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2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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Status of Microsprinkler System Design, Operation, and Maintenance in 2010

Brian Boman

University of Florida, Indian River Research and Education Center, 2199 South Rock Road, Fort Pierce, FL 34945. Email: bjbo@ufl.edu

Blake Sanden

University of California Cooperative Extension, 1031 S. Mt. Vernon Ave., Bakersfield, CA 93307. Email: blsanden@ucdavis.edu

Troy Peters

Washington State University, AREC - Prosser, 24106 N. Bunn Road, Prosser, WA 99350. Email: troy_peters@wsu.edu

Larry Parsons

University of Florida, Citrus Research and Education Center, 700 Experiment Station Road, Lake Alfred, FL 33850. Email: lparsons@ufl.edu

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Abstract*. Microsprinkler irrigation is often the preferred method of irrigation for tree and vine crops since it provides a greater degree of freeze protection than drip irrigation and provides water and energy savings over sprinkler and flood irrigation methods. With chemigation, microirrigation also provides an economical method of applying fertilizer and other agricultural chemicals on a timely basis. However, microsprinkler systems generally require more maintenance than drip or overhead systems, and they require a higher level of management expertise than sprinkler or flood irrigation methods. This paper discusses the current status of design, operation, and maintenance of microsprinkler systems and the benefits and limitations of these systems for several agricultural crops. Types and characteristics of available microsprinklers are discussed in relation to appropriate* *application considering crops, soils, and management philosophy. Topics include uniformity, clogging, insect problems, wetting patterns, emitter maintenance, chemigation, system evaluation, management for both young and mature trees, crop response, and freeze protection.*

Keywords. *Microirrigation, microsprinkler, orchard, design, operation, maintenance*

Introduction

Microsprinkler systems are primarily used to irrigate tree crops and some vine crops also use microsprinklers. Areas with the highest concentrations of irrigated tree crops include the Pacific Northwest, California, and Florida (Fig. 1). In addition to fruit and nut crops (e.g. apple, almonds, citrus, pecan, peach, palm, avocado, etc.), microsprinklers are often used to irrigate woody ornamentals in container and in-ground ornamental nursery production and also trees and shrubs in landscapes. The system designs are similar to other microirrigation systems, but microsprinkler systems generally tend to require higher flow rates per unit area. Typically, microsprinkler installations have one 40-75 L/h (10-20 gph) emitter per tree. The most common (spray) emitters have slotted caps or deflector plates which distribute water in distinct streams. Other designs (spinners) have a moving part that rotates to disperse the water stream more uniformly over the wetted diameter.

Figure 1. Irrigated lands in orchards - 2007. (Adapted from Map 07-M234, USDA, Nat'l Ag Statistics Serv., 2007 Census of Agriculture.)

Advantages and Disadvantages of Microsprinkler Systems

Microsprinkler systems have some distinct advantages over other irrigation methods including:

- Water savings - Microsprinkler systems use less water than overhead or surface irrigation methods due to higher application efficiencies.

* Freeze protection - Microsprinklers are often the preferred microirrigation method for

tree crops since they provide a greater degree of freeze protection than drip systems and do not cause tree collapse from the accumulated weight of ice common when overhead sprinklers are used for freeze protection.

- Frequent applications - The ability to maintain adequate soil water levels by applying small amounts of water at frequent intervals during critical growth stages is beneficial for several tree crops. Microsprinkler systems can often be economically designed for automatic operation and include features such as real time ET based scheduling. They can also incorporate sensors to start and/or stop irrigations.
- Wetted area - Microsprinklers are often preferred over drip systems in areas with coarse textured soils where lateral movement of soil water is limited. The larger wetting patterns of microsprinklers cover a higher percentage of the rooting area. To cover the same area with drip would require many more drip emitters, additional tubing costs, and much more complication than a single microsprinkler. Therefore, these systems generally require less management effort than drip systems.
- Chemigation - Microsprinklers provide an economical method of applying fertilizer, pesticides, and other agricultural chemicals on a timely basis.
- Reduced evaporation - Microsprinkler systems on tree crops can result in significantly lower annual water applications compared to flood or sprinkler irrigation, mainly due to higher application efficiencies and avoiding applications to non-productive areas. These water savings are especially evident in the early years of an orchard when trees are small and have limited root zones.
- Lower plant disease problems – When used under trees, the tree leaves don't get wet and this reduces problems with diseases that are encouraged by leaf wetness.
- Weed control - The limited wetted area of microsprinklers compared to flood and overhead sprinklers often results in the additional benefit of reduced weed growth in non-wetted areas.
- Cost - Microsprinkler systems have a considerably lower initial cost than permanent solid set sprinkler systems for widely spaced tree crops. In addition, due to lower pressure requirements, power costs for microsprinkler systems are also less than for overhead sprinklers.
- Flexibility - Although microsprinkler systems require higher flow rates per unit area than drip systems, the run time required to apply an equivalent amount of water is less. This can be important for multi-zone systems when irrigation must be interrupted for other cultural practices such as pesticide applications, mowing, and harvesting.
- Improved field access – Since microsprinkler systems do not have the furrows, ditches, and basins associated with gravity irrigation, access for equipment and vehicles is generally much more convenient.

