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Drip Irrigation for Vegetable Production

Drip or trickle irrigation is a very efficient method of applying water and nutrients to crops. For many crops, the conversion from sprinkler to drip irrigation can reduce water use by 50 percent. Crop yields can increase through improved water and fertility management and reduced disease and weed pressure. When drip irrigation is used with polyethylene mulch, yields can increase even further.

These benefits are only possible when a drip irrigation system is properly designed, managed, and maintained. Irrigation system design is complex and is beyond the scope of this publication. You should consult with a qualified agricultural engineer or irrigation equipment dealer to design your drip irrigation system. However, you should understand many design factors to assure that your drip irrigation system is properly designed and operated. System components, basic design principles, practical applications, and operating guidelines will be discussed in this publication.

Advantages of drip irrigation

1. Smaller water sources can be used because trickle irrigation may require less than half of the water needed for sprinkler irrigation.
2. Lower operating pressures mean reduced energy costs for pumping.
3. High levels of water use efficiency are achieved because plants can be supplied with more precise amounts of water.
4. Disease pressure may be less because plant foliage remains dry.
5. Labor and operating costs are generally less, and extensive automation is possible.

Drip irrigation of bell peppers

6. Water applications are made directly to the plant root zone. No applications are made between rows or other nonproductive areas, resulting in better weed control and significant water savings.
7. Field operations, such as harvesting, can continue during irrigation because the areas between rows remain dry.
8. Fertilizers can be applied efficiently through the drip system.
9. Irrigation can be done under a wide range of field conditions.
10. Compared to sprinkler irrigation, soil erosion and nutrient leaching can be reduced.

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Disadvantages and limitations of drip irrigation

1. Initial investment costs per acre may be more than other irrigation options.
2. Management requirements are somewhat higher. Delaying critical operation decisions may cause irreversible crop damage.
3. Frost protection is not possible with drip systems; if this is needed, sprinkler systems are necessary.
4. Rodent, insect, and human damage to drip lines are potential sources of leaks.
5. Water filtration is necessary to prevent clogging of the small emitter holes.
6. Compared to sprinkler irrigation, water distribution in the soil is restricted.

Because vegetables are usually planted in rows, drip tape with prepunched emitter holes is used to wet a continuous strip along the row. Because most vegetables are grown for only one season, thin-walled disposable tape (8 to 10 mil thick) is generally used for only one season. Less emphasis is placed on buried mainlines and sub-mainlines to allow the system to be dismantled and moved from season to season. Costs may be high, so you should develop a functional system that allows maximum production with minimal costs. You may purchase an entire system from a drip irrigation dealer or adapt your own components. Proper system design will help you avoid problems later.

Irrigation water may come from wells, ponds, lakes, rivers, streams, or municipal water suppliers. Groundwater is fairly clean and may only require a screen or disk filter to remove particles that can clog emitters. However, a water quality test should be conducted to check for precipitates or other contaminants before installing a drip system. Surface water from streams and ponds contain bacteria, algae, and other aquatic life, making more expensive sand filters an absolute necessity. Municipal water suppliers will generally provide water quality test results, making it easier to spot potential problems. However, you can expect to pay a high price for this water.

Drip irrigation system components

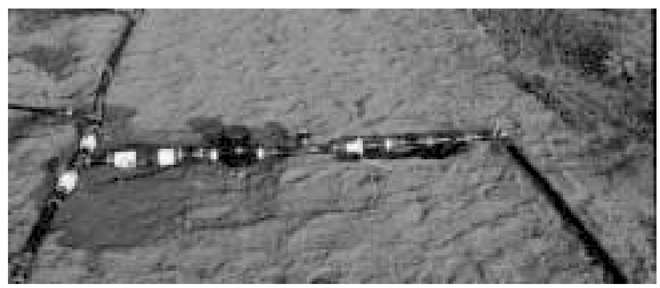
A drip irrigation system has six major components:

1. **Delivery system**
   - Mainline distribution to field
   - Sub-mainline (header line)
   - Feeder tubes or connectors
   - Drip lines
2. **Filters**
   - Sand
   - Screen
   - Disk
3. **Pressure regulators**
   - Fixed outlet
   - Adjustable outlet
4. **Valves or gauges**
5. **Chemical injectors**
   - Positive displacement injectors
   - Pressure differential injectors
   - Water-powered injectors
6. **Controllers**
   - Manual
   - Computer

How these components are put together, and which options are chosen, will depend on the size of the system, the water source, the crop, and the degree of automation desired.

