The Northeast Regional Agricultural Engineering Service prepares publications under the direction of agricultural engineers and consulting specialists. It is an official activity of 12 Land-Grant Universities and the U. S. Department of Agriculture. The following are cooperating members.

University of Connecticut
Storrs, Connecticut 06268

University of Delaware
Newark, Delaware 19711

University of Maine
Orono, Maine 04473

University of Maryland
College Park, Maryland 20742

University of Massachusetts
Amherst, Massachusetts 01002

University of New Hampshire
Durham, New Hampshire 03824

Rutgers University
New Brunswick, New Jersey 08903

Cornell University
Ithaca, New York 14853

Pennsylvania State University
University Park, Pennsylvania 16802

University of Rhode Island
Kingston, Rhode Island 02881

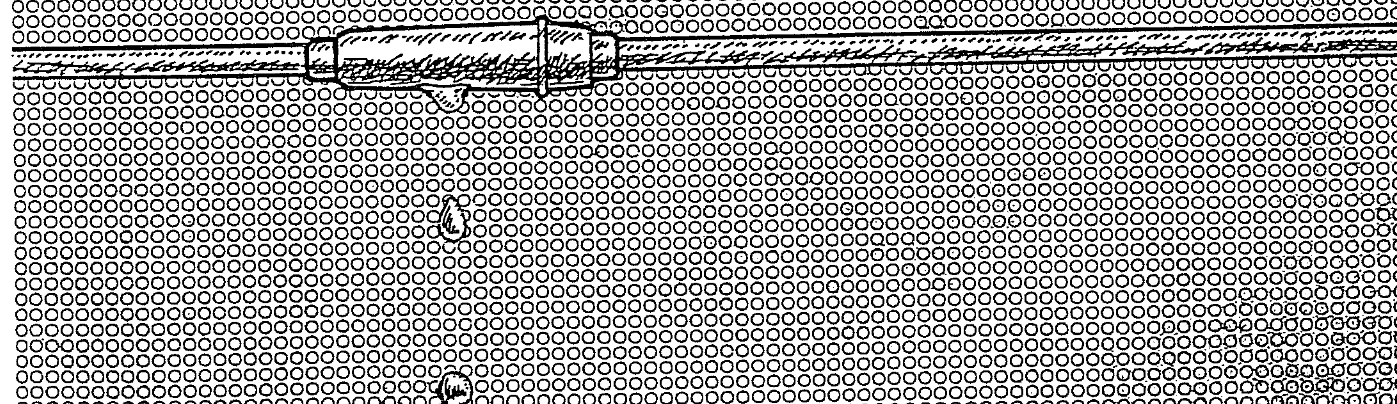
University of Vermont
Burlington, Vermont 05401

West Virginia University
Morgantown, West Virginia 26506

NRAES-4

TRICKLE IRRIGATION

in the Eastern United States



COOPERATIVE EXTENSION
Northeast Regional Agricultural Engineering Service

CONTENTS

NRAES

NRAES, Riley Robb, Cornell University, Ithaca, NY 14853. 607-256-7654

NRAES-4 Feb 1980

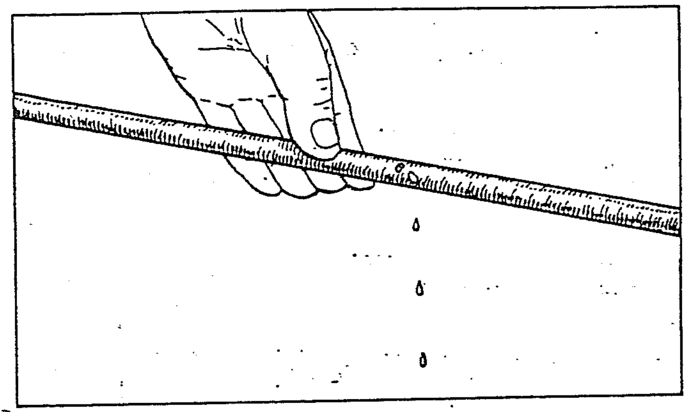
AUTHORS

D. S. Ross, Agricultural Engineering Dept., University of Maryland
R. A. Parsons, NRAES
W. R. DeTar, Agricultural Engineering Dept., Pennsylvania State University
H. H. Fries, Cumberland County Cooperative Extension, Bridgeton, NJ
D. D. Davis, RainBird, Glendora, California
C. W. Reynolds, Horticulture Dept., University of Maryland
H. E. Carpenter, Rutgers R & D Center, Bridgeton, NJ
E. D. Markwardt, Agricultural Engineering Dept., Cornell University

This manual was developed as a result of workshops held during the Spring of 1978 at Newark, DE and Albany, NY. Many individuals contributed substantially to this project. The NRAES committee and the authors particularly thank the following people for their participation and help.

