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Trickle Irrigation in the Eastern United States

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TRICKLE IRRIGATION in the Eastern United States
CONTENTS

TRICKLE IRRIGATION ......................................................... 1
  Advantages/Potential Problems

PLANT-SOIL-WATER RELATIONSHIPS ....................................... 1
  Deepperetration/Plant Water Stress/Water Measurement
  /Water Sources

SYSTEM COMPONENTS .......................................................... 4
  Pumps and Power Units/Filters/Emittance Devices
  /Distribution Lines/Monitoring and Control Equipment
  /Fertilizer Injection/Mulches

SPECIFIC CROP RECOMMENDATIONS ......................................... 10
  Tree Fruits/Small Fruits/Vegetable Crops
  /Greenhouse Irrigation/Nursery Irrigation

SYSTEM PLANNING ............................................................. 13
  Water Requirements/Field Plant/Soil Wetting Patterns
  /Numbers of Emitters/Irrigation Time/Emitter Location
  /Stirring Lateral/Submain Sizing

APPENDIX A: Designing Laterals and Submains .................................. 16
APPENDIX B: Preventing Line Clogging .................................... 19
APPENDIX C: Water Application Calculations .................................. 22

SELECTED REFERENCES ........................................................... 23

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Trickle or drip irrigation is a method of slowly applying small amounts of water to part of the plant root zone. Water is applied on a frequent, often daily, basis to prevent moisture stress in the plant by maintaining favorable soil moisture conditions. With adequate soil moisture, 25% of the root system of a fruit tree can supply enough water to prevent moisture stress. Trickle irrigation has been installed mainly in areas that are arid and have high labor costs. The system works well with water that is highly saline and on crops planted on steep hillsides. Trickle is also practical for some crops in the Northeast. While the region generally has adequate rainfall, enough may not fall at critical stages of plant growth. Trickle irrigation assures that the root zone has optimum moisture at all times. Also, some areas in the Northeast have a shortage of water and high labor costs. Trickle irrigation requires less water and labor than other irrigation systems.

**Advantages**

Trickle has these advantages when compared with sprinkler irrigation systems.
1. Smaller water sources can be utilized. Drip irrigation requires roughly half the water needed by sprinklers or surface irrigation.
2. Lower operating pressures and lower flow rates are required so less energy is needed for pumping. The pump and pipe network to deliver the water can be smaller, and, therefore, less expensive.
3. A high degree of water control is possible. Plants are supplied with the precise amount of water they need.
4. Disease and insect damage can be reduced because leaves are not wetted.
5. Labor and operating costs are generally less. Extensive automation is possible.
6. Field operations can continue during the irrigation as only a limited area around each plant is wetted.
7. There is a reduction in weed problems and cultivation costs between rows. Water is not lost to weed growth.
8. Fertilizers can be distributed by the system. Since water is delivered only near the plant, less fertilizer is needed.
9. On hilly terrain, good systems can operate efficiently with no water runoff and without interference from the wind.

**Potential Problems**

Among the problems with trickle systems are the following:
1. The small emission orifices are easily clogged by soil particles, algae, or mineral precipitates.
2. Moisture distribution in the soil is limited. The wetted volume is a function of the emitter discharge, distance between emitters, and soil type. Distribution of moisture is a major design consideration.
3. The system is not adaptable for frost protection.
4. Rodents and insects may damage some components. Occasionally laborers cause damage.
5. It is not suitable for closely planted crops such as cereal grains and alfalfa.
6. A higher level of management than other irrigation systems is required.
7. Initial investment and annual cost may be higher than for some other irrigation methods.

**PLANT-SOIL-WATER RELATIONSHIPS**

After a rain or irrigation, water moves primarily downward in response to gravity. In addition, water moves laterally due to the surface attraction of the soil particles. Water advances as a wetting front from the wet area into the dry soil. Movement is rapid at first, then becomes very slow 24 to 48 hours after water application ceases. Movement is more rapid in light soils with large pore spaces, slower in those with fine texture and small pore spaces.

Figure 1. Wet zones by soil type.
Water migrates from moist soil into plant root systems, up the stems and leaves, and out through open pores ( stomates) of the leaves into the drier air around the plant. This loss of water by plants, primarily through the stomates, is called transpiration. Loss of water from transpiration and surface evaporation is evapotranspiration.

**Figure 2. Plant-Water relationships.**

- Water returns to the atmosphere by evapotranspiration
- Water is transported upward in the plant
- Water is added to the soil by precipitation and irrigation
- Water is lost by evaporation
- Absorption by root hairs

**Evapotranspiration**

The primary factor affecting the rates of evapotranspiration (abbreviated ET) is the net radiation energy received from the sun. Sunlight provides the energy for evaporation of water from the soil and plant surfaces. Related factors include temperature, day length, cloud cover, wind, and relative humidity. Kinds of plants, size of plants and planting density are also involved.

**Figure 3. Factors affecting evapotranspiration.**

- Net Radiation
- Day Length
- Temperature
- Cloud Cover
- Relative Humidity
- Soil
- Water
- Type and size of plants
- Plant Density

**Plant Water Stress**

Water stress occurs in plants when the water lost by transpiration exceeds water absorption. During warm days with bright sunshine, absorption normally lags behind transpiration and some degree of stress is normal. As water stress increases, plants will show loss of turgor and temporary wilting during warm afternoons. With greater stress they exhibit more severe wilting, but may recover at night. When they do not regain turgor overnight, permanent wilting has been reached.

During periods of stress, the stomates close and both transpiration and photosynthesis are decreased. Plant respiration on the other hand may increase. Cell enlargement is inhibited due to low turgor and lack of photosynthates. Diameter of plant stems and of fruits may actually decrease during mid-day stress. Flowers and young fruits may drop. Crop yields and quality may be reduced due to formation of smaller fruits, misshapen fruits or vegetative tissues with physiological injury.

**Critical Periods for Water Stress**

If plants show more serious injury or yield reduction from water stress at certain stages in their development, these are called critical periods. The time of seed germination and seedling-emergence is critical for most annual crops. Transplanting time is critical for crops transplanted during the heat of summer. For many crops grown for their fruit or seed—such as sweet corn, map beans, tomatoes, peppers—the periods of flowering, fruit set, and fruit enlargement are most often critical.

**Critical period of water stress occur at different times with different crops**

For peaches, the period of final swell or enlargement of fruit is very important. Under conditions of severe water stress, crops will show response to irrigation at nearly any stage of growth. The largest responses are likely to be obtained by irrigating during these critical periods.

**Water Measurement**

Accurate measurements of soil water losses are difficult to make and require either costly equipment, much labor or both. Tensiometers are widely used to measure the energy status or availability of soil water. They are placed in the soil at one or more depths early in the growing season. Readings are taken at intervals of a few days to a few weeks to determine when

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23
APPENDIX C: Water Application Calculations

The suggested daily water application rates are derived from observations made at the University of Maryland. The daily water application rate often must be modified by a canopy factor and an irrigation efficiency. The daily water application rate for various crops can be estimated by:

\[ Q = \frac{7.48 \text{ gal/ft}^2}{12 \text{ in/ft}^2} \times C \times ET \times A \times CF \]

where:
- \( Q \) = Gallons per plant per day.
- \( C \) = Application factor from Table C-1.
- \( ET \) = Estimated average evapotranspiration, inches/day.
- \( A \) = Plant area, sq ft (distance between rows times plant spacing in the row).
- \( CF \) = Crop canopy factor from Table C-2.
- \( E \) = Irrigation efficiency. Normally between 0.8 and 0.9 for trickle systems.