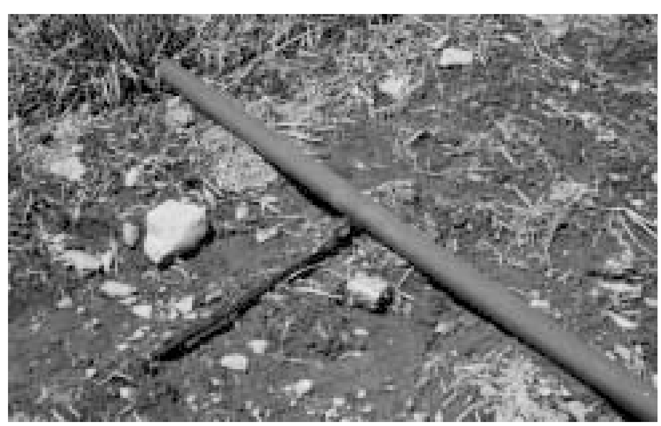
Delivery system

Mainline distribution to field: Underground polyvinyl chloride (PVC) pipe or above-ground aluminum pipe delivers water from its source (pump, filtration system, etc.) to the sub-mainline (header line).



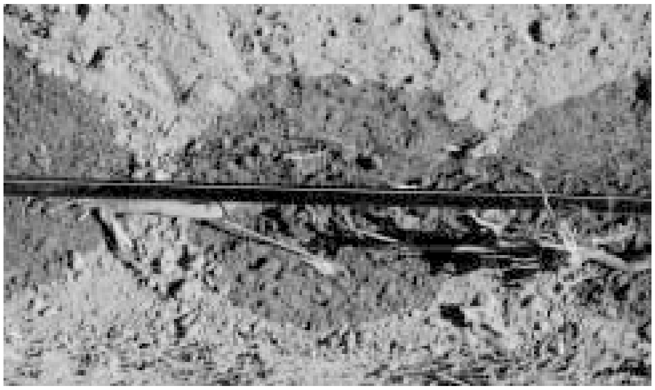
Irrigation mainline with screen filter, pressure regulator, pressure gauge, and water meter connected to sub-main

Sub-mainline (header): It is common to use vinyl “lay flat” hose (polyethylene pipe) as the sub-mainline (header line).This hose is durable, long lasting, and lays flat when not in use so equipment can be driven over it. The lay flat hose, connectors, and feeder tubes are retrieved after each growing season and stored until the following year. Since polyethylene pipe is more rigid, it is not easily rolled up at the end of the season.



Vinyl lay flat hose with connector and drip tape

Connectors/couplings: Two basic methods are used to connect the drip tape to the sub-main. One method uses small plastic tubes called feeder tubes to connect the sub-mainline (header line) to each drip tape. Feeder tubes can be inserted directly into the vinyl hose. The second method uses plastic connectors or couplings to connect the drip line to the sub-main.



Drip tape and wetting pattern

Drip lines: Two basic types of drip lines are used for commercial vegetable production, with *turbulent flow drip tape* most commonly used. This polyethylene product is thin-walled, collapses when not pressurized, and has emitters formed into its seam during manufacturing. Drip tapes are operated at pressures ranging from 6 to 15 psi. *Drip tubes with internally attached emitters* are an alternative to turbulent flow drip tapes. Products with in-line or internally attached emitters tend to be more expensive, but often have better water distribution uniformity and better clogging resistance. These products are common in permanent applications, such as subsurface drip irrigation, landscapes, or orchards.

Designing and operating a drip system requires knowledge about the drip product being used. Water flow rate, emitter spacing, wall thickness, diameter, and pressure compensation ability are important. *Water flow rate* is typically specified in gallons per minute per 100 feet of tape (gpm/100 ft) or by the emission rate of a single emitter in gallons per hour (gph). Tape flow rates typically range from 0.2 to 1.0 gpm/100 ft. For vegetable production, tapes with flow rates around 0.5 gpm are often used. Maturing vegetables grown in the northeastern United States require about 2 to 3 hours of irrigation during hot summer days when a 0.5 gpm/100 ft tape is used.

