Limitations. The clogging of emitter orifices is considered one of the most serious problems in micro-irrigation systems. Orifices can be clogged by particles of sand, silt, or clay, inorganic chemicals that form precipitates of calcium and iron, or organic material carried in the water. When emitters are partially or completely clogged, emission uniformity decreases. Vines may be damaged before clogging is detected. Clogging is usually less of a problem with micro-sprinklers, because of their large emission orifices. Also, partial plugging is more detectable with micro-sprinklers because it causes disruption in the wetting pattern. Emitter clogging can be effectively reduced through proper filtration and the use of appropriate chemical treatments. For more information, see Schwankl, Hanson, and Prichard (1995), listed in References at the end of this chapter.

SYSTEM EVALUATION

System performance should be evaluated at the time of installation and annually thereafter, since parts wear and water table levels can change. Sprinklers and micro-irrigation systems are the easiest to evaluate. You can measure the total quantity of water delivered to an area of land by monitoring a water meter installed at the wellhead. Alternatively, you can perform a pump test or measure the quantity of water delivered to an area of land, either in gallons per hour (micro-irrigation systems) or gallons per minute (sprinklers) at emission points. (This last method involves considering sprinkler spacing or the number of micro-irrigation emitters and plant spacing.) You can determine the water distribution within the vineyard by measuring the volume discharged from emission points at various locations in the vineyard. The best approach is to measure emission points closest to the pump, farthest from the pump, and at the beginning and end of each lateral. If the volumes of discharge at these points are not within 10 percent of each other, further investigation is in order. Potential problems can include poor system design, worn nozzles or emitters, leaks, misadjusted pressure regulators, clogged filters, and clogged emitters.

Surface systems are more difficult to evaluate, since the irrigation water may flow by gravity from a canal or low-head pipeline. Pumped sources can be measured with meters or pump tests. The quantity of water delivered from gravity sources such as canals can be estimated using turnout valve data sheets, weirs, or flumes. Although they are not as accurate as water meters, the data they provide are better than nothing. Distribution within the vineyard is also difficult to evaluate for a surface system. The best method is for the grower to measure, at different locations, the depth of soil wetted a few days after irrigation. To do this, use a soil auger or ¼-inch rod with a pointed end. Changes in on-flow volumes and set times can influence average water infiltration, distribution uniformity, and irrigation efficiency. The general characteristics of various types of irrigation systems used in vineyards are listed in Table 8.1.

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