Drip-Irrigation Systems for Small Conventional Vegetable Farms and Organic Vegetable Farms[1]

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A drip-irrigation system—when properly designed, maintained and operated—can be a production asset for a small farm. Using drip irrigation for profitable vegetable production requires an understanding of several basic engineering and horticultural concepts and their application. The goals of this publication are to present the principles behind drip irrigation and some practical guidelines for successful and profitable use of drip irrigation.

1. Overview of Drip Irrigation

1.1 What is drip irrigation?

Drip irrigation (also known as trickle irrigation or micro-irrigation) is an irrigation method that allows precisely controlled application of water and fertilizer by allowing water to drip slowly near the plant roots through a network of valves, pipes, tubing, and emitters. Plasticulture is the combined use of drip irrigation, polyethylene mulch and raised beds. Greatest productivity and earliness may be achieved in vegetable production by combining plasticulture with the use of transplants.

1.2 Is drip irrigation adapted to all operations?

Drip irrigation is not a silver bullet; it may not be applicable to all farms. Yet, when properly managed, it is a valuable production technique that may reduce labor and production costs while improving productivity. Small farmers considering the use of drip irrigation should evaluate both the advantages and disadvantages of this system to determine the benefits of drip irrigation for their operation.

1.3 What are the main advantages of drip irrigation?

Reduced water use: Because drip irrigation brings the water to the plant root zone and does not wet the entire field, drip irrigation typically requires half to a quarter of the volume of water required by comparable overhead-irrigation systems.

Joint management of irrigation and fertilization: Drip irrigation can improve the efficiency of both water and fertilizer. Precise application of nutrients is possible using

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drip irrigation. Hence, fertilizer costs and soluble nutrient losses may be reduced with drip irrigation. Nutrient applications may also be better timed to meet plant needs.

Reduced pest problems: Weed and disease problems may be reduced because drip irrigation does not wet the row middles or the foliage of the crops as does overhead irrigation.

Simplicity: Polyvinyl chloride (pvc) and polyethylene parts are widely available in several diameters and are easy to assemble. Many customized, easy-to-install connectors, endcaps, and couplers are available in different diameters. Cutting and gluing allows for timely repairs.

Low pumping needs: Drip systems require low operating pressure (20–25 psi at field entrance, 10–12 psi at the drip tape) compared to overhead systems (50–80 psi). Many existing small pumps and wells may be used to adequately irrigate small acreage using drip systems.

Automation: Drip-irrigation application may be simply managed and programmed with an AC- or battery-powered controller, thereby reducing labor cost.

Adaptation: Drip systems are adaptable to oddly shaped fields or those with uneven topography or soil texture, thereby eliminating the underutilized or non-cropped corners and maximizing the use of available land.

Production advantages: Combined with raised beds, polyethylene mulch, and transplants, drip irrigation enhances earliness and crop uniformity. Using polyethylene mulch also increases the cleanliness of harvested products and reduces the risk of contamination with soil-born pathogens. Reflective mulches further help reduce the incidence of viral diseases by affecting insect vectors, such as thrips, whiteflies or aphids.

1.4 What are the disadvantages of drip irrigation?

Drip irrigation requires an economic investment: Drip-irrigation systems typically cost $500–$1,200 or more per acre (Table 1). Part of the cost is a capital investment useful for several years, and another part is due to the annual cost of disposable parts. Growers new to drip irrigation should start with a relatively simple system on a small acreage before moving to a larger system.

Drip irrigation requires maintenance and high-quality water: Once emitters are clogged or the tape is damaged, the tape must be replaced. Water dripping from an emitter and the subsequent wetting pattern are hard to see, which makes it difficult to know if the system is working properly. Proper management of drip irrigation requires a learning period.

Water-application pattern must match planting pattern: If emitter spacing (too far apart) does not match the planting pattern, root development may be restricted and/or plants may die.

Safety: Drip tubing may be lifted by wind or may be displaced by animals unless the drip tape is covered with mulch, fastened with wire anchor pins, or lightly covered with soil.

Leak repair: Drip lines can be easily cut or damaged by other farming operations, such as tilling, transplanting, or manual weeding with a hoe. Damage to drip tape caused by insects, rodents or birds may create large leaks that also require repair.

Drip-tape disposal causes extra cleanup costs after harvest: Planning is needed for drip-tape disposal, recycling or reuse.

1.5 How does my drip-irrigation system affect organic certification?

Growers considering certified organic production should first become familiar with the National Organic Program (NOP) (http://www.ams.usda.gov/NOP/indexIE.htm) and the principles of organic production (Ferguson, 2004a,b; Treadwell, 2006). All production inputs used in certified organic production must follow the National List of Allowed and Prohibited Substances (Code of Federal Register [CFR] 205.600 of the National Organic Program). Drip irrigation itself (standard drip tape) is allowed. Products typically used with drip irrigation in conventional production systems that may or may not be allowed in certified organic production may be classified in four groups: water, products for drip-irrigation maintenance (algaecides, disinfectants and acids), fertilizers, and pesticides (Table 2).

The design and maintenance of a drip-irrigation system should be clearly outlined in the Organic System Plan (farm plan required for certification), including any inputs that will be delivered through the drip-irrigation system. In all cases, contact your certifying agency before using a product to confirm that use of that product will not jeopardize organic certification.

Drip-irrigation water. In most cases, groundwater, surface water, rainwater and potable water may be used in certified organic production. In some instances, the certifying agency may request a water analysis.

Products for drip-irrigation maintenance. Within stated restrictions (see Table 2), CFR 205.601 of the NOP lists the following substances as allowable as synthetic algaecide, disinfectant, and sanitizers: (1) alcohols, including (a) ethanol and (b) isopropanol; (2) chlorine materials [except that residual chlorine levels in the water shall not exceed the maximum residual disinfectant limit under the Safe Drinking Water Act], including (a) calcium hypochlorite, (b) chloride dioxide, (c) sodium hypochlorite; (3) hydrogen peroxide; and (4) soap-based algaecide/demisters. Additionally, under NOP Rule CFR 205.105, citric acid is allowed when irrigation water needs to be acidified. (See Section 4.2 of this paper for why and how much). However, other compounds commonly found in readyto-use drip-irrigation cleaners and maintenance products and typically used inconventional systems (see Section 4.2, below) are prohibited in certified organic production.

Fertilizers and pesticides. No specific ruling prohibits NOP-compliant products from being distributed through a drip-irrigation system. Plans to use drip irrigation to distribute fertilizers and/or pesticides should be clearly outlined for approval in the Organic System Plan. When in doubt, consult first with your certifying agency. All growers are obligated to follow state and federal guidelines for injecting inputs through irrigation systems (see Section 2.0, below).

1.6 Is drip irrigation considered a Best Management Practice?

Yes. Best Management Practices (BMPs) are cultural practices that help reduce the environmental impact of production while maintaining or increasing productivity. The BMP program for vegetables grown in Florida is described in "Water quality/quantity best management practices for Florida vegetable and agronomic crops" (Florida Department of Agriculture and Consumer Services, 2005). The BMP manual describes all the BMPs that apply to vegetable production, as well as a decision-tree to identify the BMPs that apply to each operation and guidelines for completing and submitting the Notice of Intent to Implement (Gazula et al., 2007).

Participation in the Florida BMP program and the organic certification program are two separate processes. Vegetable growers who are enrolled in the statewide BMP program receive three statutory benefits: (1) a waiver of liability from reimbursement of cost and damages associated with the evaluation, assessment, or remediation of nitrate contamination of groundwater (Florida Statutes [F.S.] 376.307); (2) a presumption of compliance with water-quality standards (F.S. 403.067 (7)(d)), and (3) eligibility for cost-share programs (F.S. 570.085 (1)).

Specific vegetable BMPs that address drip irrigation include BMP 33 "Optimum fertilization application/management", BMP 34 "Chemigation /fertigation", BMP 39 "Irrigation system maintenance and evaluation", and BMP 47 "Plasticulture farming". Additional BMPs involving drip irrigation include BMP 26 "Soil testing/soil pH", BMP 36 "Water supply" and BMP 40 "Irrigation scheduling". BMP implementation requires record keeping (see Table 3). When properly implemented, all BMPs that apply to drip irrigation help to increase efficiency in the use of water and nutrients.