Emitter spacing refers to the distance between emitters along the drip line. For vegetables, emitter spacings of 8 to 18 inches are common. On very sandy soils, a closer spacing may be required to assure adequate water distribution. However, closer emitter spacings translate to higher emission rates. This increases the system flow rate and requires a larger pump and pipe size, leading to a higher overall system cost. A 12-inch emitter spacing works well on many soils and is very common in the northeastern United States.

Wall thickness of drip tapes are specified in mils (1 mil = 1/1000ths of an inch). Manufacturers produce drip tapes with wall thickness ranging from 4 to 25 mil. Wall thickness selection should be based on user experience, the number of seasons a product will be used, and the potential for damage by insects, animals, and machinery. Inexperienced users needing a single-season product should begin with a 10 or 15 mil tape to minimize stretching and breaking commonly experienced when first learning installation procedures. Experienced users of single season tapes often prefer 6 to 8 mil products. Tape cost is influenced by wall thickness, so thin-walled tapes cost less than thick tapes.

A drip line installed on the soil surface is much more likely to be damaged by birds, animals, and insects than one buried 1 to 3 inches in a bed covered with plastic mulch. Buried lines will also not move around on the bed, which results from the expansion and contraction of the polyethylene. Drip lines laid on the soil surface are also prone to damage by tractors and foot traffic. Although drip tubes are commonly reused, this practice is rare by commercial vegetable growers. Reusing drip tape is an ecologically sound practice, but the cost of retrieval, storage, and repair is high.

Diameter of the drip tape is important to consider in system design and is chosen based on row length. Row length directly affects both the flow rate through the tape and pressure loss in the tape. A tape diameter of $\frac{5}{8}$ inch is the industry standard and is common where rows range from 300 to 600 feet. For rows ranging from 600 to 1,500 feet, $\frac{7}{8}$-inch-diameter tape is available. As with wall thickness, the cost of tape is proportional to tape diameter.

Pressure compensation refers to a drip line's ability to maintain a specified emission rate over a range of pressures. A pressure compensating line emits water at the same flow rate over a range of pressures. A non-pressure compensating line emits water at a rate that increases linearly with pressure. Commonly used drip lines fall somewhere in the middle and are called partially pressure compensating. For example, many drip lines will experience a 10 percent increase in emission rate when pressure is increased 20 percent. Drip tubes with internally attached emitters are fully pressure compensating, but are more complicated to manufacture and are more expensive.

The cost of drip lines varies with diameter, wall thickness, emitter design, and pressure compensation capability. Turbulent flow tapes ($\frac{5}{8}$-inch diameter) with a wall thickness from 4 to 15 mil cost $1.50 to $2.50/100 ft (about $125 to $225/acre). Tubes with internally attached emitters and a wall thickness of 5 to 15 mil cost from $2 to $4/100 ft.

Filters

Filters are essential to the operation of a drip system. Many devices and management techniques are available for cleaning irrigation water. Depending on the water source, settling ponds, self-cleaning suction devices, sand separators, media filters, screen filters, and disk filters are used with drip irrigation systems. Keeping a drip system free of debris is critical because most clogs will irreparably disable a system.

Media, screen, and disk filters are characterized by the size of the holes the water passes through in the filter element. The size of the openings is specified by the filter's mesh size. Mesh size is inversely related to the size of the filter openings. For example, a 200-mesh filter will capture smaller particles than a 100-mesh filter. For most drip tapes, 150 to 200 mesh filtration is required. For clog-resistant tubes with internally attached emitters, 100-mesh filtration is sufficient.

Settling ponds use gravity to allow particulate matter to settle to the bottom of a pond. However, other techniques are more suitable and practical, since settling is not efficient in removing suspended matter. Although sand-sized particles will settle in seconds, silt- and clay-sized particles can take hours, weeks, or months to settle. Ponds also support aquatic life that often contribute to clogging problems. Media, screen, or disk filters are preferred to remove physical material from water.

The location of the suction inlet is an important decision as it affects the quality of the water entering the filtration system. Ideally, the inlet should be located some distance from the edge of the pond, 1 to 2 feet below the surface of the pond. Attaching the inlet of the suction pipe to the bottom of a sealed, partially water-filled 55-gallon drum can serve as a self-adjusting inlet depth regulator. However, it is often impractical to locate the inlet away from the shoreline. Near the pond edge, weeds and algae are often drawn into the inlet. A *self-cleaning suction device* can reduce the amount of weeds and algae drawn into the system where the organic load is high. This device has a screened, barrel-shaped rotating basket around the inlet of the suction pipe. A pressurized water return line from the irrigation system sprays water against the inside of the screen basket, cleaning the basket and forcing weeds and algae away from the inlet.