Microsprinkler systems have some distinct disadvantages compared to other irrigation methods including:

- Management level - Microirrigation systems can require a higher level of management expertise than other irrigation methods due to frequent operation, low application rates, small emitter orifices, and wetting patterns that cover only a fraction of the root zone.
- Maintenance - Microsprinkler systems require more maintenance than conventional overhead sprinkler or surface irrigation systems. In addition, microsprinkler stake assemblies are prone to be damaged or knocked askew during normal orchard

operations such as mowing, pesticide application, and harvesting.

- <u>Frequent operation</u>-With microsprinkler systems, irrigations must be scheduled more frequently than with overhead sprinkler or surface irrigation systems since the microsprinklers wet only a fraction of the root zone. Automation may be required to efficiently utilize labor and still meet crop demands in systems where irrigation durations are relatively short and multiple irrigations per day are needed.
- <u>Discharge into air</u> - Since microsprinklers discharge water streams into the air, the application losses are generally greater than with drip systems. In areas with high-salinity irrigation water, trees may receive spray damage from wind-blown water that comes in contact with trunks and foliage.
- <u>Cost</u> - Microsprinkler systems generally have higher initial costs than comparable drip systems since the discharge rate per unit area of the emitters is greater. As a result, pumps, filters, and the piping network need to have greater capacities.

Emitter types

Microsprinkler emitters are available with a wide range of flow rates, coverage pattern, and pressure requirements. Manufacturers are continually improving and/or introducing new microsprinkler models to satisfy the market demands. However, all of the commonly used emitters can be classified into 3 categories based on their method of operation: orifice control, vortex control, or pressure compensating.

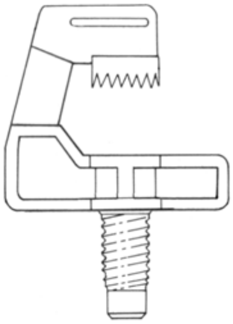
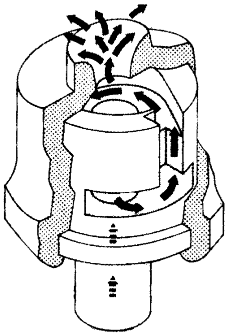


Figure 2. Orifice control (turbulent flow) microsprinkler emitter.

<u>Orifice control emitters</u>

The most common microsprinklers are orifice control emitters where the flow rate at any given pressure is governed primarily by the orifice diameter (Fig.2). Orifice control emitters are turbulent flow devices where the flow rate is regulated by dissipating energy by friction of water against the walls of the passages and between the fluid particles themselves. Turbulent flow emitters have shorter flow paths and larger diameter passages than the laminar flow devices. Thus, flow velocities are greater and the potential for clogging is less than for laminar flow devices. Flow rates are less sensitive to pressure (emitter exponent is about 0.5) and less sensitive to water temperature than are laminar flow devices.

With orifice control emitters, the base (orifice diameter) of the emitter determines the flow rate. The top of the emitter determines the pattern and diameter of spread. Numerous types are available from various manufacturers. As pressure increases, water is thrown farther from the emitter which results in an increased effective coverage area. However, the diameter typically increases more than the flow, so the application rate (expressed in depth per hour) normally decreases as the wetted pattern increases.



