DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Agriculture and Natural Resources

FSA6160

Basics of Drip Irrigation and Fertigation for Specialty Crops

Taunya Ernst
Program Associate - Horticulture

Amanda McWhirt
Extension Specialist - Horticulture

Thomas Zimmerman
Program Technician - Fruit Research Station

Erika Henderson
Program Associate - Fruit Research Station

Mataya Duncan
Graduate Assistant - Horticulture

Amanda Lay-Walters
Graduate Assistant - Horticulture

Arkansas Is Our Campus

Visit our website at:
https://www.uaex.uada.edu

Introduction:

Seventy percent of worldwide water use is for agricultural irrigation (ORCC, 2023). In response to diminishing supplies of irrigation water, many growers have installed and are using irrigation systems that maximize water use efficiency (Wang et al. 2022). Drip systems are often cited as a solution to water shortages (van der Kooij et al., 2013). In Arkansas and other parts of the Southeast drip systems also help minimize leaf wetness, which favors disease development.

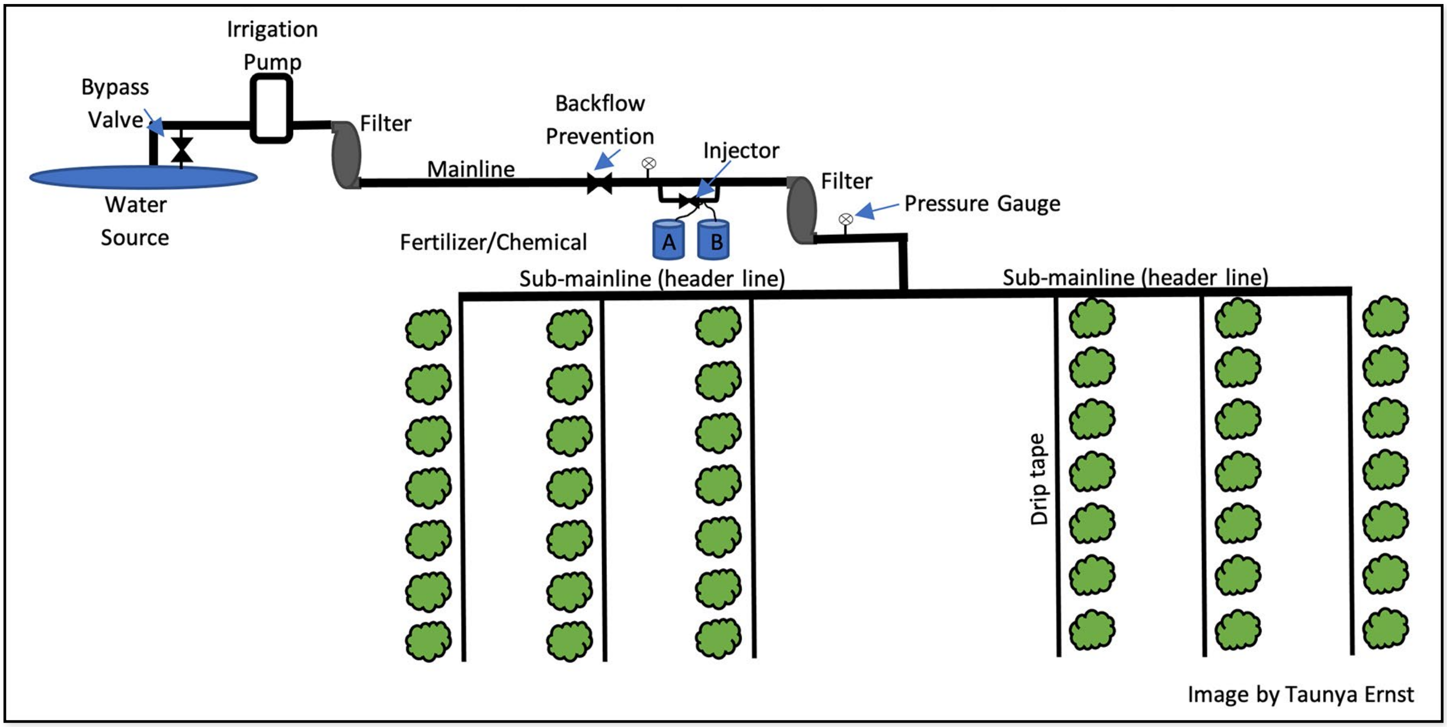
Drip or trickle irrigation applies small quantities of water at low flow rates and low pressure rates with frequent irrigation intervals. This precise system of water delivery can ensure nearly all irrigation water is used by the plant, increasing water use efficiency by 50 percent or more (Taghvaeian, 2017). In addition, the use of drip irrigation can improve yields and crop quality through the integration of dissolved fertilizer applications, or fertigation, into the irrigation system (Taghvaeian, 2017; Penn State Extension, 2016; Wang et al., 2022). Conventional pre-plant and side-dressing applications of large volumes of fertilizers give plants more nutrients than are needed at the time of application and expose the crop to potential nutrient deficiencies in-between applications (Synder and Schmidt, 2019). In contrast, fertigation gives growers increased control over the dosage and timing of fertilizer applications. Fertigation rates can be easily increased to support growing or fruiting plants and then reduced as the growth cycle comes to an end (Synder and Schmidt, 2019: Egbert et al., 2019).

