Best Practices for Drip Irrigation System Management in Vineyards

Introduction

An efficient drip irrigation system is critical for the accurate and timely delivery of water and nutrients to grape vines. Burt and Styles (2016) identify system design and suitability, and management practices as factors that have a great impact on efficiency values. The focus of this literature review is on the hydrologic unit baseline known as Distribution Uniformity (DU), what is means and how it is measured, and best practices for maintaining a high system DU. Drip irrigation systems of wine grape operations are the focus of this review. While sprinkler systems are often utilized for frost protection in vineyard settings, they are rarely the primary irrigation source. Primary research materials for this review include documents from Cal Poly's Irrigation Training and Resource Center and manuals from irrigation manufacturing companies, Toro and Netafim. In general, maintaining a high DU is achievable for most vineyard operations assuming good initial design, best management practices are implemented, and systems are regularly monitored for performance.

Drip Irrigation Basics

Drip irrigation is the most frequently used irrigation method used in irrigated vineyards. Furrow and sprinkler irrigation methods can be more prone issues related to soil variability, opportunity time and topography that lead to lower potential uniformity of applied water than drip irrigation systems. Irrigation scheduling by vineyard managers demands the type of water distribution, and control over irrigation time, that only drip systems can achieve. Because of their higher efficiencies, drip irrigation systems use less water than other irrigation methods, from reduced runoff, deep percolation, and evaporation from the soil surface before and after irrigation events. Drip irrigation systems can help vineyard managers overcome water supply shortages, high irrigation water costs, soil permeability and elevational variability. Labor costs for irrigation systems can be lower in drip systems, because pump operation can be automated. (Prichard, 2000).

The typical components of a vineyard drip irrigation system include pump(s) filter(s), chemical injectors, main and submain lines, laterals and emitters. Water sources are for many wine growing regions are dominated by underground wells that bring groundwater to the surface. Irrigation water sourced from groundwater can be irrigated directly to the field or stored in tanks or reservoirs. Water stored in tanks or reservoirs can be delivered to the field by gravitational flow or pressurized by a booster pump. Chemical injection systems and filtration devices are installed at the pump station, in addition to flow meters and pressure gauges. Pressure gauges, should at a minimum, be located on the mainline at pump discharge and post-filter to give some data to the manager about pump performance over time.

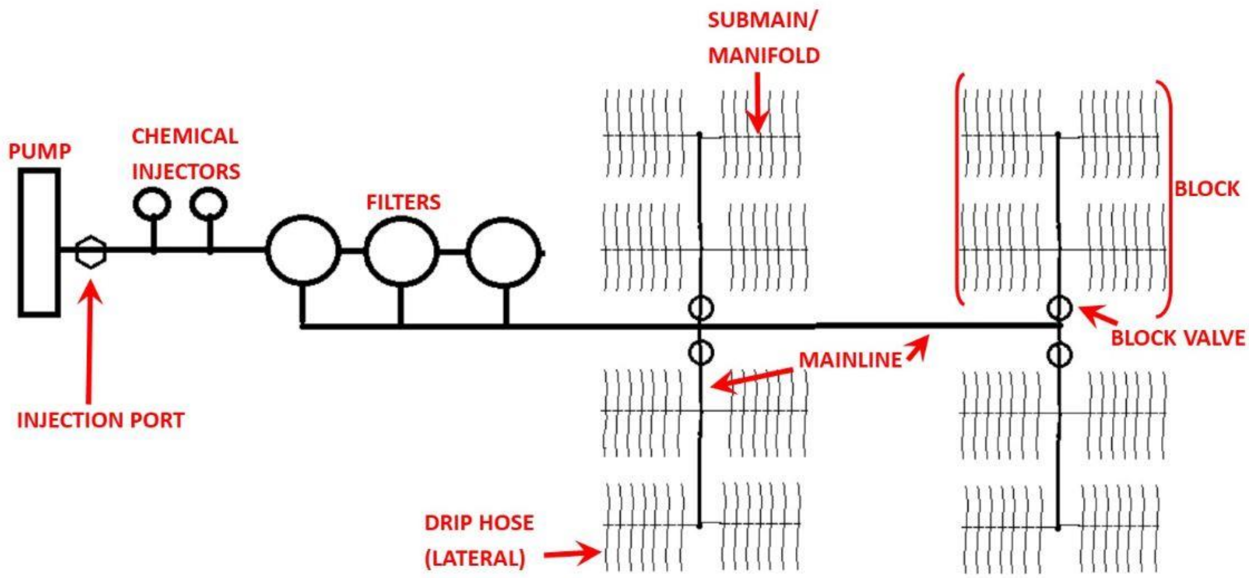

Figure 1. Typical diagram for vineyard drip irrigation system. Injection ports are located after pump discharge, before the primary filter. The field is divided into irrigation "sets" that represent portions of the vineyard that are irrigated at the same time. Block valves allow irrigators to deliver water to the correct set.