<u>Vortex Control Emitters</u>

Figure 3. Vortex control microsprinkler emitter.

Vortex control emitters (Fig. 3) are less sensitive to pressure variations than laminar or turbulent flow emitters (emitter exponent is about 0.4). In vortex emitters, water is forced to circulate forming a vortex or whirlpool at the center of the emitter. As the water rotates, centrifugal force pushes it towards the outer edge of the vortex. This action causes a low pressure area to be formed in the center, where the orifice is located. The result is a reduction in the energy of water at the discharge point, and a controlled flow rate. Emitter flow rate is controlled by vortex design and orifice diameter.

Pressure Compensating Emitters

Pressure compensating emitters (Fig. 4) use excess inlet pressure to modify the shape, length, or diameter of the flow path to control the flow rate. Generally, there is a diaphragm made of an elastic material that deforms to control the flow rate. As the pressure increases, the diaphragm restricts the passage diameter. Pressure compensating emitters are designed to discharge at a fairly constant rate over a wide range of pressures (emitter exponent is normally less than 0.1).

One of the drawbacks of pressure compensating emitters is the elasticity of the diaphragm may change over time. As a result, the flow and pressure compensation characteristics may change over time. In addition, diaphragms will often retain some moisture when the pressure is off. The moisture may allow bacteria growth within the emitter. As a result, emitter clogging may occur. Another problem can result from the invasion of ants seeking a food source. The ants may feed on the bacteria and destroy the diaphragm. Additionally, when the system is pressurized, ants and ant body parts may clog the emitter.

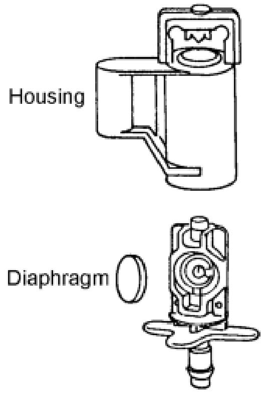


Figure 4. Components of pressure compensating microsprinkler emitter.

Emitter Wetting Patterns

Wetting patterns of microsprinklers can be an important consideration in sandy soils or where root zones are shallow. Boman (1989a) evaluated several microirrigation spinner and spray emitters to determine their distribution patterns under no-wind conditions. Spinner-type emitters were found to have much higher application uniformities than the spray-type emitters. Both types of emitters had higher uniformity when the pressure was 138 kPa (20 psi) or higher compared to 103 kPa (15 psi). Spinners had most of the wetted area receiving near-average application depths, with nearly continuous wetting throughout the pattern (Fig. 5a). Spray-type emitters were characterized by wetted spokes radiating from the emitter (Fig. 5b). The spray-type emitters typically had 50-75% of the area within the coverage diameter receiving little or no wetting. Lateral movement of water in the soil may help compensate for this in the root zone to varying degrees depending on the soil type.

In general, larger wetting patterns are considered more satisfactory for tree crops. However, larger pattern emitters need a corresponding flow rate to make it possible to manage them effectively. When the average flow rate per unit wetted area decreases to less than 2 mm per hour (0.08 in per hour), it requires very long run times to move the water into the mid and lower root zone with microsprinklers. Typically, there is more potential for wind drift, evaporation, and wetting of non-productive areas as the diameter of wetting increases. In high density plantings, it is normally most effective to provide each tree with a smaller pattern emitter than to install larger pattern emitters on every other tree. The wetting pattern from larger pattern emitters is often distorted by interference from tree trunks and low branches, resulting in shadows in the coverage pattern. The smaller wetting patterns provide more inter-tree wetting, resulting in more efficient water applications. However, small wetting patterns associated with low flow rates can lead to more plugging problems, particularly with the orifice control emitters.