The benefits of fertigation are only achieved when the irrigation system can maintain uniform water application across the area. Windy conditions disrupt water dispersal for overhead sprinkler systems, and fertilizer runoff is a problem in furrow/flood systems (Egbert et al., 2019). The trickle delivery of water and nutrients in a drip system can deliver water and nutrients directly to the root zone of the plants (Taghvaeian, 2017). This ensures that fertilizer, like water, is used efficiently, reducing cost and waste (Granberry et al., 2017). Small scale systems can be built economically and added on to over time. For these reasons drip irrigation and fertigation are preferred for most fruit and vegetable production in Arkansas. This fact sheet will cover basic and general considerations for drip irrigation and fertigation system design and construction. Many irrigation suppliers are good resources for new growers designing a system customized for a specific site and crop.

Parts of the System:

There are several major components of a drip irrigation system.

Figure 1. General design and component layout for a drip irrigation system



These will be outlined in the following sections. The order in which these components are often placed within the system is shown in Figure 1.

Water Source:

Testing the selected water source is an important first step in designing any type of irrigation system. A standard water test will show levels of salt, minerals and organic matter as well as water pH. Testing can help determine filtration and chemical treatment needs and help in the selection of nutrient sources (Liu and McAvoy, 2021). Contact your local county cooperative extension office for help with submitting a water sample for testing at the Arkansas Water Resources Center Water Quality Lab (https://awrc.uada.edu/water-quality-lab/).

Sources of irrigation water include surface water reservoirs (such as ponds, rivers or lakes), below ground aquifers (well water) and municipal water (Taghvaeian, 2017). Often more affordable and easier to access, surface water sources have greater amounts of large contaminants, such as algae, sand and organic matter. Groundwater sources are usually free of larger impurities. However, these sources often have a high mineral content and changes in water temperature, pH, and aeration can cause minerals such as iron and calcium to precipitate out of solution which can result in clogged emitters (Liu and McAvoy, 2021; Taghvaeian, 2017). In addition to adequate filtration, chemical treatments can help mitigate high mineral content in water (see the section on chemical injection). Accessing groundwater can become expensive, especially in locations that do not have high water tables. Special drilling equipment may be acquired to dig wells deep enough to access reliable water sources. However, in many parts of Arkansas, well water is a reliable and cost-effective water source.

Municipal water is clean, and suppliers will provide a water test (Taghvaeian, 2017; Penn State Extension, 2016). However, municipal water sources are not available in all areas, and, when available, are often more expensive than other sources.

Regardless of the water source chosen, some level of filtration should be included in the design of a drip irrigation system. Periodically testing the water is recommended to monitor changes or potential contamination. This is particularly important for water that may come in direct contact with crops intended for human consumption that will not be heat processed, as water can carry bacteria such as Listeria or E. coli.