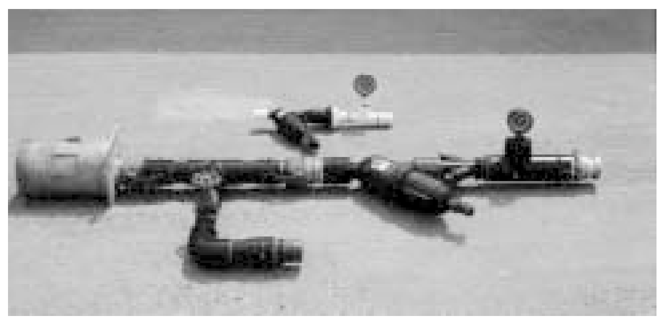
Sand separators are sometimes used in front of media, disk, or screen filters. These devices separate sand and heavy particulate matter by swirling the water passing through them. Sand separators must be sized according to the flow rate to operate properly and will not remove silt- or clay-sized material.

Media filters are the most common filters used in commercial vegetable production. Ranging from 14 to 48 inches in diameter, they are usually installed in pairs. Media filters are expensive, heavy, and large, but can clean poor-quality water at high flow rates. In a media filter, 12 to 16 inches of media (sand or crushed rock) act as a three-

Sand filter, pump, and fertigation unit

dimensional filtering agent, trapping particles within the top inch or two of media. As the media fills with particulate matter, the pressure drop across the media tank increases, forcing water through smaller and fewer channels. This will eventually disable a media filter, requiring clean water from one tank be routed backwards through the dirty tank to clean the media. This "backwashing" requires exact flow rates to make the media "dance" and be thoroughly cleaned. Large, commercial-sized filters require electronic controls and hydraulic valves to route the water. For small operations, a single tank (swimming pool filter) with manual back-washing can be used. Typically, the pressure drop across a clean media tank is 2 to 3 psi. Media tanks should be back-washed when the pressure drop is 5 to 8 psi greater than when the tank is clean.

Screen filters are used widely in commercial vegetable production and are the most common irrigation filter used by small operations if the water source is relatively clean. Screen filters can remove debris efficiently like a media filter, but are not capable of removing as much debris as a media filter before cleaning is required. Screen filters are often oversized because they only have a two-dimensional cleaning surface (compared to the media filter's three-dimensional filtering action) and a much smaller cleaning surface than do media filters. Screen filters are sometimes used as secondary filters, located downstream of media filters.



Screen filters, pressure regulators, and pressure gauges

Cleaning screen filters is important. If neglected, a portion of the screening element will become caked and clogged, forcing water through a smaller area. This can push debris through the screen element and will destroy a filter under extreme cases by rupturing the screening element. Upstream and downstream pressure gauges can judge when a filter requires cleaning. A pressure drop of 1 to 3 psi is normal for a screen filter. Screen filters should be cleaned when the pressure drop is 5 to 8 psi compared to when the filter is clean. Many screen filters contain a flushing valve, making it extremely easy to clean the filter.

Disk filters are relatively new devices that possess traits of both media and screen filters. The screening element of a disk filter consists of stacks of thin, doughnut-shaped, grooved disks. The stack of disks forms a cylinder where water moves from the outside of the cylinder to its core. Like a media filter, the action of the disk filter is three-dimensional. Debris is trapped on the surface of the cylinder and also moves a short distance into the cylinder, increasing the capacity of the disk filter. Cleaning a disk filter requires removing the disk cylinder, expanding the cylinder to loosen

Disk filters

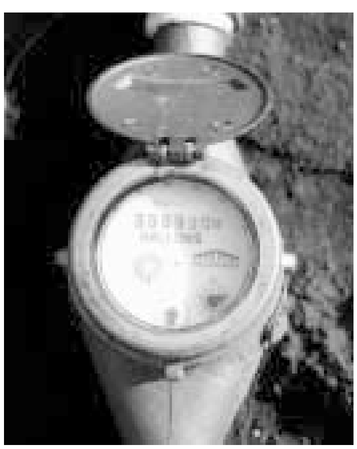
the disks, and using pressurized water to spray the disks clean. Although disk filters have a cleaning capacity between media and screen filters, disk filters are not recommended where organic matter load is high.