D. C. Coston, Horticulture Dept., Clemson University, Clemson, SC
N. J. Smith, Cumberland County Cooperative Extension, Bridgeton, NJ
Bernarr Hall, University of California Cooperative Extension, San Diego
Warren E. Hedstrom, Agricultural Engineering Dept., University of Maine
John R. Nye, Trickleez Company, St. Joseph, MI
R. E. Chapin, Chapin Watermatics, Watertown, NY
L. D. Geohring, Agricultural Engineering Dept., Cornell University
M. F. Walter, Agricultural Engineering Dept., Cornell University
R. C. Funt, Horticulture Dept., Ohio State Univ., Columbus, Ohio
N. H. Wooding, Agricultural Engineering Dept., Pennsylvania State University
E. B. Hale, Agricultural Engineering Dept., Virginia Polytechnic Institute

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

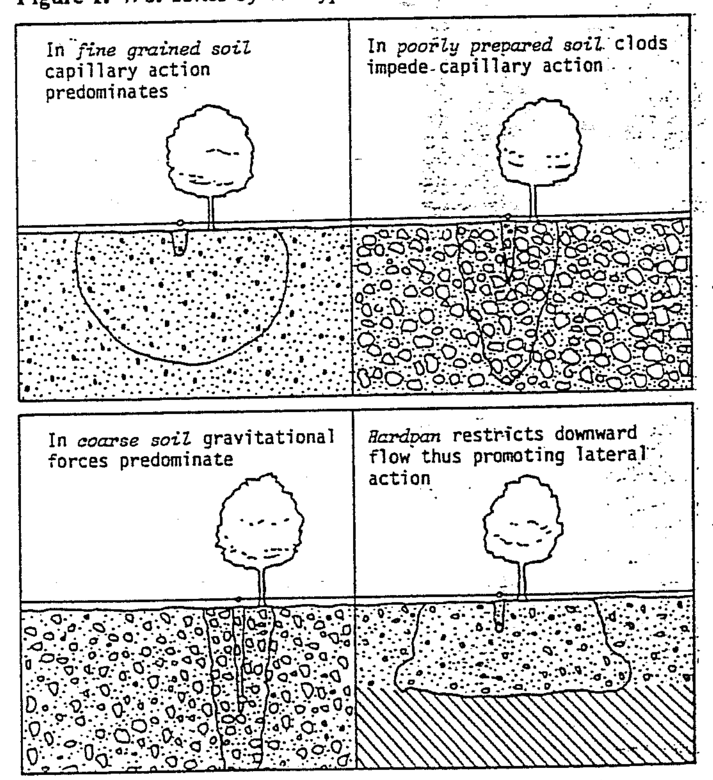
Among the problems with trickle systems are the following:

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

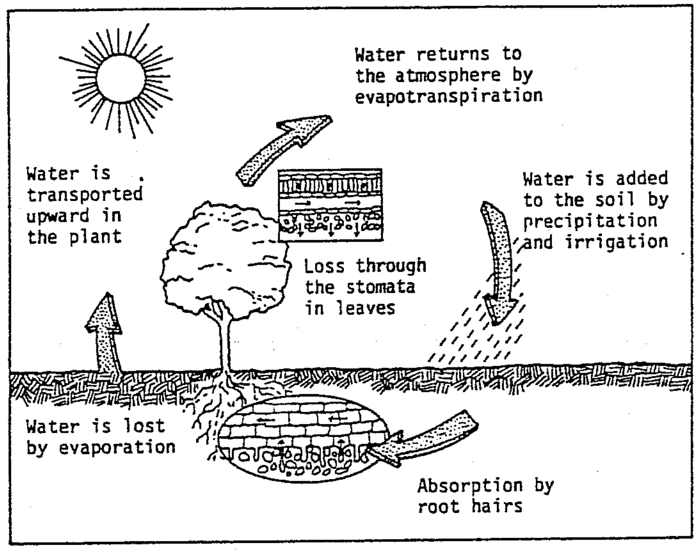
After a rain or irrigation, water moves primarily downward in response to gravity. In addition, water moves laterally due to the surface attraction of the soil particles. Water advances as a wetting front from the wet area into the dry soil. Movement is rapid at first, then becomes very slow 24 to 48 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.**