Drip systems can be designed to irrigate the whole field at once, or in separate sections called "irrigation sets." Irrigation water pressurized by pumps, or fed by gravity, is delivered directly to small areas adjacent to individual grape vines by emission devices inserted in a drip hose (lateral). There are typically one or two emitters per vine, with flow rates of 0.5 and 1.0 gallons per hour most common in vineyard operations. Emission devices typically have pressure compensating features, meaning that the flow rate between emitters is relatively the same regardless of changes in elevation and variation in drip hose pressure. Drip hoses and emission devices typically remain in one place during the growing season and can be expected to perform effectively for up to 20 years (Burt and Styles, 2016).

Irrigation Efficiency and Uniformity

The terms "irrigation efficiency" and "distribution uniformity" have become interchangeable for some managers, but there are important differences. Distribution Uniformity (DU) is a measurement of how evenly irrigation water is applied to plants throughout a field. Distribution Uniformity was defined by Burt and Styles (2016) as:

$$\mathbf{DUlq} = \frac{\text{Average low quarter depth of water}}{\text{Average depth of water accumulated in all elements}} \times 100$$

Where: the average of the lowest quarter of the values, rather than the absolute minimum value is used as "minimum value." Distribution Uniformity is now expressed as a ratio rather than as a percentage to avoid confusion with efficiency terms.

The DU value can be used to describe the performance for a drip hose, irrigation set or for the entire field, but it is *not* a term that is used to describe farm, irrigation district or basin efficiency. The concept of DU was originally developed to assist vineyard managers with irrigation scheduling, but over time it has become the accepted term to define irrigation uniformity (Burt and Styles, 2016)

The term used to describe the efficiency of a farm, district or basin is Irrigation Efficiency (IE), which is an evaluation of how much of the applied irrigation water is being utilized beneficially within the boundaries being evaluated:

$$\textbf{IE (\%)} = \frac{\text{Irrigation Water Beneficially used}}{\text{Irrigation Water Applied}} \text{ X 100}$$

Irrigation Efficiency is an efficiency term with a maximum possible value of 100%, but DU is not an efficiency term. An irrigation event may be applied through the system very efficiently (have a high DU), but if the set duration is too long, there may be runoff and deep percolation, and a resulting low IE. Runoff and deep percolation losses can be reduced by shortening irrigation set run times, but the crop will suffer if the DU of this set is not high (Burt and Styles, 2016). Water used for leaching salts out of the root zone, frost protection, crop cooling and pesticide or fertilizer applications are all considered beneficial uses not related to crop growth (Irrigation Association, 2017).

DU Evaluation and Methodology

Many growers and irrigation companies have devised methods for determining the uniformity of their fields. These often involve observations of pump and field pressures and might include flow rate analysis. The most complete method for the DU evaluation was developed by Cal Poly's Irrigation Training and Resource Center (ITRC). This evaluation method breaks down the DU calculation into components that can be measured and observed by the evaluator for entry into ITRC software:

System DU = (Flow Rate Difference DU) x (Uneven Spacing DU) x (Unequal Drainage DU)

Flow rate differences may be related to pressure variation between emitters, plugging, different emitter sizes in the same set and degradation of emitter components. Uneven spacing refers to non-uniformity that is caused by having emission units with different flow rates or number of emitters per vine in the same set. The unequal drainage component describes the percentage of emission devices that continue to drip after the irrigation set is shut off. Uneven drainage is a bigger problem in irrigation sets on steep slopes and have short irrigation duration (Burt and Styles, 2016).

The ITRC DU evaluation starts at the pump where set pressures are recorded. Observation of the type and location of pump station components are recorded. The bulk of the ITRC method is spent in the chosen block itself where the evaluator takes pressure and flow rate readings at various locations described by Burt and Styles (2016). Pressure measurement locations are designed to be able to compare:

1. **Pressure along individual hoses.** Three pressure measurements are made along each hose that is selected: head of hose, halfway down the hose, distant (hydraulic) end of the hose.
2. **Pressures between individual hoses along a single manifold.** Measurements are taken on the closest hose of the manifold and the most distant hose from the inlet of the manifold, for a total of two hoses per manifold.
3. **Pressures at the head of each manifold.** Six manifolds are selected, including the ones closest to, and most distant from the pump.