Daily ET was estimated by a modified Christianens equation. The water application rate was calculated for various soil conditions and expressed as a ratio of the average ET in Table C-1. The values assume no yield loss during the worst summer drought period (1963).

Table C-1. Maximum Daily Trickle Irrigation Application Factor, C

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Normal Crop C &lt; 0.5</th>
<th>Sensitive Crop C &gt; 0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse, shallow</td>
<td>0.85</td>
<td>0.94</td>
</tr>
<tr>
<td>Coarse, deep or heavy, shallow</td>
<td>0.75</td>
<td>0.84</td>
</tr>
<tr>
<td>Heavy</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>

1 Multiplying C by the average daily ET to obtain the maximum irrigation water requirement.

2 Volume may be reduced by 0.1 if 30% or 50% yield loss is acceptable in 1 year of

irrigation is needed. They may be used in automated systems to turn on the irrigation when a pre-determined tensiometer reading is reached.

Electrical resistance meters with gypsum blocks are also used to measure the relative availability of soil water. Gypsum blocks are placed at selected soil depths and locations early in the growing season. Gypsum blocks are not recommended for trickle irrigation systems because they are not sensitive to high moisture percentages.

Standard evaporation pans or 4 or 5 one quart cans full of water may be used to estimate evaporation (ET) near the crops. At the start of the growing season the water level in the can is measured daily to determine evaporation.

Figure 4. Water measurement devices.

ET will be about the same as pan evaporation (1) when the soil surface is wet or when plants completely cover the soil and there is readily available water in the soil. When plants are small and do not cover the soil when available soil water has been largely depleted, ET will be considerably less than pan evaporation. On the average, ET is likely to be about 70 to 80% of pan evaporation. It is desirable to check results of the estimated ET method with a few tensiometers located at strategic spots in the field.

The National Climatic Center publishes pan evaporation data obtained at certain cooperative weather stations during the growing season. Table 1 lists monthly mean pan evaporation and rainfall. Note that pan evaporation exceeds rainfall in almost all areas during the summer.

Water Sources

Water sources include municipally treated water, well water, pond or reservoir water, and canal, ditch, stream or river water. Clean water is essential if it is to be used successfully with the small orifices of trickle irrigation emitters. Line and emitter clogging by physical and chemical contaminants in the water is the single biggest trickle irrigation problem. In some early experiences, for example, as many as 60% of the emission points clogged in two weeks.

Table 1. Pan Evaporation and Rainfall at Selected Stations, Monthly Means in Inches

<table>
<thead>
<tr>
<th>Station</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Georgetown</td>
<td>6.83</td>
<td>7.44</td>
<td>6.21</td>
<td>7.28</td>
<td>5.39</td>
<td>4.09</td>
<td>3.98</td>
<td>2.51</td>
</tr>
<tr>
<td>DC (Southeast)</td>
<td>4.47</td>
<td>6.86</td>
<td>4.97</td>
<td>3.67</td>
<td>3.27</td>
<td>3.98</td>
<td>3.27</td>
<td>2.23</td>
</tr>
<tr>
<td>ME (Northwest)</td>
<td>4.66</td>
<td>5.64</td>
<td>4.44</td>
<td>3.65</td>
<td>3.50</td>
<td>3.66</td>
<td>3.65</td>
<td>3.03</td>
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<tr>
<td>ME (Central)</td>
<td>5.79</td>
<td>5.90</td>
<td>5.07</td>
<td>3.29</td>
<td>13.66</td>
<td>3.87</td>
<td>3.29</td>
<td>13.66</td>
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<tr>
<td>PA (Central)</td>
<td>3.51</td>
<td>2.51</td>
<td>2.08</td>
<td>3.41</td>
<td>2.51</td>
<td>3.41</td>
<td>2.51</td>
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<tr>
<td>NJ (North)</td>
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<td>3.48</td>
<td>4.71</td>
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<tr>
<td>NJ (SouthCentral)</td>
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<td>5.30</td>
<td>19.89</td>
<td>4.53</td>
<td>5.30</td>
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<tr>
<td>NJ (NorthCentral)</td>
<td>4.32</td>
<td>5.69</td>
<td>4.19</td>
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<td>5.69</td>
<td>4.53</td>
<td>5.69</td>
<td>4.53</td>
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<tr>
<td>NY (Great Lakes)</td>
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<tr>
<td>NY (Lake Ontario)</td>
<td>2.47</td>
<td>6.00</td>
<td>4.15</td>
<td>4.22</td>
<td>2.76</td>
<td>2.47</td>
<td>6.00</td>
<td>4.15</td>
</tr>
<tr>
<td>RI (Schoharie)</td>
<td>3.78</td>
<td>5.06</td>
<td>4.40</td>
<td>4.02</td>
<td>3.78</td>
<td>5.06</td>
<td>4.40</td>
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<tr>
<td>RI (Erie)</td>
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<td>4.37</td>
<td>4.97</td>
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<td>RI (Lake)</td>
<td>3.49</td>
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<td>1.97</td>
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<td>2.06</td>
<td>1.97</td>
<td>4.16</td>
</tr>
<tr>
<td>WI (Southeast)</td>
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<td>7.73</td>
<td>5.41</td>
<td>39.74</td>
<td>7.64</td>
<td>7.73</td>
</tr>
<tr>
<td>WA (Southeast)</td>
<td>3.51</td>
<td>6.31</td>
<td>5.90</td>
<td>4.24</td>
<td>21.51</td>
<td>4.24</td>
<td>21.51</td>
<td>4.24</td>
</tr>
</tbody>
</table>

1Evaporation and rainfall data are from Climatological Data, National Oceanic and Atmospheric Administration. U.S. Department of Commerce. Evaporation means are for the period 1966-77. Rainfall data are long-term means.

Ground water from wells is generally good quality and should be used when possible. It may contain sand or chemical precipitates, however. Surface water such as streams, springs and ponds can be used, but it is contaminated with bacteria, algae and other aquatic life. Thorough, and often expensive, multistage filtration or chemical treatment of surface water is required. All water sources contain bacteria or the elements to support bacterial growth.

In general, fast moving water contains higher levels of suspended inorganic particles. Reservoirs or ponds, if sufficiently large and if the pump suction is elevated above the bottom, should contain a relatively small amount of these particles.

Small trickle irrigation systems require only 2 to 5 gallons per minute (gpm) per acre so the source need not be large. For example: Given a 10' x 16' spacing (272 trees per acre) with one emitter discharging 1 gallon per hour (gph) per tree, in a young orchard, the water source must supply 4.5 gpm per acre.

Small fruits or vegetables planted in rows spaced 6 feet apart and irrigated by a continuous line emitter discharging 6.52 gpm per 100 feet of line will require a larger water flow rate. In this example, a flow rate of 38 gpm would be required per acre. However, several acres could be irrigated sequentially because this type system applies water quickly.

3
SYSTEM COMPONENTS

The major components of a trickle system include:
1. Pump and power unit
2. Filters
3. Emission devices
4. Distribution system
5. Controls and monitoring equipment
6. Supplemental systems

Pumps and Power Units

The pump and power unit represent a significant portion of the initial cost of a system. Therefore, some knowledge of their operating characteristics is important to make the right choice. A pump and power unit that is efficient yet reliable and low priced should be selected.