System Capacity:

An efficient and reliable drip system must be designed with care and understanding. Ensuring a pump system is large enough to irrigate a desired area is determined by several components such as the size of the area being irrigated (or the number of emitters), emitter flow rate, irrigation interval and crop (Taghvaeian, 2017). Larger fields can be split into multiple irrigation zones to accommodate pump capacity. Avoid running the system more than 18 hours a day to make time for maintenance and repairs. It is often advisable to install oversized irrigation pumps. This not only ensures a system is large enough for the current crop but also allows for expansion in cropping area over time. Many sources are available to assist growers in calculating the size of a system and selecting the appropriate irrigation pump (Scherer, 2022: Taghvaeian, 2017). Here's a simple calculation to start estimating the minimum pump size a farm may require:

Minimum pump size (gph) = Number of emitters x emitter flow rate (gph)

Additional considerations like slope and distance between the pump and crop should also be taken into consideration in determining the pump capacity. Many pumps have limits on the number of vertical feet they can lift water, and PSI is affected with each rise or fall in elevation.

There are four main styles of irrigation pumps: centrifugal, submersible, deep-well turbine, and propeller pumps (see Figure 2). Centrifugal, submersible, and propeller pumps can pump water from above-ground reservoirs, such as ponds. Centrifugal pumps can also be used as booster pumps for municipal water sources (Scherer, 2022). Deep-well turbine pumps are used to pull water from below-ground reservoirs (Scherer, 2022). The selection of the best pump type will depend on the water source and field location and characteristics. In addition to the style of pump selected, the power source, such as diesel, gas, or electric should be considered.

Figure 2: An irrigation pump.

Filtration:

Emitter openings are very small and can easily be blocked by the smallest of contaminants. Particles of silt, sand or minerals that precipitate out of solution can be enough to block these tiny openings. Proper filtration is a crucial part of an effective and efficient irrigation system, and its inclusion in the system's design cannot be overemphasized. Systems with inadequate filtration will not function reliably and will require additional maintenance.

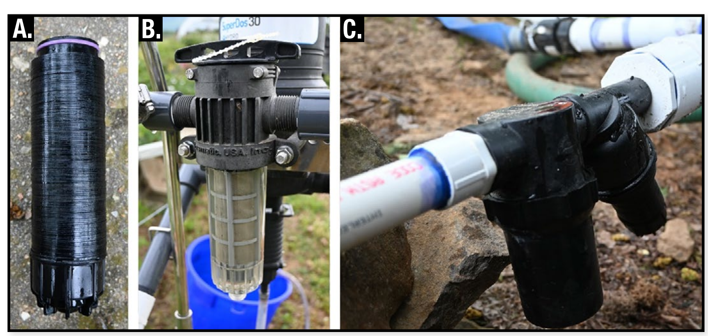
Filter selection will depend heavily on the quality of the water source and geographic location. Pond water in Arkansas, for example, will have high amounts of dirt, mud and algae that will need to be filtered out before reaching emitters. Well water, in contrast, is often clean of large contaminates but may have high levels of iron, which can precipitate out of solution and accumulate on emitters and in irrigation lines, resulting in clogs over time.

A variety of filter designs are available. Selecting and installing the correct filter or combination of filters will effectively remove clogging contaminants from the water source (Liu and McAvoy, 2021).

Common filters include:

- Media filters: usually installed in pairs, media filters are large, heavy and expensive. However, their ability to clean poor-quality water at high flow rates has made them one of the most used filter types (Taghvaeian, 2017; Penn State Extension, 2016).
- Screen filters: Stainless steel or plastic, screen filters are simple, affordable and compact. They are easy to install, clean and maintain (see Figure 3). While capable of removing debris as efficiently as a media filter, screen filters require more frequent cleanings and lower flow rates (Taghvaeian, 2017; Penn State Extension, 2016).
- Disk Filters: Moderately expensive, disk filters are a popular option for many irrigation setups (see Figure 3). Like a media filter, debris is captured while water moves a short distance, increasing the filtration capacity of the disk filter when compared to a screen filter. Pressure gauges installed on either side of a disk or screen filter can indicate when a filter needs to be cleaned (Taghvaeian, 2017; Penn State Extension, 2016).