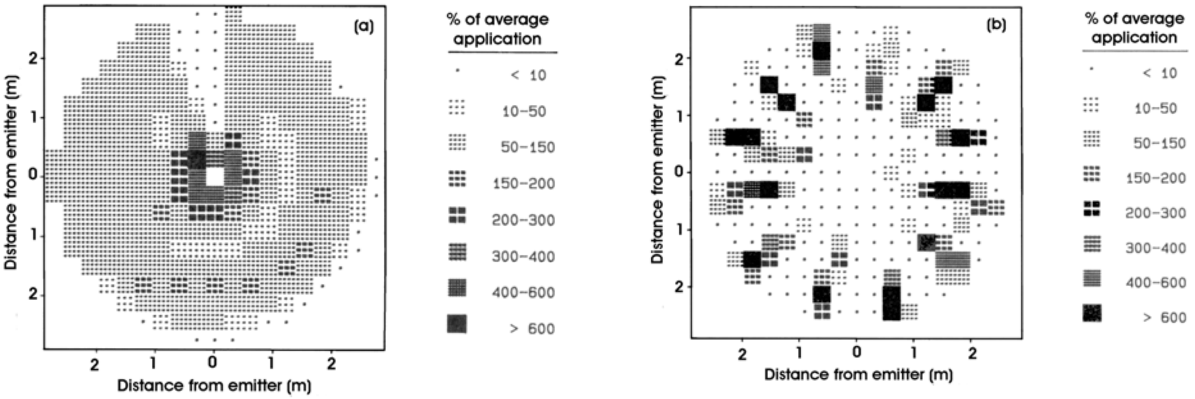


Figure 5. Catch distribution patterns of 1.02 mm diameter (0.04 inches), orifice-control, emitters operated at 138 kPa (20 psi) for 6 hours for spinner-type (a) and spray-type (b) designs.

Stake assemblies

Emitters are normally attached to stake assemblies that raise the emitter about 0.2 m (8 inches) above the ground (Fig. 6). The elevated position of the emitters provides a larger wetting pattern, and allows water to be dispersed over low-lying weeds and grass. The stake assemblies usually have 4 mm nominal inside diameter (ID) tubing made of vinyl or polyethylene (PE). Microtubing (spaghetti tubing) commonly has an outside diameter (OD) of about 6.4 mm, with an ID of 3.6 mm for vinyl and 4.1 mm for polyethylene. The length of microtubing used on a stake assembly depends on grower preference, but typically is 0.6 to 1.2 m (2 to 4 ft) long.

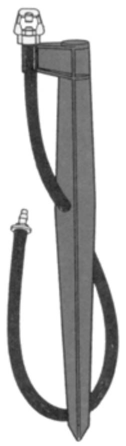


Figure 6. Microsprinkler stake assembly

System Design

Microsprinkler systems are typically designed with a single microsprinkler per tree placed midway between trees in the row, or with two microsprinklers per tree placed on either side and throwing away from the tree in a partial circle pattern (such as a 270-degree pattern). The advantage of the dual microsprinkler design is that water is sprayed away from the tree's crown, which may result in reduced disease problems.

Because microsprinklers have small orifices and narrow tubing, plugging can be a significant concern. Therefore, most systems are designed with filtration systems similar to drip irrigation, only without as fine a filtration requirement as drip. The most common filtration systems are sand media, screen, and disk filters. The type that is best depends on the system flow rate, the filtration requirement, and the particulate load of the supply water.

Most growers also take advantage of the chemically resistant properties of the microsprinkler system to chemigate and fertigate. This provides cost and labor savings as well as worker protection to apply chemicals and fertilizers. The system must be designed to EPA requirements to protect the water sources and accidental spills and/or crop damage.

Freeze protection

Microsprinkler irrigation has been shown to be effective in providing good protection for young trees and partial protection of mature trees (Fig. 7). In one study, lower leaves in the direct water spray zone stayed above freezing and were as much as 7.8°C warmer than dry leaves in non-irrigated plots (Parsons et al., 1981). Other work showed that microsprinklers maintained trunk temperatures near -1.1°C when minimum air temperature reached -9.4°C in a freeze with winds exceeding 32 km/h (Davies et al., 1984). However, improper use of water can increase evaporative cooling or ice loading and cause greater damage than if no water were used at all.

The energy released when the irrigation water drops from its initial temperature to 0°C contributes sensible heat. When temperatures drop below freezing, the latent heat of fusion is released when the water freezes. As long as enough water is continuously applied to a plant, the heat generated when water freezes can keep the plant at or near 0°C. At very low temperatures, low humidity, or high winds, more water must be applied to get adequate protection.