The centrifugal pump is best suited to pumping from most sources or shallow ground water supplies, or to boost pressure from a water main. It is a relatively low cost pump that is very efficient and available in a wide range of capacities and pressures. Submersible pumps are also well suited for small or moderate size trickle systems where the lift from a well is more than 20 feet.

Figure 5. Trickle irrigation system components.

Figure 6. Pump operation curves for a typical centrifugal pump.

A simple test for calcium carbonate is to stir in a teaspoon of household ammonia into a quart of the supply water and let it sit overnight. Use a glass container, with a smooth, clean, clear, flat bottom. Plan to control the pH in the irrigation water to a point on the bottom of the container and it cannot be disturbed by agitation nor by rinsing. This formation is best seen by using a flashlight in a dark room.

Precipitation also occurs when certain chemicals are mixed. For example, chlorine will cause iron in the water to precipitate. Most phosphate fertilizers react with the calcium in hard water and form a precipitate. Glycerophosphoric acid is an exception. It has a calcium salt which is fairly soluble, (2g/100 ml) and does not cause as much of a precipitate problem as most other phosphates.

If you wish to apply phosphorus fertilizer through your irrigation system, consider using a food grade (white) phosphoric acid. It is commonly available and one of the least dangerous acids to handle. "Green" phosphoric acid contains impurities and precipitates calcium. Keeping the pH low will help control phosphate precipitation.

A simple test can be used to predict potential precipitation problems. To a glass container of your supply water, add any chemical or combination of chemicals to the same concentration you plan to inject. Then cover it and let it sit for twelve hours. If any precipitate forms, it can be seen by examining the container with a flashlight in a darkened room.

If precipitating chemicals must be used, inject them 100 to 200 ft. upstream from the filtration system. At least two elbows should be used in the section of pipe between injection and filtration to create extra turbulence for complete mixing and to allow time for the precipitate to form before reaching the filters.

With some fertilizers, like phosphates, if the injection is stopped an hour or so before the end of the irrigation cycle, there is a better chance of flushing out the chemicals before they have a chance to react and form precipitates. Acid flushing helps too.

Line Flushing

Main line, submain and lateral line flushing is standard maintenance for permanent drip irrigation systems. Since filters only trap the larger particles, silt and clay particles (2 to 25 microns size) will enter the system. As water velocity decreases at the ends of submain and lateral lines, much of this material can settle out. It takes about 140 hours of operation for a 50 ppm sediment load to half fill the last 120 feet of lateral.1

1This assumption is based on sedimentation beginning when the biomass number drops below 4,000; 300 ft. of (in lateral carrying 4 gpm; 1 gal. volume at 10 ft.; a sedimentation time of 7 = 250h (time in min; d = in microns); and a sediment density of 100 lbs/cu ft.}

The coarser the filtration and the greater the amount of suspended solids in the water supply, the greater will be the build up of material in lines. Particles may also combine with some types of bacterial slime to form larger agglomerations that cause emitter clogging.

Periodic flushing will eliminate this buildup. Mains and sub mains should be large enough at the ends to produce flow velocities of 4 feet per second or more in the largest pipe serving the flush-out. In lateral lines, flows to produce velocities of 1 foot per second are adequate for good flushing. Flushing should start with the main lines and progress through the sub mains and laterals. Only open as many ends at a time that will sustain adequate pressure for flushing. Portions of the system may have to be shut off to accomplish this technique.

Sufficient flush time should be allowed to observe clear water running out at the ends. A regular maintenance program of inspection and flushing will help significantly in preventing emitter blockages. The nature of the emission device, the filtration system, the quality of the water supply and experience will determine how often flushing is necessary.

Off Season Maintenance

Another maintenance practice is to cycle the drip system periodically during the off season, when possible. This practice helps prevent drying out sediments in the line that may dislodge and cause blockages when the water is turned back on. It also helps prevent slime formation and may keep ants and other insects from invading the system.
Particle Agglomeration. Particles near the 2 micron size tend to stick together and rapidly form large, heavy aggregates which settle out. A chemical dispersant, such as a hexa- metaphosphate, or a settling basin normally solves the problem. The sludge and emitters that will pass large particles also help.

Suction on steep terrain. The water supply is only one source of sediment. On steep terrain, when the zone valve is turned off, erosion points at low elevations may drain the system quickly and create a suction on the emission points at the higher elevations. Automatic drain and flushing valves can make the situation even worse. If the emission points are buried, or if the outlet is submerged in the small surface puddle that often forms, very muddy water can be sucked into the lateral. The best solution to this problem is to install all outlets above ground and above the puddle. If the emission point is buried, lay the laterals on the contour so they are near the same elevation.

Pond Sediment. Runoff into ponds introduces sediment and agitates the pond. Natural convection currents can keep fine silt and clay particles (1 to 25 microns) in suspension for some time. As a result, the trickle irrigation system using a pond as a water supply must be designed to handle occasional charges of fine suspended particles. A small settling basin built next to a pond water supply will reduce the fine sediment load. In addition it makes chlorination feasible to kill both algae and any slime producing bacteria without having to worry about harming fish. If desired, flocculants, such as aluminum or magnesium polyelectrolytes, can be added to precipitate the finest particulate matter.

Because open basins accumulate floating debris, it is very important to use a coarse screened floating intake located one to two feet below the surface (Figure 7). A rope attached to its anchor allows it to be pulled over to the shore for periodic inspection and cleaning.

Precipitates. Many farm wells are drilled through limestone so the water is hard or high in calcium bicarbonates. If the temperature or the pH of the water is raised above a certain critical point, calcium carbonate precipitates and forms a scale that sticks tightly to the inside walls of the pipes. The relative effects of temperature, pH and hardness for some typical water are shown in Figure 1.

The clogging caused by hard water scale builds up slowly, but it can become very severe. Hardness can neither be filtered from water nor flushed from the lines. Acid can be used for cleaning but it will not completely reclaim partially block the lines and emitters. Even the mildest carbonate precipitate can act as a trap, securing sediment that passes the filter system so that it cannot be flushed out easily.

Water in laterals placed on the ground surface or under plastic mulch can get quite hot, especially under no-flow conditions. This high temperature will cause carbonate precipitation, if hard water is being used. Bury laterals whenever possible to avoid a temperature rise.

Keep the pH down to 7.0 by using a metering pump to inject an inexpensive acid such as a food grade phosphoric acid. Acid injection for a short duration, followed by a rinse period, has not been found harmful to drip system. In one problem associated with any kind of periodic treatment is the possibility of dislodging built up materials and causing clogging downstream. If the system is already experiencing significant numbers of blockages, it may be necessary to hand flush each emitter in addition to any other kind of reclamation treatment being used.

P H control is the most common carbonate precipitation control method, but other methods are possible including: injection of sodium hexametaphosphate (Calgon), use of commercial water softening equipment, precipitation of the carbonate before it enters the system.

Precipitation requires a settling basin or storage tank where either the temperature is raised, above that encountered in the line, or the pH is raised with the addition of lime (CaO) or a fertilizer such as ammonium hydroxide. Plan to control PH in water with over 20 grains per gallon (gpg) of hardness (340 ppm). For 10 to 20 gpg (170 to 340 ppm), operate for a year, then cut out and carefully examine a few sections of the lateral.