1.7 What is the best way (or best unit) to express irrigation rates when drip irrigation is used?

For irrigation systems that entirely wet the field (overhead or flood systems), irrigation rates are typically expressed in inches. This unit of measurement represents a vertical amount of water (or a height). The actual "volume" of water is calculated by multiplying the height of water by the field surface. For example, 1 acre inch is the volume of water present on a 1-acre-field with a 1-inch-depth: 1-acre-inch = 27,154 gallons.

Because drip irrigation does not wet the entire field, expressing drip-irrigation volumes as a height of water poorly represents reality. Instead, drip-irrigation volumes should be expressed in gallons-per-100-linear-foot-of-drip-tape. In some cases, drip-irrigation volumes can be converted to and from water heights by considering the relative surface of the field under plastic mulch. For example, the relative surface under plastic mulch of a 1-acre-field with 30-inch-wide beds of 4-ft centers is 62.5% (2.5 ft/4 x 100). Hence, if 0.5 acre inch needs to be applied to that field through a drip-irrigation system, the total volume of water needed is 8,484 gallons (27,150 / 2 x 0.625). Because in a 1-acre-field with beds of 4-ft centers there are 10,890 linear-bed-feet of plastic, the drip-irrigation rate should be reported as 78 gallons/100ft (8,484/108.90). If a drip tape with a 24-gal/100-ft/hr flow rate is used, it will take 3 hours and 15 minutes to apply this amount of water (78/3 = 3.25 hrs).

In heavy soil, it is reasonable to assume that a drip tape installed in the middle of the bed will be sufficient to wet the entire bed width. However, research has shown that, on Florida's sandy soils, the wetted width seldom exceeds 18 inches (1.5 ft) when a single drip tape is used. Hence, the assumption made in the calculation above—that the entire bed width is wetted (and, therefore, irrigated)—is not correct for most drip-irrigation systems in Florida. The actual wetted width should be used in place of the bed width.

2. Components of a Drip-Irrigation System

The type and sequence of components in a drip-irrigation system are typically the same for all field sizes. Yet, based on field size (and water need), component sizes (diameter) may vary. Larger components tend to be more expensive. The backflow-prevention devices—comprised of two check valves and the lowpressure drain, also known as "anti-siphoning device"—are the only components required by Florida law (FS 487.021 and 487.055 and Florida Department of Agriculture and Consumer Services Rule 5E-2.030) when fertilizer or chemicals are injected into the system (see Section 2.6, below). The actual selection of a specific component (with the exception of the backflow-prevention device) generally needs to be made on a case-by-case basis. (See Table 11 for additional readings on this topic.) The following is a brief description of the main components of a typical drip-irrigation system.

2.1 Water Source

Common water sources for drip irrigation are surface water (pond, river, and creek), groundwater, and potable water (from municipality, county or utility company) (Figure 1). Use the water source that will provide the largest amount of water of greatest quality and lowest cost. Potable water is of high, constant quality, but is by far the most expensive.

Figure 1. This pond provides surface water for the irrigation of strawberry.
Credits: Eric Simonne.

2.2 Pumping System

The role of the pumping system is to move water from the water source to the field through the distribution system. Pumping systems may be classified as electric powered systems, gas/diesel powered systems, and gravity systems. Gas/diesel pumps offer the greatest versatility in isolated fields (Figure 2).

Figure 2. Diesel engines mounted on a trailer offer the greatest flexibility of use.
Credits: Eric Simonne.

2.3 Distribution System

The role of the distribution system is to convey the water from the source to the field. Distribution systems may be above ground (easily movable) or underground (less likely to be damaged). Pipes are most commonly made of PVC or polyethylene plastics. Aluminum pipes are also available, but are more difficult to customize, cut, and repair. The size and shape of the distribution system may vary widely from field to field and from farm to farm.

2.4 Drip Tape (or Drip Tube)

The drip-irrigation system delivers water to each plant through a thin polyethylene tape (or tube) with regularly spaced small holes, called emitters. Selection of drip tape should be based on emitter spacing and flow rate. The typical emitter spacing for vegetables is 12 inches, but 8 inches or 4 inches may be acceptable. Dry sections of soil may develop between consecutive emitters when a wider emitter spacing (18 inches) is used on sandy soils. Flow rates are classified into low flow (<20 gal/100ft/hr), medium flow (20 to 30 gal/100ft/hr) and high flow (>30 gal/100ft/hr). The risk of emitter clogging is generally higher with the lower-flow drip tapes.

The following equivalent units are commonly used to report flow rates: gallons/100ft/hr or gallons/emitter/hr. For example, with a 12-inch emitter spacing, 24 gallons/100ft/

hr = 24/100 = 0.24 gallons/emitter/hr. In the field, drip-irrigation tape should be installed with emitters upward (looking up) to prevent clogging from sediment deposits settling in the emitters between irrigation events. Drip tapes are widely available from several manufacturers

Figure 3. Drip tapes can be distinguished and recognized by their features. Note the emitter (on the four tapes on the right) and the turbulent flow channels (on the two tapes on the left).
Credits: Eric Simonne.

2.5 Injectors

Injectors allow the introduction of fertilizer, chemicals and maintenance products into the irrigation system. Florida law requires the use of an anti-siphoning device (also called backflow-prevention device) when fertilizer, chemicals or any other products are injected into a drip-irrigation system (Figure 4). Backflow-prevention devices ensure the water always moves from the water source to the field. The devices prevent chemicals in the water from polluting the water source.

Figure 4. Back-flow prevention made of two ball valves and a vacuum breaker are placed upstream of the Venturi injector.
Credits: Eric Simonne.

The most common injectors used with small drip-irrigation systems are the Venturi (or Mazzei) injector (Figure 4) and the Dosatron (Figure 5). Because Venturi injectors involve no moving parts and are less expensive, they are commonly used on small farms (Table 2). The injector is typically located as close as possible to the irrigation zone, but before the filter.

Figure 5. Injection made possible with a Dosatron.
Credits: Eric Simonne.

2.6 Filtration System

Because drip-irrigation water must pass through the emitters, the size of the particles in the water must be smaller than the size of the emitter to prevent clogging. Nearly all manufacturers of drip-irrigation equipment recommend that filters be used. The manufacturer generally will not honor warranties unless filters are used.

The filtration system removes "large" solid particles in suspension in the water. Different types of filters are used based on the type of particles in the water. Media filters (often containing angular sand) are used with surface water when large amounts of organic matter (live or dead) need to be filtered out. Screen filters or disk filters may be used with groundwater (Figure 6). A 200-mesh screen or equivalent is considered adequate for drip irrigation. When the water contains sand, a sand separator should be used.

Figure 6. Disk filters are made of stacked disks with small openings. They are usually color coded to indicate the filtration mesh.
Credits: Eric Simonne.

Rapid clogging may occur when no filter or the incorrect type of filter is used. A filter needs to be cleaned when the difference in pressure across the filter (measured before and after the filter) is greater than 5–8 psi. A drip-irrigation system should never be operated without a filter even if the filter requires frequent cleaning. Failure to use a filter will result in clogged drip-tape emitters, often resulting in poor uniformity and sometimes in crop loss. The filter should be cleaned as often as needed. Efforts should be made to understand the cause of the rapid clogging, and remediation for the problem should be developed.

The presence of the filter after the point of fertilizer injection means totally soluble fertilizers must be used. Otherwise fertilizer particles may contribute to filter clogging. Conventional growers may use two types of fertilizer materials: ready-to-use true solutions or dissolved granular fertilizer. Ready-to-use solutions are easily injected. However, granular fertilizers are sometimes coated with a thin layer of oil to prevent dusting. Upon dissolution of the fertilizer granules, an oily film may form at the surface of the solution. Injecting the oily film together with the fertilizer may contribute to filter and emitter clogging. Certified organic fertilizers are seldom true solutions (they may be suspensions or dilute colloidal solutions), and may also contribute to filter clogging. Consequently, the actual fertilizer rate applied may be reduced by the amount of fertilizer particles trapped by the filter. In both cases, small-scale trials may be needed to assess the clogging risk of each fertilizer material used.