Microsprinklers can also raise the dew point or frost point temperature in the orchard. When the temperature drops to the frost point, heat is released as the water vapor is converted to ice crystals. When the air temperature reaches the dew point temperature, the rate of cooling slows down because heat is released as the water vapor in the air condenses. It has been suggested that microsprinklers can provide some protection above the spray zone because moist air rises and condenses higher up in the canopy.

Figure 7. Microsprinkler used for freeze protection on young citrus tree.

Depending on the dew point temperature, microsprinklers can sometimes create fog on cold nights. Fog is beneficial for frost protection, and if the fog is dense enough and the droplets are of the proper size, the rate of cooling can be slowed since fog can act like a blanket and reduce the rate of radiation loss (Parsons and Boman, 2003).

If the water application rate is high enough on the trunk of a young tree, it will be protected by the ice formation. However, on the edge of and outside of the iced zone (reach of the microsprinkler), temperatures will not be maintained at $0^{o}C$, and those parts will probably be damaged or killed.

Microsprinklers can provide some protection to leaves and wood, particularly on the lower and inner part of the canopy. A dense canopy tends to retain heat from the soil and provide better protection than a thin canopy. Damage will commonly be seen on the outer and upper parts of the tree after severe freezes. Since fruit is more sensitive to cold temperatures than leaves or wood, microsprinklers generally do not protect the fruit. At higher volumes, microsprinklers will help protect fruit a little better than no irrigation. Therefore microsprinkler irrigation is better for tree protection than fruit protection.

In young trees, the microsprinkler must be close enough to the young tree so that water sprays directly on the trunk and lower part of the tree. Emitters that produce a 90^{o} or 180^{o} pattern concentrate the water on the young tree and provide better protection than 360^{o} patterns. If the microsprinkler is too far away from the young tree, wind can blow the water away. If the water freezes before it hits the tree, milky white ice can form on the tree. Protection under milky ice is usually not as good as under clear ice. It is best to put the microsprinkler on the upwind side of the tree, 0.4 to 0.7 m from the trunk, since emitters on the downwind side of young trees have caused significantly more damage than no irrigation because of evaporative cooling (Parsons et al., 1985).

While microsprinklers are best at protecting young trees, they also provide partial protection of mature trees. The greatest benefit has been observed in calm frosts, but there have been several examples of improved recovery of mature trees when microsprinklers have been used in windy freezes. In a relatively calm frost, microsprinklers benefited trees over 4 m tall. Tree recovery and leaf canopy density 3 months after a freeze were better where microsprinklers were operated in an orchard compared to where they were not operated (Oswalt and Parsons, 1981).

In general, the higher the volume of water provided by microsprinklers, the more effective the cold protection will be. Temperatures where microsprinklers flow rates were 6.2 L/sec per ha (40 gpm/acre) were $0.1\text{-}1.0^{O}C$ warmer than with 2.3 L/sec per ha (15 gpm/acre) (Schwankl et al., 1996). Recommendations of water volume needed for adequate frost protection generally are about 19 m^3/ha-h (34 gpm/acre). Emitters with greater output provide more protection, with an application rate of 28 m^3 / ha-h (50 gpm/acre) providing even more cold protection (Parsons, 1984). Application rates this high often exceed a soil's infiltration rate and will result in ponding and runoff if the system is operated at this rate for the remainder of the irrigation season. For comparison, in eastern Washington state, most systems are designed to provide only 1.1 to 1.2 L/sec per ha (7 to 8 gpm/acre) to meet maximum crop water use requirements. Adding frost protection to microsprinkler systems increases initial costs by 30- 40% while increasing annualized costs approximately 10% (Snyder et al., 1996). The size of system components depends primarily on the flow rate in pipelines, filters, and pumps. Since most all component must be larger for freeze protection, costs increasing accordingly.

Operation and Maintenance of Microsprinkler Systems

Evaluating pattern uniformity for spinner-emitters is much easier than for spray-emitters due to the distribution of water relative to the emitter. To evaluate spinners, catch cans should be placed at intervals of 0.3-0.4 m (1 to 1.3 ft) in two or more radial legs from the emitter. The cans can be of any size, but all should be of the same height and diameter. The system should be run for one hour or more, at which time the volume of water caught in each can should be measured with a graduated cylinder. As a general rule of thumb, at least 50% of the catch cans should receive near-average application depths.

Figure 8. Catch cans laid out to conduct uniformity analysis for microsprinkler emitter. Kern County, CA.