Also, examine narrow passageways in emitters. If calcium carbonate accumulations are visible, flush the system out, such systems, such as sodium hypochlorite, may be used. Chlorine may be dangerous to use, especially in high pH water, but other methods, such as chlorination, may be used to reduce the pH. Water with less than 10 gpg (170 ppm) should not cause a problem with carbonate precipitates.

Always select a pump with a greater rated discharge capacity than the desired operating pressure than can be discharged through the emitters. A slightly oversized pump will assure that enough water is delivered at the design or slightly higher pressure. In contrast a slightly undersize pump or emitters that deliver slightly more water than expected will cause the system to operate too low a pressure for uniform flow. Pump efficiency is optimum over a range of discharge, as indicated on the chart, but decreases rapidly on either side of that range. A pump should be selected to operate within this range and, in most cases, near the right side of the chart. Then, if the operating pressure increases due to clogged emitters, the pump will still operate within the optimum range.

Power Units. Electric power pumping units are preferred for most trickle irrigation systems because they are easier than other types of systems to use with time clocks and other controls. They also operate quietly and need little maintenance. Single phase electric lines will usually handle up to 75 horse power motors.

Economical electric power is not always available at the pumping site. If a large horsepower unit is required, a three phase electric power unit or a gasoline or diesel unit can be used instead. A gasoline engine driven pump can be operated over a range of speeds, so the output volume and/or pressure can be varied slightly.

Filters. Filters are required to some degree in every drip irrigation system. They are useful in removing sand and the larger organic suspended particles. Filters cannot remove dissolved algae cells, or bacteria. Coarse screen filters are used as trash screens and for pump protection. Fine mesh screen filters are also used as trap screens downstream from sand separators and sand filters to prevent possible carryover of any materials into the system. Screen filters only remove small amounts of sand and organic matter and they load up quickly when significant quantities of algae are present. In general, the filter the screen the faster the filter load up because more material is caught. Two or more filters installed in parallel or a large filter screen area increases the time between cleaning.

Screens can either be slotted PVC, perforated stainless steel, stainless steel wire mesh, or a synthetic wire mesh, usually nylon. Some must be disassembled for cleaning while others, such as the Y strainer, can be either manually or automatically flushed. Others can back-flush the screen without disassembling. Filters designed to remove algae, such as synthetic mesh, that either filter during flushing or expand slightly during backflushing are generally more effective in distributing collected material than rigid screens.

If much organic matter must be filtered out, sand filters are more effective than other filters. Sand filters are often used for swimming pools. They utilize crushed granite or silica sand to collect impurities. Under flow conditions of less than 20 GPM per square foot of media surface they are efficient and have a relatively large sediment load. Sand filters effectively remove sand, silt and organic materials, but must be periodically backwashed either manually or automatically. Provision must be made for the discharge of wash water that is collected and disposed of in considerable volume. Periodic chemical treatment may be necessary to kill bacteria and algae in the filter bed.

Cartridge filters may be either disposable or washable and are available in smaller sizes for low flow rate systems. They are useful for very small systems with a light sediment load only. These filters should not be used if algae is present.

Filters for Heavy Sand and Silt Loads. A screen and/or sand filter is adequate for most trickle irrigation applications. But in areas where water has a high sand or silt load, sand separators or settling basins may be required.

Sand separators or cyclonic filters, are designed to remove heavy particles (with a higher specific gravity than water). A minimum of 6 psi pressure differential causes the water to spin within a chamber. The heavy particles are spun to the outside wall and slide down to a collection chamber on the
bottom that is periodically flushed out. These devices are simple and effective in removing most sand, but should have a backup screen for safety.

They have no effect on silt, clay, algae or bacteria. A properly sized, covered settling tank often removes sand and silt better than a cyclonic filter. Their most useful application is on sandy wells or fast moving water supplies where sand can be carried.

Settling basins are used where silt loads are heavy and may also be effective in removing water containing hydrogen sulfide, ferrous iron or is high in carbonates. These elements tend to displate or oxidize and precipitate prior to being used in the drip system. A 45 minute retention time allows most of the silt to settle. Unfortunately, settling basins require a large space, produce alga and pick up windborne contaminants such as bacteria and leaves.

**Choosing a Filter**

Filters are available in different sizes depending on flow rate. The emitter orifice size and water quality determine the type of filter. One rule of thumb is to select filters that retain all particles at least one tenth the diameter of the smallest passageway in the system. For example, openings in perforated tubing range from 0.05 to 0.10 inch. Therefore a filter that will remove all particles larger than 25 microns is needed.

A clean well water source may only require an 80-100 mesh filter; however, a 160-200 mesh screen normally is used to keep the particles small enough to pass through most emitters. Some emitters are designed for passage of large particles and may require only 30 mesh filtration. A sand filter is necessary whenever surface water is used.

An accident during cleaning or mainline damage can allow unfiltered water to run through the system. A small secondary filter with a 100 to 200 mesh screen should be installed at each lateral as a safety precaution.

**Filter Maintenance**

Since the filter is one of the most important elements of a successful drip system it is important to insure that it is doing its job. Install pressure gauges at the inlet and discharge to the filter to monitor filter performance and signal any changes. Screen filters should be periodically disassembled and carefully inspected for screen damage, separations of the screen mesh where it is Jones to the support tube and problems with gasket or O-ring alignment or condition.

Flush the filter as necessary either manually or automatically to prevent an excessive pressure drop across the filter. Large pressure drops lower the system pressure, may cause damage to some types of screen filters, and make the screens more difficult to clean. Filtered materials are more firmly imbedded in the screen.

**Emission Devices**

The water emission devices or emitters are unique to the trickle irrigation system. Emitters discharge water at very low flow rates through small orifices. The pressure drop across the emitter must be great enough to counteract pressure differences caused by topography and friction loss, and yet the orifice must be large enough to prevent serious clogging. This contradiction in design requirements has resulted in the manufacture of several types of emission devices. Emitters can be divided into two categories based on field application: line-source and point-source. (Figure 8).

**Figure 8. Types of emitters.**

- **Point Source Emitters:**
  - Long Source
  - Nozzle

- **Line Source Emitters:**
  - Microtube
  - Pressure Compensating
  - Double Pass

**Physical contaminants include organic matter, such as algae, bacteria, leaves, fish, etc. and inorganic matter such as silt or sand. Chemical contaminants are soluble and only become a problem when they precipitate as a solid particle or when they stimulate organic growth. For example, temperature or pH change may cause iron or sulfur precipitation to occur.**

The main causes of clogging are algae, bacterial slime, precipitation, and sediment. In general, adequate filtration, line flushing, and chemical treatment are used to inhibit or prevent clogging. Screen and sand filters were covered in the systems components section. This appendix gives more detail for those planning permanent systems.

**Algae.** Algae can be found in almost all quiet surface waters. Sunlight and water high in nutrients encourages its growth. Algae even grows in water that is blown onto an emitter after the system is turned off. Once algae gets into the line it is almost impossible to remove. Screen ing at the source is not satisfactory because it plugs screens and filters very rapidly. The best way to handle algae is to prevent it from forming. Next best is to kill it at the source and give it a chance to settle out of the water before it enters the line.