2.7 System Controls

System controls are devices that allow the user to monitor how the drip-irrigation system performs. These controls help ensure the desired amount of water is applied to the crop throughout the growing season.

Pressure regulators, installed in-line with the system, regulate water pressure at a given water flow (Figure 7), thereby helping to protect system components against damaging surges in water pressure. Pressure surges may occur when the water in the pipe has a velocity >5 feet /second ("water hammer") or when water flowing in the pipe has no avenue for release due to a closed valve or a clog in the pipe.

Water meters monitor and record the amount of water moving through a pipe where the water meter is installed (Figure 8). When a stopwatch is used together with a water meter, it is possible to determine the water flow in the system in terms of gallons-per-minute.

Figure 7. Pressure regulators are installed side-by-side in this system to allow a greater flow rate. Note the small injection port for chemical injection.
Credits: Eric Simonne.

Figure 8. Water meters installed near the field.
Credits: Eric Simonne.

Pressure gauges monitor water pressure in the system and ensure operating pressure remains close to the recommended or benchmark values. Based on where the pressure gauge is installed, it will measure water pressure in a various ranges, from 0-100 psi near the pump to 0-20 psi at the end of drip tape (Figure 9). Pressure gauges may be installed at set points (near the pump, before and after the filter, near the field; see Figure 10). They can also be mounted as portable devices and installed temporarily at the end of a drip tape.

Figure 9. A portable pressure gauge measures pressure at the end of the drip tape.
Credits: Eric Simonne.

Figure 10. A fixed pressure gauge. Note the needle bathing in oil to prevent needle vibration and damage.
Credits: Eric Simonne.

Soil-moisture-measuring devices (such as tensiometers, capacitance probes or Time Domain Reflectometry probes) are used to measure soil moisture in the root zone of the crop (Muñoz-Carpena, 2004). The Florida Extension Service recommends maintaining soil-water tension between 8 and 12 centibars 6 inches away from the drip tape and at the 12-inch-depth.

Electrical timers connected to solenoid valves (Figure 11) may be used to automatically operate a drip-irrigation system at pre-set starting and ending operating times of day.

Figure 11. Solenoid valves connected to a timer allow sequential irrigation of different zones.
Credits: Eric Simonne.

3. Tips for Design and Layout

Irrigation engineers are trained and certified to properly design drip-irrigation systems. Relying on their expertise will pay off in the long run. Many small-scale growers abandon drip irrigation because of poor performance of flawed designs or inadequately modified designs. Do not hesitate to ask for professional help when designing your drip-irrigation system or when planning major modifications to an existing system. The following section presents the basics of system design, but is not a substitute for the professional services of a qualified engineer.

3.1 Planning a Drip Irrigation System: Horticultural Considerations

The goal of drip irrigation is to bring water to the crop. The main parameters that determine crop water use are the type of crop planted and row spacing. A drip irrigation system should be able to supply 110%–120% of crop water needs. In other words, the system should be slightly oversized. In designing a drip-irrigation system, it is common to consider that vegetable crops ordinarily need approximately 1.5-acre-inches of water for each week of growth or approximately 20-acre-inches of water per crop. Actual crop water use will be more or less than this amount, depending on weather and irrigation efficiency.

3.2 Planning a Drip Irrigation System: Design Considerations

Start with what is already available—the water source or the field. If a water source is already available (pond or well), the amount of water available may be used to calculate the maximum size of each irrigation zone (Table 4).

If no water source is available, the amount of water needed by the crop—based on the size of the planted area—may be used to calculate the type of well or pond size needed (Table 5).

Lay out of beds and rows. Because differences in altitudes affect water pressure, it is preferable to lay out beds perpendicular to the slope. This arrangement of rows is called "contour farming" (Figure 12).

Figure 12. In contour farming, rows are laid perpendicularly to the natural field slope, which allows each drip tape to be parrallel to each other and contour (The drip tape is laid horizontally).
Credits: Eric Simonne.

Pipe sizing. Larger-diameter pipes are more expensive than smaller-diameter pipes, but larger-diameter pipes carry more water. All delivery mains and secondary lines should be sized to avoid excessive pressure losses and velocities and should be able to withstand a pressure of 80 psi.

Excessive pressure losses result in a large difference in pressure from the pressure level at the beginning of the line compared to the pressure level at the end of the line. Since the flow rate of the emitters is usually a function of water pressure, the water application at the beginning of the line may be very different from the water application at the end of the line. This difference will result in irregular water application on the crop.

Excessive water velocities (>5 feet/second) in the lines—the result of a too-small diameter—are likely to create a water hammer (pressure wave), which can damage the delivery lines. Growers should be aware of the maximum acreage that can be irrigated with different pipe sizes at a water velocity of 5 feet/second (Table 6).

The maximum length of drip tape should be based on the manufacturer's recommendation and the actual terrain slope. Typically 400–600 feet are maximum values for drip-tape length. Excessive length of laterals will result in poor uniformity and uneven water application. When the field is longer than 400–600 feet, consider placing the secondary (submain) line in the middle of the field—rather than at the end—and connect drip tape on both sides.

3.3 Layout Tips

A Y-connector is convenient on a drip system connected to a hose bibb because a garden hose can be connected to the other side.

To evaluate source flow rate, run water full force from an outside faucet and note the number of seconds required to fill a bucket of known volume. Calculate the gallons of flow per hour (gph) by dividing the bucket size in gallons by the number of seconds required to fill it, then multiply by 3600 seconds for gallons-per-hour:

System flow rate (in gph) = Bucket volume (in gallons) / time needed to fill (in seconds) x 3,600 seconds per hour

The maximum flow is considered to be 75% of the flow-rate measure above. Maximum flow is the largest number of gallons available for use at one time while operating a drip-irrigation zone.

Use goof plugs to plug holes in the mainline that are no longer needed due to system modification.

Common setup mistakes include not installing a filter or a pressure reducer, using excessively high lengths of mainline, and/or adding too many drip emitters.

Zones should be approximately the same size throughout your drip-irrigation system. Variation in zone sizes will reduce the efficiency of pump operation. When all zones are of the same size, pipe sizes and system cost will normally be minimal. The length of the mainline should not exceed 200 feet in a single zone.

Pressure regulators may be required if the pressure produced by the pump is too large or if zones vary greatly in size. If the pump was sized for a previously existing sprinkler system, it would likely operate at pressures that are excessive for the components of a drip system. If the system consists of different size zones, the pump must deliver the amount of water required in the largest zone at the pressure required by the tape used for lateral lines. If some zones are significantly smaller, the pump will produce higher pressure at the smaller discharges required by these zones. This pressure must be reduced by pressure regulators to the pressure-level required by the drip tape in the lateral lines.

4. Drip System Maintenance and Operation

The goal of drip-irrigation maintenance is to preserve the high uniformity of water application allowed by drip irrigation. A successful program of maintenance for a drip-irrigation system is based on the prevention-is-the-best-medicine approach. It is easier to prevent a drip tape from clogging than to "unclog" it or replace it. See Table 11 for additional readings on this topic.

4.1 Water Sampling for Drip Irrigation

An essential part of drip-irrigation management is determining water quality through water testing. Water testing will help determine water chemical composition, pH, and hardness (Table 7). These parameters have direct implications on chlorination, acidification and filtration needs for irrigation water. Analyses performed by the UF/IFAS Extension Soil Testing Laboratory (UF/IFAS ESTL) determine pH, electrical conductivity, Ca, Mg, Fe, Mn, Na, Cl, hardness, total carbonates, and suspended solids. (A sample water test information sheet is available at http://edis.ifas.ufl.edu/pdffiles/SS/SS18400.pdf.) These tests are designed to test water suitability for irrigation; they do not indicate whether water is suitable for human consumption.

4.2 The Prevention-Is-the-Best-Medicine Maintenance Program for Drip Irrigation

This maintenance program is based on filtration, chlorination/acidification, flushing and observation (see Table 8). Filters were described in section 2.5, above. Chlorination and acidification go together.

Chlorination consists of the introduction of a chlorinating compound (most often chlorine gas or sodium hypochlorite) that produces hypochlorous acid (HOCl). In its non-dissociated form, hypochlorous acid oxidizes organic matter and precipitates iron and manganese.