Figure 3: A disk filter (A) and screen filter (B). Screen filter in place in a drip irrigation system (C).



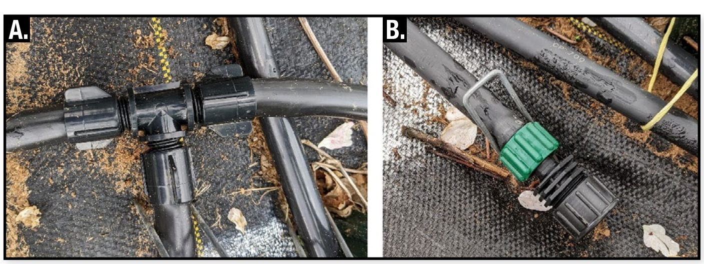
- Centrifugal style filter: For water sources with high levels of large particle contaminates (large amounts of sand particles, for example), a filter with a separator with centrifugal force may be necessary (Taghvaeian, 2017).

Irrigation Lines:

In general, one main distribution line will transport water from the water source to the field. These mainlines can be placed above or below ground and must be sized appropriately to carry the needed water capacity to feed the system (Penn State Extension, 2016). Mainlines are split into durable sub-mainlines or header lines that can be left in the field during the off-season (for perennial crops) or removed, stored and re-installed the following season (Penn State Extension, 2016). In perennial systems, header lines are often buried or suspended above ground to prevent damage from mowers, rodents or other field equipment. In annual production systems, burying header lines is seldom done as the crop may be moved each year.

Plastic couplings are used to connect sub-header lines to drip tape or drip tube, which carries water down each row to the crop (Penn State Extension, 2016) (see Figure 4). With the proper equipment, drip lines can also be buried for protection. Exposed lines are susceptible to rodent or mechanical damage. Keep a supply of couplers onsite so repairs can be done quickly. When laying drip tape, ensure emitters are placed facing up to help prevent clogging. The ends of each line of drip tape should remain accessible and capped using tubbing end caps or folded and cinched (see Figure 4). To remove potential build-up within irrigation lines, drip tape should be "flushed" periodically by opening the ends of the tape and running the irrigation for five to 10 minutes (Taghvaeian, 2017; Penn State Extension, 2016).

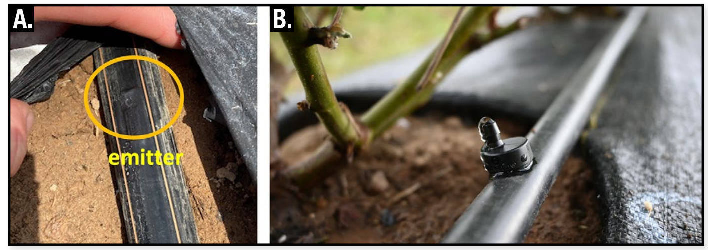
Figure 4: Coupler connecting a sub-main (or header) line to emitter tape (A). A tubing end cap (B).



Emitters:

Crop type, plant spacing and soil texture will determine the optimum flow rate (gallons per hour (gph) or gallon per minute (gpm)) and emitter spacing in the irrigation lines. Fine clayey soils, for example, will require fewer emitters per row foot to maintain adequate moisture than coarse sandy soils (Taghvaeian, 2017). Emitter design will significantly impact the incidence of clogging (Wang et al., 2022; Penn State Extension, 2016). In-line, or line-source, emitter tape is among the most used drip tape in vegetable and small fruit production (see Figure 5). Emitters are built into the tape, making installation easy.

Figure 5: In-line emitter drip tape (A) and point source emitters in hard sided drip tubing (B).



The type or design of the embedded emitters can vary. Turbulent flow emitters are considered superior and, while the cost is higher, they are more resistant to clogging (Taghvaeian, 2017; Penn State Extension, 2016). Long-term crops with wider plant spacing, such as orchards or vineyards, prefer more durable tubing with point source emitters (see Figure 5). Point-source emitters are separate from the tubing, giving growers the flexibility to place them where needed and add more as plants grow (Taghvaeian, 2017). Point-source emitters are more susceptible to clogging and will need to be monitored more closely.