If water is not exposed to sunlight, algae will not grow; do use dark colored, opaque tanks, pipe and emitters. Minimize algae formation by decreasing the sediment and nutrient flow into the pond. Regular treatment with copper sulfate will prevent algae formation and control bacterial slime after construction of the pond. Generally a dosage of one to two parts per million of copper sulfate (1 to 2 ppm CuSO4) is sufficient and safe. The higher rate is used for hard water and/or abundant algae growth. Copper sulfate should be applied when the water temperature is above 60°F in May or June. Treatments may have to be repeated two or three times.

Copper sulfate will corrode aluminum and should not be used in systems with aluminum pipe. Chlorine, such as used in swimming pools, will also kill algae, but it is more expensive for hard water.

Dying algae will use up oxygen from the water, so there is some chance of suffocating fish. To avoid this problem, treat only a portion of the pond at a time.

For very minor algae problems, sand filters are much better than screens. Flooding inlets also reduce the pickup of algae and surface trash.

**Bacterial Slime.** Certain bacteria can secrete a slime which eventually plugs emitters and small lines. Conditions which favor its development include: a low pH, but not below 4.5; a low oxygen level; temperature above 45°F; organic matter; dissolved (ferrous) iron in concretions of 0.2 to 1.0 ppm; and hydrogen sulfide in concentrations of 0.1 ppm or more. Clogging is generally not a problem if there is no iron or sulfide in the water.

Extra tubing may be added to the end or along the lateral when a pea is installed. Slime buildup can then be checked by periodically cutting a small section from the extra tubing. The slime often has the color of the tubing, but it feels greasy or slimy.

The treatment for bacterial slime is a disinfectant. The most economical and most common treatment is chlorination, either with household bleach (sodium hypochlorite) or swimming pool chloride (calcium hypochlorite). Sodium hypochlorite is preferred over calcium hypochlorite for hard water to reduce calcium carbonate precipitation in the lines. The hypochlorites are relatively safe and easy to handle by conventional injection methods, but are expensive when needed at higher injection rates. They also cause an increase in pH. Gaseous chlorine is less expensive for use on large scale operations but is extremely dangerous, requires special equipment, and special handling by trained personnel.

Injection of chlorine near the end of the irrigation cycle is sometimes called superchlorination. It is, in many cases, just as effective as and more economical than continuous chlorination. Chlorine is the most of the bacterial slime develops during the off-cycle. Chlorine must be injected during the last 30 minutes of irrigation (or the time required to fill all lines) so that 1 ppm of free residual chlorine remains at the end of the line.

*Must stains require a permit to add chemicals to water supplies.*

*2ppm ppm is 2.7 ppm per acre foot.*
Sloping Terrain

Elevation changes and their effect on pressure gain or loss must be considered in design. A 2.3 change in elevation causes a change in pressure of 1 psi. Normally laterals are run along rows that are level or nearly so. On rolling terrain careful planning by a qualified engineer or specialist is required.

Sometimes a lateral can be designed to take advantage of a downslope so that the energy loss by friction balances the energy gained by the elevation drop. Often, however, to maintain uniform pressure on slopes steeper than 5%, either laterals must be shortened or pressure-compensating emitters or pressure regulators must be installed.

Example 1: What diameter lateral should be used in a 20-acre orchard with dwarf apples spaced 8' apart in 825' long rows. A 1 gpm emitter operating at 2 psi waters each tree.

Pipes may be laid out in several ways as shown in Figure A-1. In Layout A, the figure is shown in green, 822 lateral are required. Table 6 shows that a 4 psi range in pressure from one end of the lateral to the other is acceptable for non-pressure-compensating emitters.

Table A-4 shows that the pressure drop in an 800'-long 1/2" diameter lateral will exceed 6 psi. This pressure drop should be reduced either by dividing the lateral into two-400' lines as in layout B in Figure A-1 or by using ¾" pipe. It is generally less expensive to use smaller lines.

Pressure drop in 400'-long 5/8" pipe is 1.1 psi on 1.5 psi in 15mm pipe. If the row is divided into 4 laterals as in layouts C, D, and E, 200' of ¾" pipe may be used with a pressure drop of 1.9 psi. More manifolds and valves will be required for ¾" tubing; but in some situations, it may still be more economical than 5/8" or larger pipe.

Figure A-1. Typical pipe layouts.

or greenhouses. The point-source emitter is an individual emitter that is typically connected to a plastic pipe.

Water pressure is dissipated within the emitter to achieve a low flow rate; water may pass through a long narrow path, a vortex chamber, small orifice or other arrangement before discharging. Some designs allow moderate sized particles to pass through or to be flushed out. Some emitters self-clean at low pressure.

Operating pressure for point-source emitters ranges from 5 to 60 psi with a flow rate of 0.5 to 2.0 gph. Water filtration is required and varies from 30 to 200 mesh screen size with the majority requiring a 100 or 200 mesh screen. The manufacturer should specify filtration requirements.

A major consideration of emitters used on rolling or hilly terrain is the variation of emitter discharge with water pressure changes due to elevation. Pressure compensating emitters have nearly the same discharge rate over a wide range of line pressure. The line-source emitters and many point-source emitters have moderate to large flow rate changes for moderate pressure changes. For example the pressure compensating emitters flow rate shown in Figure 9 varies from only 0.85 to 1.15 gph when pressure varies from 10 to 30 psi. The noncompensating emitter, however, varies from 2.0 to 2.6 gph over that same pressure range.

Figure 9. Typical flow rates for point source emitters. The pressure compensation emitter is useful in hilly terrain because the flow remains fairly uniform over a wide pressure range.

Distribution Lines

The water distribution system is a network of pipes and tubes of graduated sizes. Water from the pump may be carried to the edge of the field by a single large main line.
Vacuum relief is important for trickle irrigation systems. Negative pressures that develop when the system is turned off can clog emitters if dirty water is pulled back into the system. A one-inch vacuum relief valve for each 25 gpm of flow is recommended. Install the valve down-stream from the valve that controls water into a block.

Fertilizer Injection
Water soluble fertilizer may be applied through an irrigation system by installing a fertilizer injector. Nitrogen and, to some degree, potassium, will maintain plant nutrient levels throughout the growing season when added directly to the water. Trickle irrigation is particularly adapted to injection because the fertilizer is placed where it can be readily taken up by the plant’s root system and with little or no leaching. In some soils, up to 50% less fertilizer is required when it is applied through a trickle system.

Drain or flush valves at the end of each lateral line also help when flushing out the system. Manual drain valves are recommended for permanent systems in frost prone areas. A time clock can be installed to operate a solenoid valve to start/stop the irrigation for a set interval daily. This automatic control is simple and effectively applies the designed amount of water. A rainfall sensor is sometimes included to override the clock and turn off the system when heavy rains occur. (Figure 11).
APPENDIX A: Designing Laterals and Sub mains

Design Formulas

Friction loss in a lateral or up to 1/4" manifolds can be calculated by the formula:

\[ P = 0.0006 \times Q^{0.75} \times D^{1.35} \times (L + N \times L) \times F \]

where:
- \( P \) = pressure drop in the pipe in lbs. per square inch (psi),
- \( Q \) = total flow rate in gallons per minute (gpm) or the number of outlets or emitters divided by the average flow rate per outlet,
- \( D \) = pipe inside diameter in inches (Table A-1),
- \( L \) = total pipe length in feet,
- \( N \) = an emitter equivalent length factor to correct for added resistance from the emitters,
- \( F \) = a correction multiplier to account for the discharge through outlets or emitters along the pipe. Table A-3 lists \( F \) values.