In addition to these pressure measurements, emission device flow rates are observed at locations on drip hoses that are of close, medium and far distances from the water source. Additional field observations include the relative number of leaks, how long emitters run after most stop, and flushing of the most downstream drip hose until the water runs clear. These observations are input into the ITRC software, and a DU value is returned.

Table 1. Accepted categories for uniformity of vineyards based on DU values. Brand new systems are commonly designed for 0.92 or higher.

	Poor	Good	Excellent
DU	0.80 or less	0.81 – 0.89	.90 or more

For a new drip irrigation system, there should be no plugging, mixed nozzles or emitter degradation. The non-uniformity in new systems is primarily related to manufacturing cv and pressure differences. Over time the system DU will begin to decline. According to Burt and Styles (2016) the primary reasons for this decline in DU are:

- Plugging of the emitters
- Wear of the emitters
- Deterioration of the physical components of the emitters
- Mis adjustment of pressures

For optimal performance, drip systems require routine system maintenance. Agricultural water sources, fertilizer injection practices, natural limitations of filtration equipment and general agricultural growing environment make maintenance a priority (Bisconter, 2018). The DU of a drip system can degrade quickly due to causes such as insufficient filtration hardware, flushing practices and/or chemical water treatments (Burt and Styles, 2016). The following sections describe how these conditions develop in the vineyard and the steps that irrigation managers can take to maintain system DU.

Pressure Problems

Cal Poly ITRC evaluations of 329 fields provided an average DU of 0.85 for drip irrigation systems. Approximately 45% of non-uniformity was due to pressure differences, 52% was due to other causes (plugging), 1% was due to unequal drainage and 2% due to unequal application rates (Burt, 2004). The ITRC evaluation software provides recommendations for evaluators to use to improve or maintain system DU. The following recommendations are provided by the ITRC to address non-uniformity due to pressure problems by:

Remove hose screen washers and replace them with regular washers

Vineyard managers can utilize secondary filter devices such as sand separators, in-field tubular screens, and riser screen tees to capture debris that makes its way past the primary filter before they can affect emission devices. Riser screen tees are installed where submains meet lateral lines. The purpose of the mesh screens is to capture organic and inorganic materials before they can enter drip hoses. These hose screen washers tend to plug and cause large differences in pressure between various hose inlets, especially when injecting thicker organic fertilizers (Burt and Styles, 2016).

During a DU evaluation, pressures are observed with these riser screen washers installed and again when they are replaced with plain washers. If there is a pressure differential, managers are advised to remove the mesh screen and replace with plain washers, or a coarser mesh screen. Growers should also take steps to improve filtration efforts at the primary filter, install downstream foundation at manifolds and filter materials prior to injection.

Adjust block pressure regulators to the same pressure

Pressure regulating valves (PRVs) are installed at various points at the pump station, and in the field. They can be adjusted to regulate pressures based on the water demand for the set. These valves need to be cleaned and serviced as a part of a regular irrigation maintenance schedule. Valve components can degrade leading to a difference in pressure than the initial install set up. Irrigators could adjust PRVs based on field observations of pressure. As time goes on, PRVs can have pressures quite different than they were designed for. A DU evaluation can indicate if block PRVs have enough variability to warrant deeper engineering analysis to determine the correct PRV settings for the current field conditions, which may or not be the same as the original design set points.

Replace non-adjustable pressure regulators

The previous recommendation describes pressure regulators but assumes that they are adjustable. Some vineyards are installed with low quality, non-adjustable pressure regulators. If pressure problems are indicated by the ITRC results, a grower would want to consider replacing the existing regulators with high-quality, adjustable PRVs.

Eliminate large pressure losses near the pump

The pump station can be another location where pressure losses can occur. This most frequently occurs when primary filtration units are clogged, or dirty and pressure differential is greater than 10 psi. Filter pressures should be monitored frequently to account for changing water quality conditions throughout the season. This excess pressure differential may be more prone to allowing for debris to pass through the filter. The practice of installing automated backflush systems allows for filters to self-clean when a pre-set pressure differential is reached. Filters can also be serviced manually by hand with backflush valves or by disassembling screen or disk cartridges and cleaning with pressurized water and/or brushes (Bisconter, 2018).