Pressure Compensating Emitters:

Elevation changes in a drip irrigated row will affect water pressure in the system, disrupting the flow rate uniformity between emitters. This will negatively affect the water-saving and nutritional management benefits of a drip system (Wang et al., 2022). A rise or drop of a single foot can change the pressure by ±0.433 psi (Taghvaeian, 2017). Pressure regulators or pressure compensation emitters can overcome these pressure changes and help maintain the flow rate uniformity needed in a drip system.

Irrigation Scheduling:

Once the system is installed and the crop planted, the next step is to determine the duration and frequency at which that irrigation should be run. Determining the correct irrigation frequency depends on the water-holding capacity of the soil, the emitter's flow rate, and a crop's water usage (Penn State Extension, 2016). Fine texture soils, such as clay or loams, have a higher water-holding capacity than soils with a coarse texture, such as sand. Plants grown in sandy soil will require more frequent irrigation events than the same crop grown in loamy soil (Penn State Extension, 2016; Taghvaeian, 2017). Sandy soils may need to be irrigated multiple times per day during periods of hot dry weather and heavy crop loads, while clay soils may be deeply watered only a few times per week.

Most specialty crops require at least 1 inch of water per acre per week. This equates to an estimated 0.62 gallons of water per sq ft. If emitters are placed on 12-inch spacing and rated at 0.25 gph, then the system would need to be run for 4 hours to apply 1 inch of water. The frequency and duration of an irrigation cycle will change based on rainfall, temperature, cloudiness and crop growth stage. A good general rule is to irrigate when 50 percent of the available water is depleted (Penn State Extension, 2016). Check the UAEX Fruit and Vegetable YouTube channel for information on using and building soil moisture sensors.

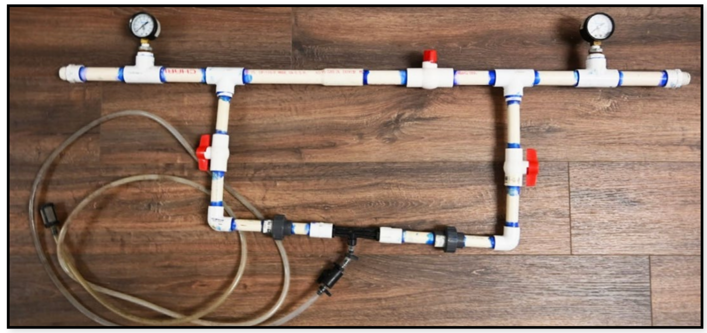
Chemigation:

Chemigation is a general term for the application of chemicals through an irrigation system, and includes the injection of fertilizers, pesticides and other solutions. The injection of chemicals, such as chlorine, can help prevent the build-up of "bacterial slime" or algae (Granberry et al., 2017) and is a good regular practice to maintain the irrigation system when pond-water is used as the water source. The injection of acid can correct high water pH and prevent minerals or nutrients from precipitating out of solution and clogging emitters (Granberry et al., 2017; Liu and McAvoy, 2021).

Among the many benefits of drip irrigation is the potential to use fertigation which is the application of fertilizer through the irrigation lines. Fertigation can significantly improve crop nutrient management by enabling the uniform and precise placement of nutrients into the root zone. Fertigation maximizes yield and quality while reducing costs (Maisiri, 2005; Granberry et. al., 2017).

Many types of injectors are available for chemigation, varying in complexity, accuracy and affordability. The Venturi bypass is simple and affordable and requires no power or outside force for injection (see Figure 6). Instead, a vacuum is created as water flows through the tapered Venturi opening. The generated suction pulls the liquid to be injected into the system. With a Venturi, injection rates can vary with changes in the water pressure, which is the source of power generating the vacuum. While this variation in injector rates is acceptable with fertilizer applications, it can be problematic with other chemicals that require more exact rates.

Figure 6: A homemade Venturi bypass injection system. For instructions on how to build this Venturi bypass see our YouTube video "How-To Build A Venturi Injector".