Table A-3. Equivalent Length Factors, \( L_e \) for Typical Emitters.

<table>
<thead>
<tr>
<th>Nominal Pipe Diameter</th>
<th>( L_e ), feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8&quot;</td>
<td>1</td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>1.5</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>2</td>
</tr>
<tr>
<td>more than 3/4&quot;</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: Assume \( L_e = 0 \) for emitter spacing 20 times \( L_e \) or greater. For example, assume \( L_e = 0 \) for 1/2" pipe when emitters are spaced 0’ (0.0 ft) or more apart.

The friction loss in 1/8" or larger pipe or small tubing used to drop the pressure between a manifold and a lateral can be calculated by the Hazen-Williams Formula:

\[ P = 4.53 \times \frac{Q}{C} \times L^{4/3} \]

where:
- \( C \) = 140 for polyethylene pipe,
- \( Q \) = flow drop in the pipe, psi,
- \( L \) = pipe length, feet

Pressure drops for 3/8", 15mm, and 1/2" polyethylene laterals with various emitter spacings and discharges have been obtained and are listed in Tables A-4, A-5, and A-6. These tables are developed from pipe friction formula [1]. Maximum length, operating pressure and flow rate for line source emitters are specified by the manufacturer.

**Example:** How much chlorine bleach must be injected to control bacterial slime in a system that has a 200 gpm flow rate.

\[ \text{Gal/hr. of bleach} = \frac{0.048 \times 200 \text{ gpm}}{3.75\%} = \frac{9.6 \text{ gpm chlorine}}{0.069 \text{ gal/hr}} \]

**Mulches**

Water use efficiency is increased when trickle irrigation is used under mulches because they limit the evaporation of water applied to the soil. This method is often used on tomatoes, black polyethylene is used on melons, eggplants and sweet corn. Black polyethylene is used on melons, eggplants, peppers and tomatoes.

Aluminum foil is used primarily on fall squash because it repels aphids. In N.J., for example, foil mulched fall squash can be raised without being infected with mosaic virus. The foil has also been used on other crops such as Chinese cabbage which are susceptible to the same virus.

In a typical operation a four foot wide mulch and line source emitters are laid at the same time. Row lengths vary, but trickle tubing is held to a maximum of 300' long to maintain uniform distribution. Mulch can be used for either seeded or transplanted crops. A cutter should be rigged on the planter or transplanter to cut a hole in the plastic to grow through. Polyethylene mulch (4' wide, 1/16" mil) costs about $150 per acre (1979) for 6' row spacing; foil costs $400 per acre and line source emitter tubing costs approximately $3200 per acre. Several methods of removing the plastic have been tried, but on small acreages it is removed by hand by running a coulter down the center of the row and picking it up from each side. At present mulch and trickle tubing have not been reused successfully, so new materials are needed each year. Several research projects are developing equipment and methods that will allow the reuse of these materials.
SPECIFIC CROP RECOMMENDATIONS

Tree Fruits, Thornless Blackberries and Grapes

Apples, peaches and grapes respond to irrigation in dry weather with better growth and better fruit size. Newly planted young trees and vines have responded well to irrigation in dry springs and summers. Under proper cultural conditions, irrigated plants have produced fruit one year earlier than unirrigated plants. Nitrogen fertilizer applications can be reduced up to 50 percent on tree fruits when trickle irrigation is used.

Apples require a constant supply of water for maximum fruit growth. Trees require adequate water two weeks before harvest for fruit set. Next year's bud formation and shoot growth also depend on adequate moisture. Irrigation should begin immediately at the time of new planting, particularly on dry soils. Established plants should be irrigated between June 1 and September 1.

When trickle irrigation is used in an orchard or vineyard it is normally a permanent system with above ground point-source emitters and buried mainlines and submain lines. The laterals may be either buried or left above ground.

Figure 12. Layout of point source emitters in tree or other widely spaced crops.

Emitters should be placed at the drip line, the outer edge of the plant canopy, for young trees and within the drip line for mature trees. The emitter should be kept away from the tree trunk to reduce possible disease damage. As plants mature their water consumption increases; increased water flow rate must be planned for in advance. The system will have to operate longer or have reserve capacity to handle additional emitters in the future (Table 6). A combination of both approaches may be used to keep operating time and system size optimal. Trickle irrigation equipment installed in fields of tree crops or grapes is considered to be permanent for the life of the crop (10-20 years). Therefore main lines are buried for protection and convenience. Emitters and lateral lines should be compatible with cultural and harvesting activities to reduce damage to the system.

Small Fruits

Small fruits include strawberries, blueberries, blackberries and raspberries. The crops in this group are close enough together to use line source emitters such as perforated tubing. (Point source emitters can be used on blueberries). Strawberries and blueberries are shallow rooted and depend on the moisture in the top foot of soil. Generally one inch of supplemental water per week from June to September will meet the plant needs when irrigation is inadequate. However, during extreme dry periods at least 0.20 inch of water per day (1.4 inches/week) may be required. Water may be needed in April or May if soil moisture is low or a new planting is being established. Planting on raised beds is a practice which aids in soil drainage and, as a result, requires more irrigation water.

Figure 13. Layout of line source emitters in closely spaced small fruit planting. The trickle tube contains both the distribution lateral and the emitters.

There are 365/5 = 59 rows in the field, so the water demand for full operation will be 90.5 gpm (19.02 x 5/295/100). A pump that delivers 90.5 gpm through a large (214") or (7") main line is needed for the entire field at once. But it is better to divide the field into four zones or subzones because the main lines can be reduced to 1/4", 1/5", and only a 23 gpm pump would be needed. The total system operating time would then increase to 4 x 2.2 = 8.8 hours per day.

Example: A line source emitter system is designed to apply 68 gallons per 100' of row per day to a two acre square field (295' lateral length) by the emitter system. The Emitter's water use is 0.52 gpm per 100 feet of run. What is the irrigation time?

Irrigation time = Daily application

= 68 gal/ 100'/day

= 0.52 gpm/100'

= 131 min = 2.2 hr

Emitter Location

Line-source emitters are either buried several inches deep or placed beside the main line in a row to wet the root zone. A guiding principle is to size lines so there is no more than a 20% difference in discharge between the first and last emitter on the line.

With non-pressure compensating emitters, discharge should not vary more than 20% if the pressure difference from the first emitter to the last emitter varies 25% to 30%. For example the pressure on a typical emitter that discharges 1 gph at 15 psi may vary from 13 to 17 psi and the discharge will only vary 25% or from 0.9 gph to 1.1 gph. Pressure may vary from 20% to 30% on pressure compensating emitters before flow varies more than 20%. Use Table 6 as a guide to allowable line losses.

Most trickle systems are divided into subunits such that a submain or manifold connected through a valve to main line feeds several lateral lines. The total pressure variation in both the submain and laterals must be considered when sizing them.

Submain Sizing

In many cases laterals may be level or nearly so, but the submain that feeds them is not. Where slopes are 5% or more, submain must often be modified by one of the following techniques to prevent too great a pressure variation in the subunit.

1) Divide the submain into shorter lengths so it doesn't have more than about a 10' elevation drop between the inlet and the lowest outlet. Then size the submain so total friction loss is equal to the elevation pressure gain.