Valves, regulators, flow meters, pressure gauges, controls and pumping equipment should be inspected periodically to ensure proper settings and functionality. Broken equipment should be replaced or repaired immediately with the same or similar equipment so that the performance matches the original design. Make sure valve diaphragms, O-rings, solenoids and control tubing are not damaged and functioning, and that wiring is in good condition. Mechanical devices should be lubricated according to the service intervals provided by their manufacturers. Calibrate monitoring devices such as flow meters and pressure gauges to ensure that readings are accurate (Bisconter, 2018)

Another source of pressure loss at pump stations is a result of a common design error that reduces the application of chemicals into irrigation systems. Some systems are designed such that operators must partially close off a mainline valve to create a pressure differential necessary to operate the chemical injector. This lowers the pressure of the irrigation system so that the irrigation system DU (and injected chemical DU) is very low (Burt and Styles, 2016).

Plugging

Clogging of emission devices can be considered one of the most serious problems for drip irrigation systems. Emitter orifices can be clogged by sand, silt or clay, inorganic chemicals that form precipitates of calcium and iron, or organic material carried in the irrigation water. Vineyard uniformity decreases when emitter performance decreases due to partially or completely plugged emitters (Prichard, 2000). The

ITRC recommends consistent hose flushing, filter maintenance and chemical treatments to prevent bacteria and mineral deposits and to maintain a high DU.

Treat irrigation water with chemicals

Drip irrigation systems require very clean water to reduce the potential for plugged emitters. Properly functioning filtration units are an important component, but in many cases chemical treatment is of equal importance. Chemical treatments are recommended to avoid plugging due to bacterial growth and/or chemical precipitation in the drip hoses and emitters (Burt and Styles, 2016).

The irrigation system component manufacturer, Netafim (2012), recommends the injection of different chemicals to prevent, eliminate, dissolve or solve instances of clogging in drip hoses and emission devices. Acid treatments are recommended to dissolve, prevent and/or decompose salts, carbonates, phosphates, hydroxides, etc. Another commonly recommended chemical treatment is chlorine which is used to prevent slime, oxidize iron, sulfur, manganese, etc., clean organic sedimentation and improve filtration efficiency of sand filters.

For very dirty irrigation systems, a shock treatment of a very strong dose of chemical might be recommended. According to Burt and Styles (2016), the typical recommendation is to apply a strong dosage of chemicals until it arrives at all emitters, shut the system down, and let it set and work on the dirt, which they state is not very effective. In this method, emitters that are closer to the block manifold will emit large quantities of chemical before the chemical reaches the furthest end of the field. Burt and Styles (2016) describe their recommended method for shock treatment in detail:

> **Shock Treatment:** Inject the chemical but only allow the water to flow into a relatively small area of the field at once. Before injecting, turn the systems on and then open the ends of the hoses. Then begin injecting at the desired concentration. Continue to leave the hose ends open until the chemical reaches the ends of the hoses. Then shut the system down and let the concentrated chemical work on the contaminants. This will accomplish three things:
>
> 1. There will be an initial flush of contaminants from the hose ends, which will reduce the number of contaminants the chlorine must work on.
> 2. The chlorine will reach the endso the hoses in a small fraction of the time that it would normally take.
> 3. There will be much more uniform contact time of the chlorine throughout the system.

Vineyard managers much identify the type of material causing the plugging of their emission devices. Burt and Styles (2016) identified five types of plugging that commonly require chemical injections into drip irrigation water. The following sections describe these problems in detail.

Slimy Bacteria

Slimy bacteria grow on the interior walls of drip hoses and emitters. Clay particles in irrigation water, which are too small to be removed by filtration, stick to slimy bacteria and provide a food source that feeds bacterial populations. These large growths can dislodge and move downstream, entering emission devices and plugging the orifice. Common ways to treat slimy bacteria include:

1. Chlorine – applied continuously in low doses, or occasionally at higher dosages at the ends of hoses.
2. Chlorine Dioxide
3. Sulfur Dioxide gas – lowers water pH, reduces carbonate precipitation. Can lower soil pH.

4. Ozone. Has a very short half-life, so it is effective at killing organic material entering the system, it is ineffective at the ends of hoses where material is growing.
5. pH control. Acid treatments enhance the effectiveness of chlorine, and in many cases are enough to eliminate slimy bacteria.
6. Various polymers and Special mixes. Numerous products available. Effectiveness may depend on water pH and total salinity.