Another common injector is a positive displacement metering pump (see Figure 7). Usually pricier than a Venturi bypass, these pumps offer more control over injection rates, making them more precise when water pressure or flow rate is variable (Granberry et al., 2017; Snyder and Schmidt, 2019). Metering pumps can be powered by small electric motors or use a hydraulic drive system, which uses water pressure to power the pump (Snyder and Schmidt, 2019).

Figure 7: A Dosatron injector pump, a type of positive displacement metering pump.

No matter the type of injection system used it should be sized to the flow rate of the system, if the injector is poorly sized it will likely experience excessively long run times. Long run times for fertigation increase the risk of flushing nutrients past the rooting zone.

When using a pump for fertigation, additional filters can be placed after the injector before the fertilized water reaches the emitters. Characteristics of the chosen water source, such as pH and concentration of cations/anions, can cause nutrients in added fertilizers to precipitate out of solution and clog emitters (Liu and McAvoy, 2021). Be aware that some positive displacement metering pumps have components that are susceptible to corrosion when exposed to certain chemicals (Snyder and Schmidt, 2019).

Backflow Prevention:

When chemigation is used in a drip irrigation system, water flowing through header and sub-header lines, as well as drip tubing, are contaminated with chemicals, pesticides and fertilizers. In between irrigation events, there is a risk of this treated water flowing backward through the system and contaminating the water source (Taghvaeian, 2017). Placing a backflow prevention valve between the water source and the injection system will prevent this contamination and protect the integrity of your water source. If municipal water is used a backflow preventer will likely be required for the system. Check with your local officials for more information.

Fertilizer Selection:

Selecting fertilizers that are appropriate for fertigation and compatible with each other can help prevent clogged emitters due to fertilizer precipitates. Fertilizers containing phosphates or sulphates will react with calcium forming precipitates (Liu and McAvoy, 2021). To avoid this, calcium fertilizers are mixed and stored in separate tanks from those containing phosphates and sulphates, often referred to as the A and B tank mixes. Table 1 lists common water-soluble fertilizers used in fertigation of specialty crops. Many resources exist to assist growers in selecting compatible fertilizers. Companies such as Peter's Professional and Agrolution offer pre-mixed NPK blends.

It is critical that fertilizer be completely dissolved prior to being injected into the lines, in order to avoid clogging and ensure plants receive the nutrients.

Table 1. Common Water-Soluble Fertilizers for Fertigation.

Nitrogen Fertilizers:		
Ammonium Nitrate	34-0-0	
Ammonium sulphate	21-0-0	Never mix with nutrients containing calcium.
Calcium Nitrate	15.5-0-0	Never mix with nutrients containing phosphate or sulphate.
Potassium nitrate	13-0-44	Can be slow to dissolve.
Urea	46-0-0	
Phosphorus Fertilizers:		
Monopotassium phosphate	0-52-34	Never mix with nutrients containing calcium.
Phosphoric acid	0-52-0	
Potassium Fertilizers:		
Potassium chloride	0-0-60	
Potassium nitrate	13-0-44	
Potassium sulphate	0-0-50	Never mix with nutrients containing calcium.

Fertilizer quantity, type of nutrients and water temperature will affect solubility (Egbert et al., 2019; Granberry et al., 2017). A set amount of water can only dissolve a certain quantity of fertilizer. Exceeding this "solubility limit" will cause particles or clumps of fertilizer to settle in the mixing tank, posing a risk to emitters (Snyder and Schmidt, 2019). Solubility limits are often listed on the fertilizer container. Some nutrients are not compatible with others and could cause one or both to precipitate out of solution (Egbert et al., 2019). The combined solubility of two or more fertilizers can be easily tested by mixing them in a cup or five-gallon bucket to see if they dissolve completely (Granberry et al., 2017). When testing, use the same concentration of both fertilizers that will be present in the stock tank.

When fertigation is complete, running fresh water through the system can help prevent nutrients such as calcium from forming crusts on emitters (Taghvaeian, 2017). Chemically treating the water — adding acid for pH control or chloride for algae, for example — and periodically flushing the system can also help in eliminating emitter blockage (Taghvaeian, 2017; Penn State Extension, 2016).