Evaluating distribution uniformity for spray-type emitters with catch cans is more difficult due to the elongated, alternating, wet and dry surface patterns around the head (Fig. 8). This petal pattern makes it difficult to place the cans directly under the spray jet or in the petal pattern itself. In addition, interpretation of any catch can data may not truly reflect sub-soil water redistribution. Visual observations of soil wetting patterns from each radial leg should be used for evaluation of spray-type emitters. The ideal distribution should resemble a petal pattern along each radial. The more uniform each radial leg is in creating a petal pattern, the more uniform will be the wetting throughout the rootzone surrounding the tree. Microspirnkler systems typically have poor surface uniformity of application for any one emitter, but high distribution uniformities across the orchard (Table 1), with DU values averaging 80-85%, and capable of 95% DU with high maintenance and in-field pressure regulation

Table 1. Distribution uniformity (DU) of 448 evaluations of microsprinkler systems conducted by the Northwest Kern Resource Conservation District Irrigation Mobile Lab from 1988-2006 summarized by size of system (Courtesy of Brian Hockett, Bakersfield, CA)

Size of block		No. of systems	Avg. size		DU			
(acres)	(ha)		(acres)	(ha)	Mean	Min	Max	Median
<21	<9	48	17	8	82	17	97	87
21-40	9.5-18	90	36	16	81	45	96	83
41-80	18.5-36	110	66	30	82	48	96	85
81-160	36.5-73	121	132	60	81	35	98	84
161-320	73.5-145	53	233	106	80	49	93	84
>320	>145	26	544	247	86	73	93	86
	Total	448	120	55	81	17	98	84

A soil probe can be used to measure the horizontal and vertical distribution of applied water relative to the tree's root zone. Figures 9 and 10 demonstrate the re-distribution of water in the soil after a 24 hour irrigation applied with two, overlapping spoke type microsprinklers in a Kern County, California almond orchard with sandy clay loam soil. In sandy soils, the soil should be probed between 2-4 hours following the irrigation. In most situations, trees should have at least 40% of their potential rooting zone wetted (i.e., with 4 x 7 m tree spacing (28 m^2), at least 11.2 m^2 should be watered). The soil probe will also provide information on how deep the water is moving. Excessive water movement below the crop's root zone may result in leaching of fertilizers, water-logged conditions, and/or waste of water.

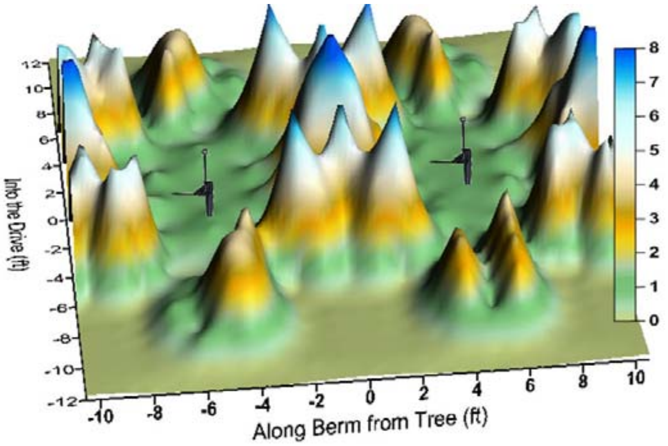


Figure 9. Distribution of water caught in catch cans for Bowsmith A-40 Fan Jet operated at 138 Kpa (20 psi) for 24 hours (1 m = 3.28 ft, 1 cm = 0.394 inch. Scale in inches. Sanden, unpublished data.).

Microsprinkler emitters are generally durable and will last many years in the field. However, wear on emitter orifices over long periods of operation can significantly increase the orifice diameter and therefore the microsprinkler flow rates and wetting patterns, especially if the irrigation water contains sand. In one study (Boman and Parsons, 1993), several combinations of flow control method, base size, and operating pressures were examined to determine their effects on long-term microsprinkler flow rates. Flow control methods were by orifice control (OC), vortex control (VC), and by pressure compensation (PC). Emitters with nominal flows of 38 L/h and 57 L/h with the three flow control methods were operated at 138 and 206 kPa for 2,000 hours. Both OC and VC emitters had increases in flow rates of 8-11% after 2,000 hours of operation. After 500 hours of operation, the 57 L/h PC emitters had reductions in flow of about 7% when operated at 138 kPa and 18% when operated at 207 kPa. These reductions in flow rate resulted from changes in the properties of the diaphragm. After 2,000 hours of operation, the flow rate of the PC emitters was about 8% less than initial values.