The chlorination point should be placed before the main filters so the precipitates that form by the chlorination can be removed from the water. In Florida, most groundwater is alkaline (pH up to 8.4). The proportion of hypochlorous acid in the non-dissociated form (HOCl) is significantly greater at lower pH. Hence, acidification makes chlorination more efficient. In conventional production, hydrochloric acid (HCl and also called muriatic acid), sulfuric acid or phosphoric acid may be used.

The amount of acid and chlorine needed to achieve a 1- or 2-ppm free chlorine concentration at the end of the line may be calculated by following the direction provided in EDIS Publication CIR1039 *Treating Irrigation System with Chlorine*. When applied correctly, the small amount of chlorine needed for drip-tape maintenance will be harmless to the crop grown in the soil.

Water acidification may be a challenge in certified organic production because NOP standards allow only acetic acid, citric acid, peracetic acid and other natural acids for use as a cleaner for drip-irrigation systems. It may take large, unpractical and expensive amounts of these acids to significantly reduce water pH.

Certified organic growers have three alternative options for drip-tape maintenance. First, chlorination may be done without acidification although this is less efficient and will require more product. Second, when economical and feasible, certified organic growers can choose to use potable water for drip-tape maintenance. Potable water may have a lower pH than well water, but analyses of both waters are needed to make this assessment. Third, non-chlorine-based products—such as natural chelating agents, hydrogen peroxide, or ozone—may be used to oxidize organic matter in the water. When in doubt, however, consult with your certifying agency for an acceptable plan for maintenance of your drip irrigation system.

Flushing may be accomplished automatically at each irrigation cycle when self-flushing end caps are used. Additional labor is required for flushing when the drip tape is tied or capped. Flushing may also be achieved by increasing pressure so to temporarily increase water velocity in the drip tape to 4–6 feet/second. Flushing takes all the precipitates and slime that may develop outside of the drip tape.

Observation and record keeping are needed throughout the season to ensure that the performance of the drip-irrigation system does not change. Measure pressure and flow, including how these change throughout the season (Table 9).

4.3 Scheduling Drip Irrigation

An adequate method of irrigation scheduling is needed to reduce water needs, maximize crop yield and uniformity, and reduce nutrient movement below the root zone.

Scheduling irrigation consists of knowing when to start irrigation and how much to apply. A complete irrigation-scheduling program for drip-irrigated vegetables includes a target rate of water application adjusted to weather demand and plant age (Table 10), as well as a measurement of soil moisture, an assessment of rainfall contribution, a rule for splitting irrigation, and detailed record keeping (tables 3 and 11). The actual size of the wetted zone may be visualized by injecting a soluble dye into the water and digging the soil profile (Simonne et al., 2005).

Because drip irrigation does not wet the entire field, the best unit for expressing crop water needs and irrigation amounts is volume-of-water-per-length-of-row, such as gallons-per-100-feet (gal/100ft), which is the most commonly used unit. Vertical amounts of water (expressed in inches; 1 acre inch = 27,154 gallons) are commonly used with overhead and seepage irrigation, but should not be used for drip irrigation. (See Table 11 for additional readings on this topic.)

4.4 Fertigation and Chemigation

Fertigation (the injection of soluble fertilizer through the drip-irrigation system) should be considered an integral part of the fertility program based on soil testing. Detailed fertigation schedules for all major vegetable crops grown in Florida are available in the Vegetable Production Handbook for Florida (Olson and Simonne, 2007). This series of EDIS publications is available online http://edis.ifas.ufl.edu/TOPIC_VPH. Proper nutrient management for vegetables grown with drip irrigation includes (1) soil testing, (2) understanding the recommendation, (3) correctly calculating fertilizer rates (see Table 12), (4) monitoring plant nutrient content, and (5) trapping residual nutrients by planting a second cash crop or a cover crop. In addition, fertilizer applicators should be properly calibrated.

Conventional growers have a wide array of soluble-fertilizer sources to choose from. Important characteristics of liquid fertilizers are the fertilizer content (lbs of N, P_2O_5 and K_2O/gallon of liquid fertilizer) and the ratio among elements. When all the P_2O_5 is applied pre-plant, most vegetables require a 1:0:1 type of liquid fertilizer (as much K_2O as N and no P_2O_5). However, certified organic growers have fewer choices for liquid fertilizers. The NOP rule limits the use of sodium nitrate ($NaNO_3$) to 20% of the total N. For example, if the seasonal N rate is 150 lbs/A—as for watermelon or cantaloupe (muskmelon), 20% of the seasonal N represents 30 lbs N/A/season. If the seasonal N rate is 200 lbs/A—as for tomato and bell pepper, 20% represents 40 lbs N/A/season. Some formulations of seaweed or fish emulsions may be allowed by the NOP, but the use of these fertilizers in a drip-irrigation system may increase the risk of emitter clogging.

5. Glossary of Terms

Acid: A compound that releases H^+ ions when dissolved into solution. Compounds such as hydrochloric acid (HCl) or acetic acid (CH_3-COOH) are acids.

Acidification: The introduction of an acid—such as phosphoric, sulfuric or hydrochloric (muriatic) acid—into an irrigation system. This practice is mostly done in maintenance to improve the effectiveness of chlorination.

Algicide: A substance toxic to algae.

Anti-siphon device (see backflow-prevention device): A safety device used to prevent back flow of irrigation water into the water source by back-siphonage.

Application efficiency: The percentage of water applied by an irrigation system and stored in the root zone available for water use.

Application rate: The average rate at which water is applied by an irrigation system. For drip irrigation, rate is expressed as gallons/hour/100ft or gallons/minute/emitter.

Backflow-prevention device (see anti-siphon device): A device required by Florida law and preventing contaminated water from being sucked back into the water source should a reverse-flow situation occur.

Bactericide: A substance that kills bacteria.

Base: A compound that produces OH^- ions when dissolved into solution. Compounds such as potassium hydroxide (KOH) or sodium hydroxide (NaOH) are bases.

Best Management Practices (BMP): A set of cultural practices known to increase the efficiency of the irrigation and fertilization program while minimizing the environmental impact of production.

Certifying agency: An independent, accredited third party that verifies that a certified-organic operation is compliant with the regulations described in the National Organic Standards as appropriate for their farming system.

Chelate: A compound that binds polyvalent metals at two or more cation-exchange sites. Chelate is often a component of ready-to-use formulations for drip-irrigation cleaning. The use of synthetic chelates is not allowed in certified-organic production for cleaning drip-irrigation systems, but synthetic chelates may be used in certified-organic production to correct a documented micronutrient deficiency.

Chemigation: A general term referring to the application of water-soluble chemicals into the drip-irrigation system. Chemigation includes (when allowable) the application of fertilizers, acids, chlorine and pesticides.

Chlorination: The introduction of chlorine—at a calculated rate—into an irrigation system. Chlorination can use liquid sodium hypochlorite (household bleach) or chlorine gas. Some chlorinating agents are allowed in certified organic production.

Cleaning agent: A substance used to remove dirt, filth and contaminants.

Control valve: A device used to control the flow of water. Control valves turn on and off water to the individual zones.

Detergent: A synthetic substance that is not a soap and that is used to change the surface tension to remove oil and grease and other substances relatively insoluble in water. Detergents are not allowed in certified organic production.

Disk filter: A stack of round, grooved disks used to filter water in a drip-irrigation system. As the size of the groves decreases, the more the water is filtered. Each disk has groves on both sides. Sediments and organic matter accumulate on the disks as water passes through the groves.

Disks are reusable. Once taken apart, they can be easily cleaned with pressured water and/or a detergent solution.

Drip irrigation: A method of irrigation using the slow application of water under low pressure through tube openings or attached devices just above, at or below the soil surface.

Electronic Database Information System (EDIS): The on-line database where the science-based, peer-reviewed and up-to-date recommendations of UF/IFAS Extension are accessible (http://edis.ifas.ufl.edu).

Emitter: A dispensing device or opening in a micro-irrigation tube that regulates water application. An emitter creates a controlled flow expressed in gallons/minute/emitter or gallons/100ft/hr.