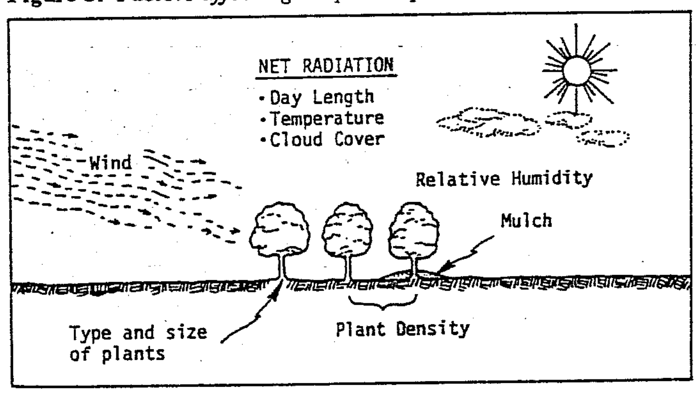
Figure 2. *Plant-Soil-Water relationships.*



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.*



During the long warm days of early summer with bright sunshine, evapotranspiration proceeds rapidly from large plants growing in moist soil. In June or July ET rates may be 0.20 to 0.25 inch per day or even more when soil and plant surfaces are wet. Rates are comparably lower with cloudy skies, cooler temperature and small plants. As the soil water is depleted the rate decreases. Mulches reduce the loss of soil water by decreasing evaporation from the soil surface.

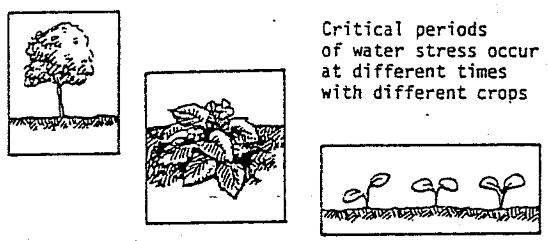
Plant Water Stress

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. Diameters 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, snap beans, tomatoes, peppers—the periods of **flowering, fruit set, and fruit enlargement** are most often critical.



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 determine when

SELECTED REFERENCES

Books

Baars, Ir. C. 1976. *Design of Trickle Irrigation Systems.* Agric. Univ. Wageningen, The Netherlands.

Clark, J. W. 1971. *Water Supply and Pollution Control.* International Textbook Co., Scranton, Pennsylvania.

Davis, S. 1975. "Drip Irrigation." Chapter 20, pp 508–520, in: *Sprinkler Irrigation,* 4th Ed., Sprinkler Irrigation Association, 13975 Connecticut Avenue, Silver Spring, MD 20906.

Davis, S. 1977. Drip Irrigation Management. *Water and Irrigation.* Published by Internat. Drip Irrigation Assn. pp. 14, 15, 30.

Environment Protection Agency. 1973. *Manual of Individual Water Supply Systems.* USEPA Office of Water Programs, Water Supply Div. EPA-430-9-73-003.

Goldberg, D., B. Gornat and D. Rimon. 1976. *Drip Irrigation.* Drip Irrigation Scientific Publications, Kfar Shmaryahu, Israel. 296 pp.

Karmeli D. and J. Keller. 1975. *Trickle Irrigation Design.* Rain Bird Sprinkler Mfg. Corp., Glendora, CA 91740.

Kramer, Paul J. 1969. *Plant and soil water relationships: A modern synthesis.* McGraw-Hill, New York, N.Y.

Midwest Plan Service. 1972. *Private Water Systems* (MWPS-14) Midwest Plan Service, Iowa State University, Ames, Iowa.

Schnedl, D. 1976. *Fertilizer and Chemical Injection.*

Taylor Co. 1954. *Modern pH and Chlorine Control.* Baltimore, MD.

U.S. Department of Commerce. *Climatological data.* National Oceanic and Atmospheric Administration, Environmental Data Service, National Climatic Center, Ashville, NC.

Wright, F. B. 1956. *Rural Water Supply and Sanitation.* J. Wiley, N.Y.

Proceedings

Second International Drip Irrigation Congress. San Diego, CA. 1974

1975 International Drip Irrigation Association, Fresno, CA. 1975

Fourth International Drip Irrigation Association, Fresno, CA. 1976

Annual Technical Conference. 1978. The Irrigation Assoc. Cincinnati, OH.

Annual Technical Conference. 1976. Sprinkler Irrigation Assoc. Kansas City, MO.

VII International Agric. Plastics Congress, San Diego, CA. 1977

Periodicals

Drip/Trickle Irrigation. Munford Publications, Fresno, CA.

Irrigation Journal. Brentwood Publications, Elmgrove, WI.

Leaflets and Papers

Hale, E. B. and P. A. Rak. May 1977. Trickle Irrigation for Fruit Trees. ME-104, Agricultural Engineering Department, Extension Division, Virginia Polytechnic Institute and State Univ., 8 pp.