Calculating Fertilizer Rates:

Step 1: Calculate the size of the area being fertilized. Fertilizer calculations are based only on the area that is actually planted. The ground between planted rows is not irrigated and will therefore receive no fertilizer. Use the equation below to calculate the total area. Total row length is the sum of all row lengths. For example, a field with four rows, each 50 feet in length, would have a total row length of 200 feet.

Total fertilized area (acres) = (Total row length (ft) x Row width (ft)) / 43,560 ft2/acre

Example: Four 50-foot-long rows each with a 3-foot-wide bed top

(200 x 3) / 43,560 = 0.014 acre

Step 2: Calculate the amount of nutrient needed for the area: A crop's need for a specific nutrient can be determined from several sources. Soil tests, foliar analysis, nutritional management guides and grower knowledge and experience can supply this needed information. For example, a soil test may recommend the addition of 42 pounds of nitrogen per acre, to be applied across six split applications. Use the equation below to calculate the amount of that nutrient to apply in each application.

Nutrient applied per application (lbs./application) = (Total nutrient applied (lbs./acre) x Total fertilized area (acres)) / number of applications

Example: 42 lbs. of N x 0.014 acre / 6 applications = 0.1 lbs. of N per application

Step 3: Calculate the amount of fertilizer applied per acre for each application: A bag of fertilizer will indicate how much of its actual weight is a particular nutrient. For example, potassium nitrate is only 13.5 percent nitrogen. So, in one pound of potassium nitrate there are only 0.135 pounds of actual nitrogen. Use the formula below to calculate the amount of fertilizer to apply to the fertigated area per application.

Applied fertilizer (lbs./area x application) = Nutrient applied per application (lbs./application) / percent of nutrient in fertilizer (lbs.)

Example: 0.1 lbs. of N per application / 0.135 nitrogen per lb. of potassium nitrate= 0.73 lb. of potassium nitrate applied 6 times

Step 4: For each application, dissolve the calculated amount of fertilizer, from Step 3, in the appropriate amount of water.

Step 5: Start the irrigation system and run until all emitters are dripping, and the system is fully pressurized. This may take 5-10 minutes.

Step 6: Start the injection system and run until all the fertilizer has been injected.

Step 7: Run the irrigation system for an additional 5-10 minutes to ensure all fertilizer has been pushed out of the emitters and none remains in the lines.

Maintenance:

Blocked emitters are the most common issue with drip irrigation systems. While filtration and chemical treatments can significantly reduce the occurrence of clogging, proper system maintenance can further reduce blockage and extend the life of the system. Filters should be checked often and cleaned when needed. Systems that include pressure gauges can be monitored daily for pressure drops, indicating a dirty filter or leak in the system. While irrigating, check weekly (or more often) that source pumps and backflow systems are functioning properly, and check tape/tube for leaks, damage or non-working emitters. Having spare parts and components on-hand to quickly address issues can reduce repair time and keep irrigation on schedule (see Figure 8). Proper winterization of the system can ensure a longer lifespan of pumps and injectors.

Figure 8: A coupling connecting two sections of drip tape after a leak was repaired.

Conclusion:

A properly designed drip irrigation system can stretch water and fertilizer inputs to cover more acreage. Integrating a fertigation system and program into a drip system can save costs on fertilizer while improving yields through enhanced control over nutrient management. Drip and fertigation components must be carefully selected, installed and maintained to sustain uniformity and achieve all possible benefits.

References:

Egbert, K., Yost, M., Sorensen, B., Cardon, G., Niel, A. and R. Larsen. 2019. "Fertigation Facts." Utah State University Extension. https://extension.usu.edu/crops/research/fertigation-facts#:~:text=The%20most%20common%20nutrient%20that,also%20extremely%20susceptible%20to%20leaching.

Liu, G. and G. McAvoy. 2021. "How to Reduce Clogging Problems in Fertigation." Horticultural Science Department, UF/IFAS Extension. HS1002. https://edis.ifas.ufl.edu/publication/HS1202?downloadOpen=true.