Emitter spacing: Distance between two consecutive emitters. Typical emitter spacings for vegetable crops are 4, 8 and 12 inches.

Evapotranspiration (ET): The combined losses of water by evaporation from the soil and transpiration from the plant.

Fertigation: The application of soluble fertilizer (plant nutrients) through a drip irrigation system. Fertigation is allowed in certified-organic systems provided the fertilizer sources used are allowed by NOP standards.

Field capacity: The water content of the soil after all free water has been allowed to drain by gravity.

Filter: A canister device containing a screen or a series of disks of a specified mesh or filled with a coarse solid medium and designed to catch solid particles large enough to clog emitters.

Fittings: The array of coupling and closure devices used to construct a drip system and including connectors, tees, elbows, goof plugs and end caps. Fittings may be of several types, including compression, barbed, or locking (spin or ring).

Flow: The amount of water that moves through pipes in a given period of time. For micro-irrigation (drip irrigation), flow is expressed in gallons-per-hour (gph) or gallons-per-minute (gpm).

Flow meter: A device used to measure changes in flow in a drip-irrigation system over the course of a crop cycle.

Goof plug: An insertable cap used to plug holes in mainline and microtubes where drip devices have been removed or are no longer needed or when an accidental hole needs to be plugged.

Hole punch: A device that makes round holes in the pipes so to connect drip tape with laterals (available in different diameters).

Hydrochloric acid (HCl): An acid often used to lower the pH of water to increase the efficiency of chlorination. Use of HCI is prohibited in certified organic production.

Hypochlorous acid (HOCl): The weak acid generated by chlorinating products. Hypochlorous acid destroys organic matter. Use of HOCI is restricted in organic production.

Irrigation schedule: The watering plan and procedures that determine the proper amount of water to apply, the operating time, and the frequency of an irrigation event.

Mainline: The tubing used in the drip system. Mainline is sometimes called lateral line. It may be made of hard PVC or soft polyethylene material and comes in diameters ranging from 0.5–4 inch.

Mazzei injector (see venturi injector): Patented T-shaped, venturi-type injector that does not involve moving parts.

Media filter: A pressurized tank filled with fine gravel and sand. The sand is placed on top of the gravel. Sharp-edged sand or crush rock are more efficient in catching soft algal tissue than round particles. Media filters should be used for filtering water that contains high levels of organic matter.

Micro-irrigation: Synonym for drip irrigation.

Muriatic acid: Another name for hydrochloric acid (HCl).

National Organic Program (NOP): Federal program created as a result of the Organic Foods Production Act of 1990 (title IX if the 1990 Farm Bill) and operated under the USDA Agriculture Research Service (http://www.ams.usda.gov/nop/indexIE.htm).

Organic Materials Review Institute (OMRI): A national, nonprofit organization that determines which input products are compliant with the National Organic Program Standards (http//www.omri.org). The use of OMRI-listed products requires the approval of a certifying agency. Listing of a product on OMRI lists is not a guarantee of efficacy.

Overfertigating: Applying more fertilizer than the recommended rate. Overfertigating may result in nutrient leaching below the root zone.

Overwatering: Applying more water than necessary to meet the crop needs and/or applying water in excess of soil water-holding capacity. Overwatering potentially results in nutrient leaching below the root zone.

Part-per-million (ppm): The ratio of one in one million: 1 ppm = 1/1,000,000. The "ppm" measurement may also represent concentrations: 1 ppm = 1 mg/L.; 1% = 10,000 ppm.

Peracetic (acid also known as peroxyacetic): A mixture of acetic acid (CH_3- COOH) and hydrogen peroxide (H_2O_2) in an aqueous solution that can be used in certified organic production as a substitute for prohibited chlorination products.

Permanent wilting point: The water content of the soil in the plant root zone when the plant can no longer extract water from the soil.

pH: A number between 0 and 14 that represents the amount of acidity (H^+ ion concentration) in solution and calculated as: pH = -log[H^+]. pH can be simply measured with a pH-meter. A solution is acidic when pH<7, neutral when pH = 7, and basic when pH>7. pH affects the solubility and ionic forms in solution. pH is the single most important chemical parameter for water or soil.

Phosphoric acid (H_3PO_4): An acid often used to lower the pH of water so to increase the efficiency of chlorination. Use of phosphoric acid is prohibited in certified organic production.

Pressure: The "force" propelling water through pipes. Common static (nonflowing) pressure in irrigation systems is 20 - 70 psi (pounds-per-square-inch). Irrigation systems operate under dynamic (flowing) water pressure, which is reduced with elevation gain and friction loss caused by the water rubbing on the sides of pipes.

Pressure due to gravity (in pounds-per-square-inches or psi): This measurement may be calculated as gain (downhill) or loss (uphill) by multiplying the height of the water column in feet by 0.433. For example, if a 200-ft drip tape is laid on a field with a downhill slope of 3ft/100ft (3%), the gain in pressure due to gravity will be 200 x 0.03 x 0.433 = 2.59 psi.

Pressure loss: The loss of water pressure under flow conditions caused by debris in a filter, friction in pipes and parts, and elevation changes.

Pressure rating: The maximum pressure a pipe or drip-system component is able to handle without failing. For example, Class 160 PVC pipe refers to plastic irrigation pipe with a pressure rating of 160 pounds per square inch (psi). Aluminum irrigation pipe has a pressure rating of 145–150 psi. These pressure ratings will normally be adequate for mainlines in drip-irrigation systems.

Pressure-relief valve: A valve that opens and discharges to the atmosphere to relieve the high pressure condition when pressure in a pipeline exceeds a pre-set point.

Pressure-compensating emitter: An emitter designed to maintain a constant output (flow) over a wide range of operating pressures and elevations.

Pressure-sensitive emitter: An emitter that releases more water at the higher pressures and less at lower pressures, which are common with long mainlines or terrain changes.

Pressure regulator: A device that reduces incoming water pressure for lowpressure drip systems. Typical household water pressure is up to 50–60 psi while drip systems are designed to operate so not to exceed 8–12 psi in the drip tape. Due to friction losses, pressure in the delivery pipes may be 20–30 psi, thereby requiring a pressure regulator. The important ratings of a pressure regulator are the diameter, the downstream pressure and the maximum flow allowed by the pressure regulator.

Root zone: The depth and width of soil profile occupied by the roots of the plants being irrigated.

Sand separator: A device also called hydrocyclone that utilizes centrifugal force to separate sand and other heavy particles out of water. It is not a true filter, but could be considered a pre-filter.

Screen filter: A type of filter using a rigid screen to separate sand and other particulates out of irrigation water.

Self-flushing end cap: A spring-loaded device that lets water go out at the end of the drip tape when the water pressure is less than the threshold of the cap.

Sulfuric acid (H_2SO_4): An acid often used to lower the pH of water so to increase the efficiency of chlorination. Use of sulfuric acid is prohibited in certified organic production.

Sulfur, powdered: Elemental sulfur (S) in the yellow powder form is allowed in certified organic production. It is commonly used to decrease soil pH, but this requires chemical conversion by soil microorganisms. Powdered sulfur should not be used for chlorination purposes.

Soap: Alkaline salts of fatty acids used to remove hydrophilic particles.

Strong acid: An acid that is totally dissociated in water. Common strong acids are hydrochloric acid (HCl) and sulfuric acid (H_2SO_4).

Tape-to-lateral connector: A device sometimes called a barbed adapter and that is placed at the end of the drip tape (screw end) to connect it with the lateral (snap end).

Tape-to-tape connector: A device used to repair or replace a leaking section of drip tape. The tape-to-tape connector allows two pieces of drip tape to be connected together.

Trickle irrigation: Synonym for drip irrigation.

Turbulent-flow emitter: Emitters with a series of channels that force water to flow faster, thereby preventing particles from settling out and plugging the emitter.

Uniformity of water application: A measure of the spatial variability of water applied or stored in an irrigated field down a row and across several rows. Uniformity of water application is usually expressed as a percentage, 100% representing perfect uniformity.

Venturi injector: A tapered constriction which operates on the principle that a pressure drop accompanies the change in velocity of the water as it passes through the constriction. The pressure drop through a venturi must be sufficient to create a negative pressure (vacuum), relative to atmospheric pressure. Under these conditions, fluid from the tank will flow into the injector.