Both disk and screen filters are configured with electronic controls, hydraulic valves, and special devices to operate as self-cleaning filters. With these attachments, self-cleaning disk and screen filters can be used in place of media filters if the organic matter load is not high. These devices have the advantage of being smaller and lighter, but cost about the same as media filters.

Pressure regulators

Pressure regulators reduce the water pressure in the irrigation system manifold (the pipeline feeding the drip lines) to the working pressure of the drip lines. Both fixed outlet and adjustable outlet pressure devices are available for a wide range of flow rates. Globe valves regulate pressure by constricting the water flow path. However, they are not recommended because any change in the system flow rate or operating pressure also affects downstream pressure. This could happen when water is routed to a different zone or as a system begins to experience some clogging. The danger of having an unreliable pressure regulator is the system becoming over-pressured. Tape may deform or burst at pressures as low as 30 psi.

Valves or gauges



Water meter

Watering several fields or sections of fields from one water source can be accomplished by using automatic or manually operated valves to open and close various zones. A backflow/anti-siphon valve is necessary if using a well or municipal water source or when injecting fertilizers or chemicals into the system. Hand-operated gate or ball valves or electric solenoid valves automate the system using a time clock, water need sensor, or automatic controller box (computer controller). It is also recommended to install a water meter to monitor total water usage and flow rate in the system.

Chemical injectors

Fertilizer injector

Three types of chemicals are typically injected into drip irrigation systems: fertilizers, pesticides, and anti-clogging agents. Fertilizers are the most common; the ability to “spoon-feed” nutrients is partially responsible for the yield increases resulting from drip irrigation. Systemic pesticides are also frequently injected into a drip irrigation system to control insects and protect plants from disease. Chemicals that prevent or repair clogging problems are also injected. Chlorine is used to kill algae, and acids are used to modify water pH and dissolve certain precipitate clogs.

The type of chemical being injected is a key consideration in determining the appropriate chemical injector. For fertilizers, maintaining an accurate injection rate is not critical, unless fertilizer is injected on a continuous basis.The most important feature of a fertilizer injector is that it has a high-enough injection rate to complete the injection cycle in a reasonable period. An injector with a capacity of 1 gpm is likely to be sufficient for injecting fertilizer into irrigation zones of less than 10 acres.

In contrast, injecting chemicals to prevent clogging requires an accurate and very low injection rate. Since these materials are usually injected continuously at concentration rates of 1 to 10 ppm, a separate injector is often used. Pesticide injection is similar to fertilizer injection, but the volume of material required is usually small compared to the volume of fertilizer required. For this reason, most pesticides can use injectors suited to either fertilizers (high injection rate/low accuracy) or clogging prevention (low injection rate/high accuracy).

The type of power available at the injection site can affect injector choice. Injectors are powered by gasoline engines, by the PTO shaft of a tractor, by A/C power, and by the pressure of the irrigation system.

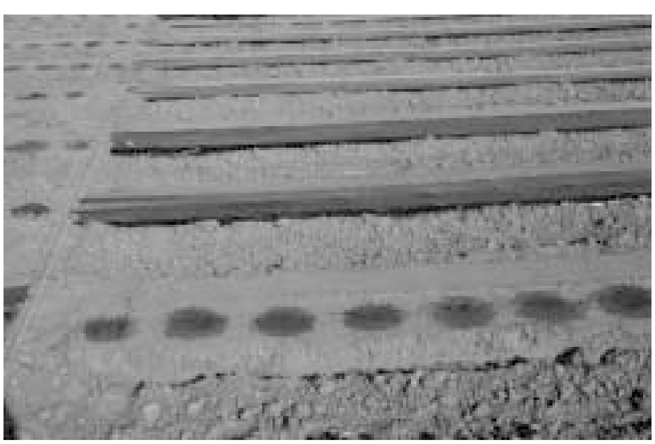
Positive displacement, pressure differential, and water-powered injectors make up the majority of injectors used for chemigation. Externally powered diaphragm, piston, gear, lobe, and roller (peristaltic) pumps are all *positive displacement injectors.* These injectors are typically powered by gas, diesel, or electric, have a high chemical resistance, and are medium to high in cost. The injection rate of diaphragm pumps can be adjusted, but piston pumps must be stopped to adjust the injection rate. A piston pump is more chemically resistant than a diaphragm pump, and its injection rate is less affected by downstream pressure. Many growers purchase an expensive, high-quality diaphragm or piston pump for injecting fertilizers. With high cost comes reliability, durability, and peace of mind.