2) Install pressure regulators along the submain to reduce pressure variation due to slope.

3) Install flow control devices between the submain and each lateral. Adjust to equalize flow into each lateral.

4) Connect the laterals to the submain with small diameter tubing. By selecting the proper length and diameter the flow to each lateral can be regulated. Different length tubes must be installed for each lateral.

5) Use pressure compensating emitters. This solution may be expensive and is unnecessary if the laterals are level.

6) Using a special poly pipe design technique to select several pipe sizes to, in effect, taper the submain. The pipe's friction loss due to taper then balances the increase in pressure due to slope. This design is rarely used for small wells typical of the Northeast. Fabrication is more complicated plus the additional fittings and pipe sizes required add to the cost.

On hilly terrain it is very important that the main line be connected only to the top or near the top of sub mains. On level fields the submain can be smaller if the center, instead of one end is connected to the main line. Flow rate, submain length and number of outlets are then divided by two to calculate manifold size.
Generally, irrigation laterals should be level. Typical line-source emitter tubes can be run only 200 to 300 feet. Half-inch diameter plastic lateral with point-source emitters can be 500 to 1000 feet long on level terrain. A permanent system with above ground point-source emitters and buried pipelines is common for tree crops. Line-source emitters are used on a few annual vegetable crops and discarded at the end of the season. The section on Specific Crop Recommendations has more detail on systems for specific crops.

### Soil Wetting Patterns

A key to trickle irrigation is the controlled placement of the irrigation water. Any design must consider the wetting pattern to create the optimum moisture environment in the root zone without wasting water.

The wetting pattern depends on the emitter discharge rate and spacing and the soil type. In general, the diameter of the wetted volume will increase with an increase in clay content or with an increase in discharge rate. The shape of the wetted volume depends on soil capillary forces and gravity. In clay soils the capillary forces are very strong and so gravity can be almost neglected. Flow from the emitters moves horizontally and vertically at almost the same rate to form a bulb shaped wetted volume.

Unlike clay soils, gravity plays an important role in sandy soils. The result is a cylinder shaped wetted volume. After irrigation is stopped, the water will redistribute until equilibrium is reached. The diameter and area of the soil wetted by an emitter is listed in Table 4. Generally emitters with high flow rates (2 gph) that operate a long time in mature trees wet more area. (Table 4).

### Number of Emitters

A rule of thumb is to wet about 25 percent of the plant root zone area (projection of canopy onto ground) or approximately:

- Wetted area = 0.2 (Diameter of root zone)

The rate of application should be sufficient to cause water to stand in a small area of the surface to assure good lateral movement of water. A lower rate of delivery may be required on heavy soils. Table 5 can be used as an emitter selection guide. (Table 5).

<table>
<thead>
<tr>
<th>Type of Crop</th>
<th>Emitter Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deciduous Trees</td>
<td>One or two 1 gph emitters per plant. Space 2'-3' from the trunk.</td>
</tr>
<tr>
<td>Fruits and Berries</td>
<td>Normally use 1 gph emitter per plant. Use one emitter per 2 plants when closely spaced (2'-4' apart).</td>
</tr>
<tr>
<td>Crop and standard trees</td>
<td>Two 1 gph emitters per area. May need 3 emitters in sandy soils.</td>
</tr>
<tr>
<td>Vegetables</td>
<td>Calculate water requirements for line source emitter.</td>
</tr>
</tbody>
</table>

**Example:** At maturity apple trees spaced 18' apart in rows 26' wide should receive 18 gallons per day (Table 2). Several essential factors may influence the irrigation design but several possibilities include:
- Use one 1 gph emitter for 18 hours
- Use two 1 gph emitters for 9 hours
- Use three 1 gph emitters for 6 hours
- Use two 2 gph emitters for 4.5 hours

Assuming the trees just touch in the rows, their diameter is 9 feet (mature tree). The desired wetted area for a mature tree is:

\[
A = 0.2(19^2) = 66.8 	ext{ sq. ft.}
\]

The emitters wet a 12 to 20 sq. ft. circle in medium soil (Table 4) so plan to install two emitters to meet the minimum conditions.

### Irrigation Time

The duration of each irrigation can be determined after the following are known:
1. Gallons of water per day per plant
2. Desired interval between irrigations
3. Application rate of emitter per outlet or unit length.

Divide the gallons of water per day per plant by the application rate per emitter to calculate the length of time the system must run daily.

**Hours per irrigation:** Gallons of water per plant per day

If the system operates less frequently than daily, increase the hours of irrigation or add emitters to compensate. Ideally a system can be designed to run 24 hours per day, but most systems run no more than 18 hours and usually less. Time is needed for servicing, allowance for breakdown, and to permit extra operation in severe weather. In addition, long running emitters may allow water to go below the root zone and be wasted. Orchard applications generally operate longer than row crop applications because the row crop tubing applies water faster.

### Vegetable Crops

Adapted hybrids of eggplants, peppers, tomatoes, cantaloupes, and summer squash have given excellent results when grown with trickle irrigation and plastic mulch. The vigor, early fruiting, and strong disease resistance of the better hybrid lines, combined with good cultural conditions, provide outstanding production.

A line source emission system is used for row crops. Water is applied to a row banded down each row and is more fully applied to the space between rows. The emission tubes may be placed on the surface adjacent to the crop rows, a few inches below the soil surface, or beneath a plastic film mulch near the rows.

The pipe and wire for the emitter lines are attached to a small diameter black polyethylene pipe (designed for trickle application) or a flexible lay-flat vinyl hose. These supply pipes are perpendicular to the row direction and may lie on the surface or be buried a few inches beneath the surface. Small plastic feeder tubes are inserted into holes punched into the header or manifold to supply water to the emission lines adjacent to each crop row. Single emission lines may be used to water two adjacent rows if they are no more than 15-18 inches apart.

**Figure 14.** Trickle Irrigation of a vegetable crop with typical line source emitter supply lines.

### Greenhouse Irrigation

Greenhouse crops require one pint of water per square foot per watering to saturate the growing media and provide some leaching. Many crops require this amount of water every day during the high light and temperature seasons.

One person with a hose can properly apply this much water to only 0.3 to 0.4 acre per day. So it costs well over $10,000 per acre per year to manually water greenhouse plants. An automated system, however, costs less than half that to install.

The free draining nonsoil mixes, in wide use commercially, allow automated water application. Even when watered 2-3 times a day, they drain excess water within 10 minutes of saturation to provide ample air in the media for excellent root growth.

Automated watering systems will fail with a soil mix (even with perlite) because it will not drain freely. On the other hand must mix mixes are too porous for them. The system must be on a time clock to pay for itself. Liquid feeding is too expensive because of the labor required to mix and hook up proportioners to the many different crops.

#### Types of Systems

Many systems are available to water any size container uniformly. Of any of the choices, the Spaghetti watering systems do the most precise job of watering. They do not wet the foliage or flowers, and they teach excess salts at every cycle. Spaghetti watering systems are virtually trouble free when used with clean (municipal) water. A 200 mesh line strainer should be installed in the system as a precaution.

**Figure 15.** Spaghetti tube.

The physical tangle of small tubes limits the system to a maximum of 4 pots/sq. ft. One or two pots per sq. ft. for mixed cropping benches is better.