Water applied: The amount of water actually applied during an irrigation cycle. For drip irrigation, it is expressed in gallons/100 feet of drip tape.

Water hardness: The sum of multi-valent ions—such as calcium, magnesium, aluminum, or iron—in solution. Hardness is expressed in mg/L of calcium carbonate equivalent, and its value is used to classify the water as soft (0-20 mg/L), moderately soft (20-40 mg/L), slightly hard (40-60 mg/L), moderately hard (60-80 mg/L), hard (80-120 mg/L) or very hard (>120 mg/L).

Water alkalinity: Ability of water to neutralize acids. Water alkalinity is based on the content of hydroxide (OH^-), carbonate (CO_3^{--}) and bicarbonate (HCO_3^-) ions.

Water velocity: The speed at which water travels inside a pipe, usually expressed in feet/second.

Water hammer: Pressure surge that occurs because of sudden stoppage or reduction in flow or because of a change in direction of flow. Water hammer may be reduced by slowly turning water on and also by an irrigation-system design in which water velocity is less than 5 feet/second.

Weak acid: An acid that is only partially dissociated in water. Common weak acids are phosphoric acid (H_3PO_4), boric acid (H_3BO_3), acetic acid (CH_3-COOH) and citric acid [COOH-CH_2-(COOH-C-OH)-CH_2-COOH].

Zone: A section of an irrigation system that can be operated at one time by means of a single control valve.

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Table 1. Estimated itemized startup fixed costs and annual operating costs for a 2-inch-diameter drip-irrigation system for 10 acres[u]

Drip irrigation system components[v]	Unit Cost[w] ($)	Quantity	Total Cost[x] ($)	Comments
		Installation Costs		
Mazzei injector	150	1	150	
Dosatron injector	2100	1	2100	2-inch-pipe diameter, 5 - 100 gpm, 2–120 PSI, 1:500–1:50 dilution ratio
Pressure gauge	15	5	60	Actual number may vary, and range of pressure needs to match the placement in the system; one should be portable
Water meter	412	1	412	2-inch-wide water meter
Water meter fittings	11	2	22	
Water filter	87	1	87	Complete unit 2-inch 250-mesh polyester element
Backflow prevention system	405	1	405	Mandated by Florida law for fertigation
Ball valves	12	4	48	Mandated by Florida law
Irrigation water main line	0.51/ft	660 ft	337	Schedule 40, 2-inch-diameter PVC pipe. Price may vary depending on supplier.
PVC fittings[y]	3.2	10	32	Fittings here refers to crossesand tees.
Solenoids valve	31	10	310	
Irrigation controller	250	2	500	Most controllers may control six zones
Pressure regulators	32	10	320	Pressure depends on position in the system; check that unit does not restrict flow.
Total fixed cost			2,683	Caculated using a mazzei injector.
		Annual Costs		
Irrigation water sub main line	69	1200 ft	250	1-inch-diameter vinyl tube (lay-flat type); may be reused based on state of repair
Drip tape	105	10 roll	1050	5/8″ diameter 8-mil thickness 12-inch-spacing tape
Poly-to-drip tape connectors[z]	50	3 bags of 100	150	May be re-used if collected and cleaned at end of season
Tape-to-tape connectors	50	2 bags of 100	100	May be re-used if collected and cleaned at end of season
Flush caps	75	3 bags of 100	225	Recommended to have. May be re-used if collected and cleaned at end of season
Replacement filters (screen only)	15	1	15	Frequency of replacement depends on maintenance
Total annual costs			1,790	

[u] 10-acre field divided into 10 irrigation zones; each zone measures 330 x 130 square feet; shape of zones and type of crop will affect the number of rows, and thereby the number of connectors needed; Annual costs should also include pumping station maintenance, gas and oil for pumping station, and chlorination kit
[v] Shipping cost of parts not included
[w] Prices may vary depending on supplier
[x] Costs of well and pump installation and maintenance are not included.
[y] PVP pipe connection requires saw and PVC cement
[z] Drip tape connection also requires knife and whole punchers

Table 2. Water, maintenance products, fertilizer, pesticides and supplies commonly used with drip irrigation, their allowable status for certified organic production, their National Organic Program (NOP) class, and the corresponding NOP rule reference (Sources: Organic Materials Review Institute Generic Material List[z] and the NOP Final Rule)

Status[y]	NOP Class[x]	Material Name	NOP CFR Rule Reference
Water			
Allowed	CT	Water, non synthetic. Levels of contaminants in crops grown with water polluted by unavoidable residual environmental contamination cannot exceed 5% of the EPA tolerance for these contaminants in conventionally grown crops.	205.105, 205.671
Drip Irrigation Maintenance Products			
Allowed	CT	Acetic acid, non synthetic. For use as a drip irrigation cleaner.	205.105, 205.601(m)
Allowed	CT	Chelates, non synthetic. Non synthetic chelates—including amino acid, citric acid, tartaric acid and other di- and tri-acid chelates and synthetic lignin sulfonate—are allowed.	205.105
Prohibited	CT	Chelates, synthetic. Prohibited chelating agents include DTPA, EDTA, HEDTA, NTA, glucoheptonic acid and its salts, and synthetic amino acids.	205.105(a)
Restricted	CT	Chlorine materials, synthetic. Calcium hypochlorite, sodium hypochlorite, chlorine dioxide. Flush water from cleaning irrigation equipment that is applied to crops or fields cannot exceed the Maximum Residual Disinfectant Limit under the Safe Drinking Water Act, currently 4 mg/L (4 ppm) expressed as chlorine. For use as algaecide, disinfectant and sanitizer.	205.601(a)(2)
Allowed	CT	Citric acid, non synthetic. Used as a drip-irrigation cleaner and pH adjuster.	205.105
Allowed	CT	Drip-irrigation cleaners, non synthetic. Allowed non synthetic drip irrigation cleaners include acetic acid, vinegar, citric acid, and other naturally occurring acids.	205.105
Prohibited	CT	Drip irrigation cleaners, synthetic. Prohibited drip irrigation cleaners include nitric, phosphoric and sulfuric acids.	205.105(a)
Restricted	CT	Drip irrigation cleaners, nonsynthetic. Restricted nonsynthetic drip-irrigation cleaners include bleach and chlorine materials.	205.601(a)(2)
Prohibited	CT	Hydrochloric acid (muriatic), synthetic.	205.105(a)
Allowed	CT	Hydrogen peroxide, synthetic. As algaecide, disinfectant, and sanitizer including irrigation system cleaning systems.	205.601(a)(4)
Allowed	CT, CP	Natural acids, non synthetic.	205.105(a), 205.206
Restricted	CT, CP	Ozone gas, non synthetic. For use as an irrigation system cleaner only.	205.601(a)(5)[F]
Allowed	CT	Peracetic acid, non synthetic. For use in disinfecting equipment.	205.601(a)(6)
Allowed	CT	pH buffers, non synthetic. Must be from a non synthetic source such as citric acid or vinegar. Lye and sulfuric acid are prohibited.	205.105
Prohibited	CT	pH buffers, synthetic. Buffers such has lye and sulfuric acid are prohibited.[w]	205.105
Prohibited	CT	Phosphoric acid, synthetic.	205.105(a)
Drip Irrigation Materials and Supplies[v]			
Restricted	CT	Plastic mulches and covers, synthetic. Must not be incorporated into the soil or left in the field to decompose. Use of polyvinyl chloride as plastic mulch or row cover is prohibited.	205.206(c), 205.601(b)(2)(ii)
Restricted	CP	Mulch, synthetic. See restrictions under plastic.	205.601(b)(2)(ii)As weed barriers (i) newspapers or other recycled paper, without glossy or colored inks; (ii) plastic mulches and covers (petroleum-based other than polyvinyl chloride)
Allowed	CP	Paper, synthetic. For use as weed barriers newspapers or other recycled paper, without glossy or colored inks.[u]	205.601(b)(2)(i), 205.601(c)

[z] The OMRI Generic Material List is a compilation of the generic materials that are allowed or prohibited for use in organic production, processing and handling under the USDA National Organic Program (NOP) Rule. [y] Allowed substances include nonsynthetic materials that are not specifically prohibited by NOP Rule section 205.602. Prohibited substances are generally defined in NOP rule 205.105. The certifying agency makes final determination of whether the use of a material is allowed, restricted or prohibited. [x] NOP class: CT = crop management tool; CP = crop pest, weed and disease control. [w] Although listed as such, sulfuric acid is not a buffer (it is a strong acid). [v] Drip tapes are not listed, and are, therefore, not prohibited. [u] The water-conservation role of mulch is not mentioned in the original documents.