Iron and Manganese

Some species of bacteria present in irrigation water can oxidize iron or manganese for use as an energy source. Iron in irrigation water can be oxidized chemically and precipitate out of solution. In a manner like slimy bacteria, described above, these growths can form masses that break off and clog downstream emission devices. If these materials are observed, treatments should start with servicing at the well. Clean well casings will help to reduce bacteria populations.

Burt and Styles (2016) outline options for treating high content iron and manganese irrigation water before it enters the filter:

1. Discharge the water into a reservoir. Allow the water to sit for 12-24 hours to allow oxidation to occur. This will remove the iron.
2. Inject a strong oxidizer into the water upstream of the filter to oxidize iron. The most common oxidizer is chlorine.
3. Inject a polymer that has been specifically designed to "sequester" the iron and manganese so that they stay in solution.
4. Use a special sand, called "green sand" in a deep media filter.

Iron and Manganese Sulfides

Iron and manganese sulfides are present in irrigation water in the form of a black, insoluble precipitate, and are usually associated with contaminated well water. Burt and Styles (2016) recommend a combination of aeration, acidification and chlorination to precipitate out sulfides that reach the surface.

Calcium and Magnesium Carbonate Precipitation

Carbonate precipitates occur within the emission devices and can result in plugged emitters. This type of plugging is identified by placing a drop of hydrochloric acid on the emitter and looking for fizzing. The most popular solution for removing carbonates from irrigation water is continuous acid injection.

A Note on Organic Nutrients

The application of organic nutrients through the drip irrigation system requires special attention (Netafim, 2011). Organic nutrients are usually sold in solutions that are less soluble in water and contain a high percentage of suspended solids. These solids can build up on interior walls and in emitters like the slimes, and chemical precipitates described above. Vineyard managers must take care to avoid certain combinations of organic nutrients and perform frequent and effective filter and irrigation system maintenance such as system flushing and chemical treatments. Secondary filtration at each block valve or management zone can help to capture materials that have precipitated out of solution between the pump station filter and zone inlet (Bisconter, 2018).

Inject fertilizers upstream of filters, rather than downstream

Chlorine is typically injected downstream of filters, but Burt and Styles (2016) recommend that in most cases, chemical injections should be done upstream of the primary filter. Filters are necessary to remove any dirt introduced by dirty hose connections, sludges from the bottom of chemical tanks, or dirt and chemical precipitates that form during the injection process. While very strong acids are sometimes injected downstream of filters to avoid corrosion damage, extreme caution must be made when injecting any materials downstream of the filters (Burt and Styles, 2016). Netafim agrees that chlorine should be injected as close as possible to the primary water source noting that chlorine prevents the growth of bacterial slime in the mainline and provides better overall protection than when the injection point is far from the source.

Change the type of filter being used

The type of filter installed at the pump station needs to be matched to irrigation system design and water needs of the vineyard. Tubular screen filters are effective if water sources are very clean, and the filters can be cleaned frequently, either with automated backflush or manual cleaning. Media tanks are the most popular solution for dirty water, as they are good at removing organic materials. Disc filters are not very effective if a high amount of sand is present in irrigation water. Sand is considered one of the most harmful elements that can enter into a drip system. Sand does not decompose and cannot be removed or dissolved upon entering emission devices (Netafim, 2012). In some cases, pre-treatment of irrigation water with sand separators or chemical treatments is required for primary filtration units to be most effective (Burt and Styles, 2016).

Flush the ends of hoses more frequently and for longer duration

Netafim recommends that drip irrigation systems are flushed at regular intervals, as often as once a month, that depend on water quality and capabilities of the flushing program. Bisconter (2018) agrees that flushing is often overlooked and should occur as often as needed to keep irrigation lines clean, and is dependent on seasonal water quality, temperature and effectiveness of the system filter. Proper flushing of drip irrigation systems reduces the accumulation of system pollutants, pushing them out of the system (Netafim, 2012).

Flushing is most effective when flow rates within the mainlines, sub-mainlines and drip hoses are increased. This can be achieved by increasing flow rate at the pump, or by flushing a smaller number of hoses at a time. Netafim (2012) recommends flushing mainlines and sub-main lines at 1.5 m/sec and drip hoses at 0.5 m/sec. Flushing the system at increased velocities allows for water to break up sedimentation on interior drip hose walls and drippers (Netafim, 2012).