Maisiri, N., Senzanje A., Rockstorm J. and S. J. Twomlow. 2005. "On farm evaluation of the effect of low-cost drip irrigation on water and crop productivity compared to conventional surface irrigation system." Physics and Chemistry of the Earth, Parts A/B/C. 30(11-16): 783-791.

Medellín-Azuara, J., Escriva-Bou, A., Rodríguez-Flores, J. M., Cole, S. A., Abatzoglou, J., Viers J. H., Santos, N. and D. A. Sumner. 2022. "Economic Impacts of the 2020-22 Drought on California Agriculture. Prepared for: The California Department of Food and Agriculture. Water Systems Management Lab. University of California, Merced 35p. Available at https://wsm.ucmerced.edu/drought_study/.

Meiramkulova, K., Mkilima, T., Baituk, G., Beisembayeva, K., Meirbekov, A., Kakabayev, A., Adilbektegi, G., Tleukulov, A. and G. Tazhkenova. (2022). "Treatment of waste stabilization pond effluent using natural zeolite for irrigation potential." PLOS ONE, 17(6), e0259614. https://doi.org/10.1371/journal.pone.0259614.

ORCC- Water and agriculture. 2023. "Managing water sustainably is key to the future of food and agriculture. https://www.oecd.org/agriculture/topics/water-and-agriculture/.

Pathak, T. B., Maskey, M. L., Dahlberg, J. A., Kearns, F., Bali, K.M. and D. Zaccaria. 2018. "Climate Change Trends and Impacts on California Agriculture: A Detailed Review." Agronomy: 8(3):25. https://doi.org/10.3390/agronomy8030025.

Penn State Extension. 2016. "Drip Irrigation for Vegetable Production." Agricultural Alternatives. p8. https://extension.psu.edu/drip-irrigation-for-vegetable-production#:~:text=Drip%20or%20trickle%20irrigation%20is,water%20and%20nutrients%20to%20crops.&text=Crop%20yields%20can%20increase%20through,yields%20can%20increase%20even%20further.

Granberry, D. M., Harrison, K. A. and W. T. Kelly. 2017. "Drip Chemigation: Injecting Fertilizer, Acid, and Chlorine." University of Georgia Extension. Bulletin 1130. https://extension.uga.edu/publications/detail.html?number=B1130&title=drip-chemigation-injecting-fertilizer-acid-and-chlorine.

Scherer, T. F. 2022. "Irrigation Water Pumps." North Dakota State University Extension. AE1057. https://www.ndsu.edu/agriculture/ag-hub/publications/irrigation-water-pumps.

Snyder, R. G. and A. M. Schmidt. 2019. "Fertigation: The Basics of Injecting Fertilizer for Field-Grown Tomatoes." Mississippi State University Extension. Publication 2037. https://extension.msstate.edu/sites/default/files/publications/publications/P2037_web.pdf.

Taghvaeian, S. 2017. "Drip Irrigation Systems." Oklahoma Cooperative Extension Service, Division of Agricultural Sciences and Natural Resources. p4. https://extension.okstate.edu/fact-sheets/drip-irrigation-systems.html.

Van der Kooji, S., Zwarteveen, M., Boesveld, H. and M. Kuper. 2013. "The efficiency of drip irrigation unpacked." Agricultural Water Management. 123(31): 103-110. https://doi.org/10.1016/j.agwat.2013.03.014.

Wang, H., Ling G., Wang W., Hu X. and X. Gao. 2022. "A Prediction Model of Labyrinth Emitter Service Duration (ESD) under Low-Quality (Sand-Laden Water) Irrigation." Water: 14(11):1690. https://doi.org/10.3390/w14111690.

TAUNYA ERNST, program technician, horticulture, **AMANDA L. MCWHIRT**, extension specialist, horticulture and **MATAYA DUNCAN**, agriculture farm technician are with the University of Arkansas Division of Agriculture, Cooperative Extension Service in Little Rock. **THOMAS ZIMMERMAN**, assistant, and **ERIKA HENDERSON**, program associate, fruit research station in Clarksville, Arkansas. **AMANDA LAY-WALTERS**, senior graduate assistant, is at the University of Arkansas in Fayetteville.

FSA6160-PD-5-2023