Table 3. Fertilization and irrigation record keeping requirements for the Florida vegetable BMP program (all apply to drip irrigation)

Record keeping requirement	BMP title[z]	BMP number and page[z]
Fertilization		
Record or sketch where soil samples were taken within each area.	Soil testing/soil pH	26, page 79
Record date, rate of application, materials used, and method of application when liming.	Soil testing/soil pH	26
Keep the soil testing lab report for each field and crops, as well as information about the soil-testing lab and the soil-test method used (extractant name)	Soil testing/soil pH	26
Fertilizer used and dates amounts applied	Optimum fertilization management/ application	33, page 93
Irrigation		
Maintain records of well construction	Well head protection	6, page 28
Flow rate and pressure delivered by the injector and irrigation pumps(s), as well as the energy consumption of the power unit of the irrigation pump	Chemigation/fertigation	34, page 99
Record operating values of irrigation design and how they change throughout the crop. (See Table 9 for specifics.)	Irrigation system maintenance and evaluation	39, page 112
Record the flow rate, pressure delivered by the pump, and energy consumption of the power unit frequently enough to gain an understanding.	Irrigation system maintenance and evaluation	39
Keep records of irrigation amounts applied and total rainfall received. Note with an asterisk when rainfall exceeds a leaching-rainfall event.	Irrigation scheduling	40, page 115
Keep permanent records of crop history	Seasonal or temporary farming operations	49
Keep records of flooded field duration, levels, and water quality analyses	Seasonal or temporary farming operations	49
[z] Page referenced in the BMP manual for vegetable crops (FDACS, 2005).		

Table 4. Determining how much water can be stored in a pond

Situation: A 2-acre pond with an average depth of 10 feet is available for drip irrigation. Questions: (1) How much water (in gallons) is available for irrigation use, considering that an average of 4 feet of water needs to be left in the pond? (2) What approximate vegetable acreage can be irrigated if the crop needs an estimated 20 acre-inches of total water?
Answer (1) Let's assume that loss of water from the pond by evaporation is compensated by rainfall. Because we need to keep a minimum of 4 feet of water in the pond, 6 feet of water (10-4 = 6) can be used from the pond. There are 6 ft x 12 inches x 2 acres = 144 acre-inches of usable water. (If 1 acre-inch = 27,150 gallons, this total corresponds to 3,909,600 gallons available for irrigation).
Answer (2). The water in this pond will allow the use of approximately 144 / 20 = 7.2 acres-inches of water for drip irrigation. Note that these 7.2 acres represent the cropped acres, not the field surface. Acreage of successive crops needs to be cumulated. For example, a spring crop grown on 2 acres followed by a fall crop grown on 1 acre should be counted as 2+1 = 3 acres of drip-irrigated vegetables.
Note: As explained in Section 1.7, drip-irrigation rates should be expressed in gallons/100 feet of drip tape. However, it is realistic to use acre-inches (as in the calculations above) when calculating water-storing capacity of ponds or reservoirs.

Table 5. Determining water needed from a well based on estimated crop water use and irrigated acreage

Situation: A farmer wants to develop a drip-irrigation system for a 4-acre field. He/she also plans to buy a 3-acre adjacent property.
Question: Assuming the whole farm will be planted with drip-irrigated sweet corn, using a high-flow drip-irrigation tape (a scenario with the highest water demand), how much water will need to be available from the well?
Answer: The total potential surface will be 3 + 4 = 7 acres. Sweet corn is planted in rows 2.5 ft apart. Hence, there will be 43,560/2.5 x 7 = 121,968 ft of sweet corn row. If a 30 gal/100ft/hr, high-flow drip tape is used, the entire 7-acre farm will have a water requirement of 121,968/100 x 30 = 609 gallons/minute.
Note that if 1-acre zones are designed and irrigated sequentially, the water requirement becomes 609/7 = 87 gallons/minute for each zone. Also note that if there are 7 zones, each zone could be irrigated for a maximum length of 3 hours per day (7 zones x 3 hr/zone = 21 hours out of 24 hours per day).

Table 6. Maximum length of drip tape (feet) and maximum irrigatable field size (acre) with low- and medium-flow drip tape at a water velocity of 5-feet-per second for selected diameters of Class 160 PVC pipes

Pipe diameter (inch)	Maximum flow rate with water velocity <5 feet/second (gal/min)	Low-flow drip-tape[z]			Medium-flow drip-tape[y]		
		Max. length of drip tape (feet)[x]	Max. irrigatable area with 30-inch row spacing crop (acre)[w]	Max. irrigatable area with crops planted on 6-ft bed spacing (acre)[v]	Max. length of drip tape (feet)[x]	Max. irrigatable area with 30-inch row spacing crops (acre)[w]	Max. irrigatable area with crops planted on 6-ft bed spacing (acre)[v]
0.5	5	1,880	0.10	0.25	1,250	0.07	0.17
0.75	8	3,008	0.17	0.41	2,000	0.11	0.27
1	13	4,887	0.28	0.67	3,250	0.18	0.44
1.5	32	12,030	0.69	1.6	8,000	0.45	1.1
2	59	22,180	1.3	3.0	14,750	0.8	2.0
2.5	86	32,330	1.8	4.4	21,500	1.2	2.9
3	128	48,120	2.7	6.6	32,000	1.8	4.4
4	211	79,323	4.5	10	52,750	3.0	7.2

[z] Assuming a 16 gal/100ft flow rate (0.266 gal/min/100ft) and a 100% efficiency.
[y] Assuming a 24 gal/100ft flow rate (0.400 gal/min/100ft) and a 100% efficiency.
[x] Estimated maximum length of drip tape at maximum flow rate, calculated by dividing pipe flow rate (gal/min) by drip-tape nominal flow rate (gal/min/100ft); the length of each drip tape should not exceed the maximum length provided by the manufacturer.
[w] For bare-ground crops typically planted with a 30-inch row spacing, such as sweet corn or snap beans, 1 acre = 17,424 linear feet of row.
[v] For mulched crops typically planted with a 6-foot bed spacing, such as tomato, pepper or eggplant, 1 acre = 7,260 linear bed feet.

Table 7. Water quality parameter levels for emitter-plugging potential of drip-irrigation systems (adapted from Pitts et al., 2003)

Factor	Plugging hazard based on level		
	Slight	Moderate	Severe
pH	<7.0	7.0 to 7.5	>7.5
Dissolved solids (mg/L)	<500	500 to 2000	>2000
Manganese (mg/L)	<0.1	0.1 to 0.5	>0.5
Iron (mg/L)	<0.1	0.1 to 0.5	>0.5
Hydrogen sulfide (mg/L)	<0.5	0.5 to 2.0	>2.0
Hardness (mg/L $CaCO_3$)	<150	150 to 300	>300

Table 8. Components of the "prevention-is-best-medicine" maintenance plan for drip-irrigation systems[z]

Component	Description
Filtration	**Goal:** Remove solid particles from the water. Sand filters, disc filters, screen filters or centrifugal sand separators are used to remove precipitates and solid particles (200 mesh or equivalent for screen and disk filters) (Haman et al., 2003a,b)
Chlorination	**Goal:** React with microorganisms in the water and precipitate ions in solution by injecting hypochlorous acid (HOCl) in the water. A 1-ppm residual Cl concentration at the end of the drip line indicates adequate reaction (Clark and Smajstrla, 2006)
Acidification	**Goal:** Reduce pH to around 6.5 so to increase efficiency of chlorination (Clark et al., 2005) and other precipitates. Acid injections are also used as cleaning events for non-biotics, such as scale and calcium deposits.
Flushing	**Goal:** Allow solid particles and precipitates to leave the drip tape by ways other than the emitters (end of drip line; Smajstrla and Boman,1999)

[z] See Table 2 for product-allowable status under the National Organic Program (NOP).