There are two waves of contaminants that workers should be aware of when flushing irrigation lines. The first wave is the removal of solid materials that are collected at the downstream portions of drip hoses. The second wave is the result of flushing effect due to velocity previously described. The coloring of the second wave will not be as dark as the first wave and will occur some time after the first wave. Vineyard mainlines, sub-mains and drip hoses should be flushed until water draining from lines flows clear for at least two minutes. Netafim (2012) provides the following flushing time calculation as:

$$\textbf{Flushing time}\text{ (minutes)} = \frac{\text{Length of pipe (meters)}}{\text{Flow rate (m/sec)}} \text{ X } 60$$

System Maintenance

Regular observations of system performance and routine maintenance is essential to maintaining a high DU. Start evaluating system performance as soon as it is installed and annually after. Perform regular pump testing and record applied water with a flow meter. Baseline readings of flow, pressure and condition of flush waster will provide guidance on when irrigation system maintenance should be scheduled (Bisconter, 2018). Emission flow rates and pressures can be taken regularly at predetermined points in the field. The Irrigation Association (2017) agrees that documenting how well a system is performing can help a grower understand how water is being distributed across their field. By looking at how the system changes over time, an indication of emission device performance and effect of maintenance practices can be understood.

Filtration system maintenance is one of the most important practices for maintain high DU. Filters should be inspected periodically for clogging, tears or corrosion and disk filters inspected for wear or clogging of the grooves within the disk stack. Check O-rings for wear. Drain sand media filters and allow to dry out so that sand levels can be check and sand inspected for signs of degradation. Inspect backflush systems to verify that excess sand is not exiting the filter during backflush. Chlorinate filters periodically to prevent growth of micro-organisms (Bisconter, 2018).

A proactive approach to irrigation system maintenance allows managers to anticipate problems before they shut down operations completely. This has a positive impact on irrigation efficiency, while a reactive approach that waits for problems to occur means that water is wasted. Tracking maintenance procedures and their associated costs can help managers make decisions on when system components need to be modified, upgraded or replaced (Irrigation Association, 2017).

Control Pests

Vineyard managers must also consider the impact of animals and insects on irrigation system efficiency. Burt and Styles (2016) note unusual circumstances where fresh water clams grow inside hoses, or insects that choose to nest in emitter orifices. Rodent, mammal and insect damage to drip hoses is more commonly observed. Burt offers the following solutions for controlling pests.

1. Using thick wall tape
2. Turning on the irrigation system as soon as the tape is installed
3. Killing insects with chemicals such as Vapam, Ridamil and Diazinon
4. Using owl boxes to control gophers
5. Using “noise” to frighten animals away
6. Providing water basins in the hope that critters will drink from them rather than chew on drip lines
7. Providing cow bones to play with rather than drip lines
8. Eliminating the animals

Bisconter (2018) agrees that drip hoses are susceptible to mechanical damage by mammals, rodents and insects, and pests must be managed or controlled. She offers the following solutions in addition to chemigation:

1. Using repellents to keep animals away from the lateral lines – injected through the irrigation system – anhydrous or aqua ammonia or insecticides
2. Baiting or trapping to control the animal population
3. Elimination of the animal’s food supply
4. Providing a drinking water source other than the lateral lines.

Conclusion

The DU of a vineyard drip irrigation system will degrade over time, but the age of the vineyard is not necessarily related to a low DU (Burt and Styles, 2016). Some vineyards can, by poor design, start with a less than ideal DU, but it is possible to maintain DU over time with good management practices. The ITRC has documented excellent DU values on many vineyard irrigation systems well over 10 years old. What these systems have in common is good initial design consistent hose flushing, chemical filtration and well-functioning filtrations units.

REFERENCES

Bisconter, Inge. 2018. Toro Ag Owner's Manual 3rd Edition: English and Metric Units.

Burt, Charles M. 2004. Rapid field evaluation of drip and micro spray distribution uniformity.

Burt, Charles M. and Styles, Stuart W. 2016. Drip and Micro Irrigation Design and Management for Trees, Vines and Field Crops, Practice plus Theory. 5th Edition.

Irrigation Association. 2017. Principles of Efficient Agricultural Irrigation.

Netafim. 2012. Guidelines for Irrigation System Maintenance.

Prichard, Terry L. 2000. Establishing the Vineyard, Vineyard Irrigation Systems.

Stubbs, Megan. 2016. Irrigation in U.S. Agriculture: On-Farm Technologies and Best Management Practices.