For crops spaced 3 plants per sq. ft. or closer, the capillary pad systems do an excellent job, if kept moist. The pad does not allow leaching, so the media must be kept moist or salt injury to roots can be catastrophic. Capillary pads grow algae, particularly when liquid fertilizer is used, so they must be dried and wire brushed between crops to maintain the wicking potential. Overhead sprinklers or spray stakes are the choice for bedding plants in cell packs.

**Maintenance.** Keep maintenance to a minimum by installing quality materials and using experienced employees to set up.
the system. Be sure to:
- Include line strainers that can be easily cleaned.
- Use high quality polyethylene pipe.
- Use quality controllers that permit separate time cycles for each water station.
- Have enough separate stations for the greenhouse range to provide growing flexibility.
- Insulate, ground and waterproof controls and wiring.
- Place piping out of the way so workers do not kick or otherwise abuse it.

Nursery Irrigation

The potential growth period of nursery stock in the Northeast is about 140 days. The loss of growth from moisture stress is liable to be 20% to 30% during the best of the summer. An irrigation system that maintains even moisture during the growing season could mean reducing a 3 year growing cycle down to 2 years.

Most nurseries, on heavier texture soils, do not have regular irrigation. Nurseries on lighter texture soils have limited irrigation for dry years but the low land cost in relation to crop value per acre ($200) has dictated that a year or two of additional production time is less expensive than an adequate irrigation system. However, an irrigation system that can cut 1 to 3 years from the production cycle can be profitable if interest and taxes on an acre rise to $200 to $300 per year.

Types of Systems

Large "big gun" sprinklers can be used for most nursery stock, if blocks are arranged to utilize them. The annual cost ($1978) is $100 to $135 per acre (10 year life). Trickle or drip systems are used for some nursery crops at an annual cost of $100 to $220 per acre ($1878), depending on plant population and spacing. Movable aluminum pipe with sprinklers when used for most low growing (under 4"") nursery stock costs $80 to $100 per acre per year.

Trickle tubes buried 2" to 4" deep encourage the development of an excellent root system and insure good transplant survival. However, when the plant is dug a 3" to 4" long piece of tubing is left in the soil to complicate the planting of succeeding crops.

Deep burial (15" to 17") has not been tried on nursery stock. It may be that the slow growing roots of nursery stock will not go deep enough to provide the best growth the first year. In addition, it is possible that, after a year or two, the bulk of the active root system may be concentrated at the 12" to 17" depth and be missed when the root ball is dug at harvest. Research is needed on deep placement of drip tubes in nursery stock.

Placement above ground may work for some crops. Damage from cultivation tools could be a problem but the system must be secured from wind dislocation. A permanent system, above ground or buried 2" to 3", should be excellent for bed-grown plants.

Spaghetti tubes, spitter sticks, spray tubes, water loops or other water placement systems produce superior growth of container grown nursery stock compared to overhead systems. This equipment:
- Reduces water and fertilizer use since it only wets the container, not the total area.
- Can be used during the winter when plants are covered.
- Can be automated and, because of relatively low water flow rates, the control zones can be relatively large.
- Works well on dense canopy plants such as Rhododendron where sprinkler irrigation does not penetrate effectively.
- Allows irrigation when workers are in the area.

WATER APPLICATION RATES FOR ROOF CROP1

<table>
<thead>
<tr>
<th>Crop (Spacing in feet)</th>
<th>Plant Age, yrs</th>
<th>1 2 3 4 5 6-20</th>
<th>&lt; Refill</th>
<th>Gallons per day per plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweet Potato, Evening</td>
<td>1.0 1.5 1.5</td>
<td>1.5 2.0 2.0</td>
<td>1.5 2.0 2.0</td>
<td>6.0 9.0 12.0</td>
</tr>
<tr>
<td>M.S. Variety (E + 18)</td>
<td>1.0 2.0 2.0 2.0 2.0 2.0</td>
<td>2.0 2.0 2.0 2.0 2.0</td>
<td>10.0 10.0 10.0 10.0 10.0</td>
<td></td>
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<td>1.0 2.0 2.0 2.0 2.0</td>
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<td></td>
</tr>
<tr>
<td>Peas, Muster, Plus</td>
<td>1.0 2.0 2.0</td>
<td>2.0 2.0 2.0</td>
<td>6.0 9.0 12.0</td>
<td></td>
</tr>
<tr>
<td>Standard (18 + E)</td>
<td>1.0 2.0 2.0</td>
<td>2.0 2.0 2.0</td>
<td>6.0 9.0 12.0</td>
<td></td>
</tr>
<tr>
<td>Squash, Thimble, Blackberry</td>
<td>1.0 2.0 2.0 2.0 2.0</td>
<td>2.0 2.0 2.0 2.0</td>
<td>3.0 3.0 3.0</td>
<td></td>
</tr>
<tr>
<td>(E + 18 or E + 12)</td>
<td>1.0 2.0 2.0</td>
<td>2.0 2.0 2.0</td>
<td>3.0 3.0 3.0</td>
<td></td>
</tr>
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</table>

1 Assumes pan evaporation average 0.7" and evaporation is 90% of pan evaporation.

SYSTEM PLANNING

Thorough planning is essential to properly design, install, and operate a trickle irrigation system. Consider the following factors before choosing a specific system.

Water Requirements

- Determine the cost and availability of water for each application. The cost should cover the entire cost of water, including the cost of irrigation equipment.
- Consider the amount of water required by each crop. The amount of water required will depend on the crop's water needs.
- Consider the water quality. The water quality will affect the performance of the irrigation system.
- Consider the availability of water. The availability of water will depend on the source of water.

Water Use

Water use can be estimated from Table 2 and 3. The values can be used to estimate the water use for any crop. The values are based on the crop's water needs. The values are based on the crop's water needs.

Table 2. Water Application Rates for Crops using Point Source Emitters1

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</table>

1 Assumes pan evaporation average 0.7" and evaporation is 90% of pan evaporation.

Vegetable and Melon

The water required daily per 100 feet of rowcrop can be determined by the equation:

\[ Q = 50 + E \times S \]

Where:
- \( Q \) = Gallons required per 100' per day
- \( E \) = average daily pan evaporation in July in inches per day
- \( S \) = row spacing in feet

The average daily pan evaporation in July is 0.25" in southern New Jersey, southern Delaware, and parts of eastern Maryland and Virginia. Most of the rest of the northeast, including northern New York and Maine has an average daily evaporation loss of 0.18" to 0.21" in July. Vegetable crops may be watered daily for one or two hours or two or three times a week for two to four hours each time.

Plan an application rate of about 5 gallon per 100 feet of row.

Example: Plant melons on 5 foot row spacing in southern Delaware for a total of 1000 feet of row. The row is 10' wide. Pan evaporation is estimated to be an average of 0.27 inches/day in July. How much water should be applied each day?

The quantity of water needed is:

\[ Q = 50 + E \times S = 50 + 0.27 \times 5 = 67.5 \text{ gallon per 100' per day} \]

Field Plan

A map showing the size, shape, elevation contours and distance from the water source to the area to be irrigated should be drawn. Also note such items as soil type, climate and distance to a source of electricity. Consider various planting arrangements as they affect production and movement through the field and to accommodate the irrigation system layout in an effective manner. The spacing of plants within the row, spacing between rows, and the choice of single or double row planting must be known to choose and size components.