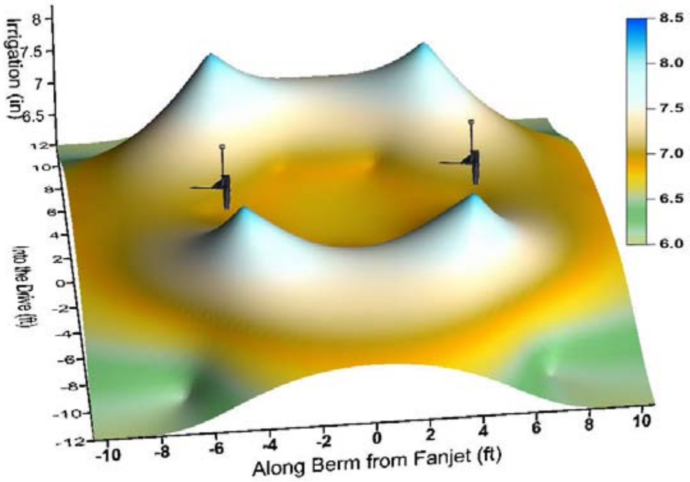


Figure 10. Root zone wetting total for 0-90cm (0-3 ft) depth by microsprinklers following 24 hour irrigation with microsprinkler as interpolated from 5 neutron probe access tubes in the wet to dry application areas (1 m = 3.28 ft, 1 cm = 0.394 inch. Scale in inches).

Microsprinkler systems need to be designed with consideration given to the effects of wear on system components. Pumps, filters, and other system components should be designed with enough extra capacity so that increases in flow rates as much as 10-15% due to wear on emitter orifices can be accommodated. The amount of increase in emitter flow rates over time depends on several factors such as operating pressure, materials used in emitter manufacturing, water source, filtration, and hours of operation. If the water contains sand or abrasive grit, the wear problem can be greatly accelerated.

Conclusion

Installed costs for microsprinkler systems in the USA range from \$2000-\$3000/ha (\$800 - \$1200 per acre) or more and represent a considerable long-term debt load for an orchard or vineyard. From 15% to 20% of the hardware costs for microsprinkler systems is associated with the polyethylene tubing and microsprinklers (Schwankl et al., 1999).

The emitter selection process should consider uniformity as well as other factors such as cost, wind effects, system constraints, maintenance, and soil type so that the best emitter for a particular field condition is selected. Wetting patterns of emitters should be compatible with the soils, tree spacing, and rooting pattern of the trees. Consideration should be given to the water requirements of mature plants. Higher density plantings with smaller trees will require less water per tree than more widely spaced plantings. Larger wetting patterns may be more desirable for more widely spaced trees. In all cases, designers should ensure that tree water requirements can be met with reasonable run times, and minimize movement of nutrients and water below the root zone.

Microsprinkler systems should be capable of applying the maximum water replacement quantity required by the crop plus any inefficiency. The emitters selected should have a coverage area sufficient to cover as much of the plant root zone as possible. Emitters should also have a sufficient application rate in the wetted area so that the required run times are compatible with the power unit and labor availability. However, the application rate should not exceed the soil’s steady-state infiltration rate in order to avoid ponding and runoff. Applying too much water at one time can lead to leaching of nutrients and pesticides. By adjusting spray diameter, irrigation duration, and emitter flow rate, microsprinkler systems can be managed to meet tree water needs while minimizing over irrigation and chemical leaching. Experience has shown that factors like application uniformity, clogging potential, wetting patterns, and ease of maintenance, are important to consider when designing, installing, operating, and maintaining microsprinkler systems.

Whatever the system design employed, it is essential that proper system filtration, flushing, chlorination, and operation procedures be followed to minimize maintenance problems. Users should verify system performance by field testing to ensure actual operation meets design standards. When repairing broken or missing emitters, original equipment should be replaced with emitters with similar flow characteristics to maintain emission uniformity within the system.

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