Table 9. A checklist for maintenance of a drip-irrigation system during the growing season[z]

What to Check	Frequency	Compared to What	What to Look For	Possible Causes
Pump flow rate and pressures for each zone	Weekly	Design or benchmark flow rate and pressures	High flow and /or low pressure Low flow and/or high pressure	Leaks in pipelines Leaks in laterals Opened flush valves; Opened ends of laterals Closed zone valves; Pipeline obstruction Tape clogging Pump malfunction; Well problems
Pressure difference across filter	Every irrigation	Manufacturer specifications	Exceeds or is close to maximum allowable	Filter becoming clogged Obstruction in filter
Operating pressures at ends of laterals	Monthly, unless other checks indicate possible clogging	Benchmark pressures	Pressure greater than expected Pressure lower than expected	Possible clogging; High system pressure; Obstruction in tape Broken lateral; Leaks in lateral; Low system pressure
Water at lateral ends & flush valves	Bi-weekly	Water source	Particles in water Other debris	Broken pipeline Hole in filter screen; Tear in filter mesh Particles smaller than screen; Filter problem Chemical/fertilizer precipitation Algae growth; Bacterial growth
Overall pump station	Weekly	Manufacturer specification	Leaks, breaks, engine reservoir levels, tank levels	Poor maintenance Old equipment
Injection pump settings	Weekly	Calibrated setting at startup	Proper setting for length of injection time	
Overall system	Weekly	System at start up	Discoloration at outlets or ends of laterals Leaks in tape Wilting crop	Indicates possible build up of minerals, fertilizer, algae, and/or bacterial slime Pest or mechanical damage Tape off of fittings Tape blowout from high pressure Tape clogged, obstructed, or broken. Crop may also be affected by pathogens

[z] Most benchmark and in-season values in this table are also BMP record keeping requirements.

Table 10. Summary of irrigation-scheduling recomendations for vegetables grown with drip irrigation

Irrigation scheduling component	Description/Comments [z]
1. Target water application rate	May be obtained from historical weather data or crop evapotranspiration (ETc) calculated from reference ET or Class A pan evaporation (Simonne et al., 2006). May also be obtained empirically (by experience). As a general guideline, target daily water applications for vegetables grown with plastic mulch should not exceed 15 - 25 gal/100ft/hr when plants are small and 70 - 80 gal/100ft/hr when plants are fully grown
2. Fine tune application with soil-moisture measurement	Maintain soil-water tension in the root zone between 8 and 15 cbar or between 9% and 12% volumetric water content (Muñoz-Carpena, 2004; Muñoz-Carpena and Dukes, 2005). Soil moisture should be determined in the morning each day before the first irrigation cycle, approximately 6 inches away from the drip tape.
3. Determine the contribution of rainfall	Poor lateral water movement on sandy and rocky soils in Florida limits the contribution of rainfall to crop water needs to (1) foliar absorption and cooling of foliage and (2) water funneled by the canopy through the plant hole. On these soils, irrigation may be needed even after a rain. When a spodic layer is present, rainwater will accumulate above it. The water table above the spodic layer will rise by approximately one foot for every inch of rain. On these soils, the contribution of rainfall should be deducted from the irrigation schedule; irrigation is not needed after heavy rains.
4. Rule for splitting irrigation	Vertical water movement in Florida's sandy and rocky soils is rapid. Irrigations greater than 12 and 50 gal/100ft (or 30 min and 2 hrs for medium flow rate) when plants are small and fully grown, respectively, are likely to push the water front and soluble nutrients below the root zone.
5. Record keeping	Irrigation amount applied and total rainfall received. Daily irrigation schedule.

[z] Efficient irrigation scheduling also requires a properly designed and maintained irrigation system. Assuming 100% application efficiency, irrigation needs are increased when plastic mulch is not used.
[y] Required by the BMPs.

Table 11. Additional reliable resources related to drip irrigation

Topic	Title	Reference
Drip irrigation	Principles of micro irrigation	Haman and Izuno, 2003; Haman and Smajstrla, 2003; Clark et al., 2002a
	Drip Irrigation: The BMP Era - An Integrated Approach to Water and Fertilizer Management for Vegetables Grown with Plasticulture	Simonne et al., 2003
Wells, pumps, energy	Water wells for Florida irrigation systems	Haman et al., 2003e
	Energy requirement for drip irrigation of tomatoes in North Florida	Smajstrla, et al., 2002b
	Evaluating irrigation pumping systems	Smajstrla et al., 2005
Filters	Screen filters in trickle irrigation systems	Haman et al., 2003b
	Media filters in trickle irrigation systems	Haman et al., 2003a
Fittings and connectors	Fittings and connections for flexible polyethylene pipe used in micro-irrigation systems	Haman and Clark, 2003d
	Hose connection vacuum breakers for home backflow prevention	Smajstrla, 2005
Controllers	Irrigation system controllers	Zazueta et al., 2002
System maintenance	Causes and prevention of emitter plugging in microirrigation systems	Pitts et al., 2003
	Treating irrigation systems with chlorine	Clark and Smajstrla, 2006
	Flushing procedures for microirrigation systems	Smajstrla and Boman, 2002
	Maintenance guide for microirrigation systems in the Southern Region	Runyan et al., 2007
	Neutralizing excess bicarbonates from irrigation water	Kidder and Hanlon. 2003
Irrigation scheduling	Estimating crop irrigation requirements for irrigation system design and consumptive use permitting	Smajstrla and Zazueta, 2002
	Irrigation scheduling with irrigation pans	Smajstrla et al., 2000
	Farm ponds in Florida irrigation systems	Clark et al., 2002b
	Basic irrigation scheduling in Florida	Smajstrla et al., 2006
	Field devices for monitoring soil water content	Muñoz-Carpena, 2004 Muñoz-Carpena and Dukes, 2007
	Principles and practices of irrigation management for vegetables	Simonne et al., 2007a
	On-farm demonstration of soil water movement in vegetables grown with plasticulture	Simonne et al., 2005
	Irrigating with high salinity water	Haman et al., 1997
Fertigation schedule (and other UF/IFAS production recommendations)	Commercial vegetable fertilization principles	Hochmuth and Hanlon, 2000; Simonne and Hochmuth, 2007
	Cole crops (head cabbage, CityplaceNapa cabbage, broccoli, cauliflower, collard, kale, mustard)	Olson et al., 2007a
	Specialty Asian vegetables	Lamberts, 2007
	Cucurbit crops (cucumber, summer squash, winter squash, pumpkin, muskmelon, watermelon)	Olson et al., 2007b
	Eggplant	Simonne et al., 2007b
	Legumes (snapbean, lima bean, southernpea, snowpea)	Olson et al., 2007d
	Okra	Simonne et al., 2007c
	Pepper	Olson et al., 2007d
	Potato	Hutchinson et al., 2007
	Strawberry	Peres et al., 2007
	Sweet corn	Simonne et al., 2007d
	Sweetpotato	Simonne et al., 2007e
	Tomato	Olson et al., 2007e

Topic	Title	Reference
Produce safety	Principles and practices of food safety	Simonne, 2007
	Small farm food safety and fresh produce	Lapinski et al., 2007
	Worker health and hygiene	Simonne et al., 2005
	Fresh produce handling	Mahovic et al., 2002a,b
Chemigation	Injection of chemicals into irrigation systems: Rates, volumes and injection periods	Clark et al., 2005
	Chemical injection method for irrigation	Haman et al., 2003c

Table 12. Calculating a liquid fertilizer rate for injection into the drip-irrigation system

We want to use liquid 8-0-8 to apply a rate of 1 lbs N/acre/day. What volume of 8-0-8 is needed?
When the actual density of a liquid fertilizer is not known, it is common to assume that 1 gallon of liquid fertilizer weighs 10 lbs. Hence, there are 0.8 lbs of N in 1 gallon of liquid 8-0-8. Hence, we need 1/0.8 = 1.25 gallons to supply 1 lb of N when liquid 8-0-8 is used
How much P_2O_5 is applied with that rate of 8-0-8?
Zero.