Pressurized mixing tanks and venturi injectors are two common *pressure differential injectors.* These devices often have no moving parts and tend to be very simple because they use the difference in pressure between two different locations on an irrigation system to power the injection process. Pressure tanks are the simplest types of injectors and can work well for fertilization where delivery accuracy is not critical. The venturi injector is more efficient and more accurate than a pressurized mixing tank. Both require that the injector be plumbed parallel to the irrigation mainline and that a constriction be placed in the mainline between the line delivering water to the injector and the line returning to the mainline. Venturi injectors can deliver chemicals very accurately and can be sized for a particular injection rate. They can be used either for injecting fertilizers or chemicals used for clogging prevention.

Water-powered injectors are driven by the pressure of the irrigation system. Thus, their principal advantage is they do not require an external power source. Both piston and diaphragm types are available. Their injection rate is either proportional to the system pressure or to the flow rate through the injector. Proportional injectors insert chemicals in proportion to the flow rate. They are particularly useful where chemicals are injected for clogging prevention and a fixed concentration of chemical is required. Changing the system flow rate (for example, by switching from one zone to the next) will not change the concentration of material injected with proportional injectors.

Water management

Irrigation scheduling determines how often to irrigate and how much water to apply. The appropriate irrigation frequency is influenced by the rate at which crops use water and by the water-holding capacity of the soil. The amount of water to apply with each irrigation application can be calculated from known soil and plant characteristics.



Drip wetting pattern with plastic mulch

Soil in the root zone acts as a reservoir for water. Soil texture is the primary factor influencing the amount of water stored. Available water is defined as the amount of water plants can easily withdraw from the soil and use (Table 1). Fine-textured soils, such as clays, silt loams, and loams, can hold much more water than coarse-textured soils. Thus, coarse-textured soils must be irrigated more frequently. For most crops, an appropriate goal is to irrigate when 50 percent of the available water is depleted.

Water-storage capacity is influenced by soil depth. Nearly all irrigated vegetable and agronomic crops extract water from the top 2 feet of the soil profile, even though the roots may extend much deeper. In fact, 75–95 percent of most plant roots are in the top 12 to 18 inches of the soil profile. Proper irrigation results in this plant root zone being refilled, but not overfilled. Filling the root zone beyond its capacity results in leaching. The proper duration can be calculated from the plant root zone depth, soil texture, and water flow rate.

Tensiometer

Tensiometers indicate available soil moisture by measuring soil tension (also referred to as soil suction or vacuum). Soil tension indicates how tightly water is held by the soil, increasing as moisture in the soil is depleted. This force draws water out of a tensiometer through its porous tip, creating a vacuum inside the tensiometer. This negative pressure, or tension, is registered on a vacuum gauge. However, tensiometers do not work well in the fine-textured soils common in Pennsylvania and require constant maintenance. Because of this, most vegetable growers rely on their experience to determine critical periods of plant water demand and proper irrigation.

System maintenance

Clogging is the most serious threat to a drip irrigation system and arises from physical, biological, and chemical contaminants. Filtration can remove physical contaminants, and chemical water treatment is often necessary to eliminate or remove biological and chemical contaminants.

The drip system filter should be checked daily and cleaned if necessary. A clogged screen filter can be cleaned with a stiff bristle brush or by soaking in water. Sand filters need to be backwashed. Drip lines should be checked for excessive leaking. A large, wet area in the field indicates a leaking drip line. You can install a connector to the leaking line or bypass the leak with a short piece of feeder tube. Excessive mineral deposits on drip lines can be dissolved with acids, usually phosphoric acid. Tapes buried under plastic mulches are much less apt to become clogged from mineral deposits.

Bacteria, algae, and slime in irrigation lines can be removed with chlorine or commercial bacterial control agents injected through the fertilizer injection system. A 2-ppm chlorine daily rinse at the end of the irrigation cycle or a 30-ppm "shock treatment" can be used if slime becomes a problem in the system. Consult your irrigation system dealer for dilution rates for commercial cleaning products.

Periodic flushing of the mainline, sub-mainline, and drip tape is an excellent maintenance practice. Adapters are available for the ends of each drip tape to automatically flush lines at the end of each irrigation cycle, or they can be manually opened to allow a few gallons of water to flush from the end. This will prevent any build-up of particles or slime at the end of the drip line.

Drip irrigation as part of a plasticulture system

Drip irrigation works well with plastic mulch in an efficient production system that helps retain moisture for the crop, in addition to other benefits. Water and nutrients can be placed into the crop root zone very efficiently with little loss. The cost for irrigating 20 acres with drip irrigation in conjunction with plastic mulch is presented in Table 2. More information on drip irrigation and plasticulture can be found on the Penn State Center for Plasticulture Web site: http://plasticulture.cas.psu.edu/

Laying plastic mulch and drip tape

Table 1. Available water-holding capacity for different soil textures.

Soil Texture	Available Water-Holding Capacity (inches of water per foot of soil)
Sand	0.25–1.00
Loamy sand	0.75–1.50
Sandy loam	1.25–1.75
Loam and silt loam	2.00–2.75
Clay loam	1.75–2.50
Clay	1.50–2.25

(C. A. Storlie, 1995)

Table 2. Component list for 20-acre plastic mulch drip irrigation system.*

Component description	Total price ($)
Engine and pump (14-hp engine and pump)	4,000
24" media filter and fertilizer injector	3,200
Lay flat, header pipe 4"	3,030
Drip tape (7,500'/roll)	2,700
Plastic mulch (1.0 mil black)	3,200
Valves (pressure regulation and air release)	990
Miscellaneous connectors, adapters, clamps, etc.	550
Lay flat connectors and holepunch	610
Total	$18,280

*Only plastic mulch and drip irrigation components are included. The field is assumed to be level with a surface water supply (pond) adjacent to field. The filters designed in this system are capable of irrigating 5 acres at one time. The system contains media filters, a venturi injector, and a 14-hp engine and pump. Additional equipment to consider includes a secondary filter, additional pressure regulators, pressure gauges, and water meters. No sales tax, freight, or field labor was included in the estimate.

(Source: Henry Johnson, Johnson Irrigation Co., Advance, NC)

For more information

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Storlie, C. “Irrigation Scheduling with Tensiometers.” Rutgers Cooperative Extension Service Factsheet FS657, 1995.

“Trickle Irrigation in the Eastern United States.” NRAES-04. Cost: $6. Available through the Publications Distribution Center, The Pennsylvania State University, 112 Agricultural Administration Building, University Park, PA 16802-2602. Telephone: 814-865-6713. E-mail: AgPubsDist@psu.edu.

The following articles are available in the 1998 Proceedings of the Seminar on “Vegetable Production Using Plasticulture” available from the American Society for Horticultural Science, 113 South West Street, Suite 200, Alexandria, VA 22314, phone: 703-836-4606.

Clark, G. A. and A. G. Smajstrla. “Design Considerations for Vegetable Crop Drip-Irrigation Systems.” pp. 10–16.

Hartz, T. K. “Water Management in Drip-Irrigated Vegetable Production.” pp. 16–20.

Hochmuth, G. J. “Vegetable Crop Fertigation.” pp. 20–26.

Clark, G. A. and A. G. Smajstrla. “Injecting Chemicals into Drip-Irrigation Systems.” pp. 26–32.

Selected Web sites

Basics of Vegetable Crop Irrigation, Alabama Cooperative Extension System (http://www.aces.edu/department/extcomm/publications/anr/anr-1169/anr-1169.html)

Center for Plasticulture, The Pennsylvania State University, Department of Horticulture (http://plasticulture.cas.psu.edu/)

Irrigation in Ohio: Eight Major Factors, Ohio State University Extension (http://ohioline.ag.ohio-state.edu/aex-fact/0370.html)

Irrigation Scheduling Methods, University of Georgia (http://www.ces.uga.edu/pubcd/b974-w.html)

Plasticulture for Commercial Vegetable Production, University of Georgia (http://www.ces.uga.edu/pubcd/b1108-w.html)

Selecting a Sprinkler Irrigation System, North Dakota State University Extension Service (http://www.ext.nodak.edu/extpubs/ageng/irrigate/ae91w.htm)

Using Soil Moisture Sensors for Making Irrigation Management Decisions in Virginia, Virginia Cooperative Extension, (http://www.ext.vt.edu/pubs/rowcrop/442-024/442-024.html)

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