Kenworthy, A. L. May 1974. Trickle Irrigation. . . Simplified Guidelines for Orchard Installation and Use. Research Report 248, Agricultural Experiment Station, Michigan State University, East Lansing, 7 pp.

Kenworthy, A. L. and J. E. Mites. July 1975. Trickle Irrigation: Guidelines for Use in the Home Garden. Research Report 285. Agricultural Experiment Station, Michigan State University, East Lansing, 7 pp.

Marsh, A. W., R. L. Branson, S. Davis, D. C. Gustafson, and F. K. Aljibury. 1975. *Drip Irrigation.* University of California Leaflet No. 2740. Berkeley.

Prince, A. B., and W. A. Raney. 1961. Some morphological, physical, and chemical properties of selected Northeastern United States soils. N.H. Ag. Exp. Sta. Misc. Pub. 1.

Shoji, K. Nov. 1977. "Drip Irrigation," Scientific American. Vol. 237, No. 5, pp. 62–68.

Sojak, M. 1977. Iron Oxide Problems in Ontario Drains. ASAE paper NA 77-206 presented at annual meeting of North Atlantic Region of ASAE. Fredericton, N.B., Canada.

Watters, G. Z. and J. Keller. 1978. Trickle Irrigation Tubing Hydraulics. ASAE paper 78-2015.

Wu, I-Pai and Harris M. Gitlin. 1975–1978. Dept. of Agricultural Engineering, Engineer's Notebooks. Univ. of Hawaii, Honolulu.

Wu, I-Pai and H. M. Gitlin, 1978. Drip Irrigation Design in British Units. Univ. of Hawaii, Honolulu. Misc. Pub. 156.

APPENDIX C: Water Application Calculations

The suggested daily water application rates are derived from observations made at the University of Maryland. These values were checked by a moisture budget analysis based on weather data measured at The Pennsylvania State University during drought periods in August 1960, July and August 1962, July 1965, August 1966 and August 1972. The budget equation used was:

$$Q_m = \frac{\Sigma ET - (P \times AM + R)}{n}$$

where: Q_m = Maximum daily application rate.

ET = Summation of each days maximum potential evapotranspiration.

P = Fraction of the available moisture that may be depleted without causing plant moisture stress.

AM = Maximum available moisture in the root zone.

R = Total rainfall during period.

n = Number of days during period.

Daily ET was estimated by a modified Christiansen 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 (1962).

Table C-1. *Maximum Daily Trickle Irrigation Application Factor, C.*[1,2]

Soil Type	Normal Crops P = 0.5	Sensitive Crops P = 0.3
Coarse, shallow (available moisture = 1.5")	0.85	0.94
Coarse, deep or heavy, shallow (available moisture = 2.5" to 3")	0.75	0.84
Heavy, deep (available moisture = 5")	0.6	-

[1] *Multiply C by the average daily ET to obtain the maximum irrigation water requirement.*

[2] *Values may be reduced by 0.1 if 3% to 5% yield loss is acceptable 1 year in 4.*

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:

$$Q = \frac{7.48 \text{ gal/cu ft}}{12 \text{ in/ft}} \times C \times ET \times A \times CF$$

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.

Table C-2. *Crop Canopy Factor, CF*

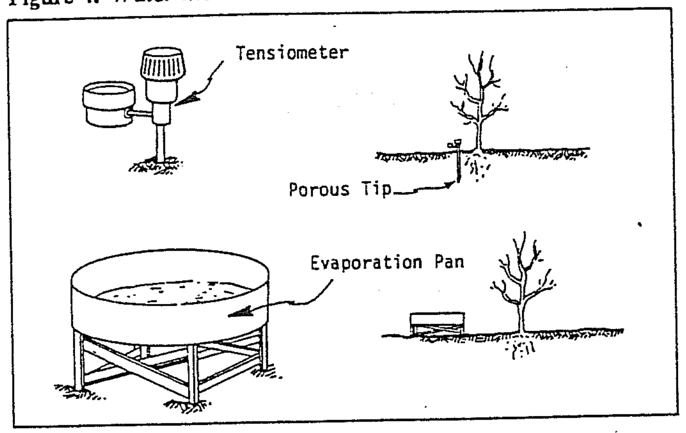
Trees	
mature	0.8
1/2 mature	0.6
1/4 mature	0.3
Vegetables & melons	1.0
Grapes	0.7
Small fruits	0.5

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 at high moisture percentages.

Standard **evaporation pans** or 4 or 5 one quart cans full of water may be used to estimate evapotranspiration (ET) near the crops. At the start of the growing season the water level in the cans 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 (2) when there is readily available water in the soil. When plants are small and do not cover the soil or 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 emission devices. 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.*[1]

Station		May	June	July	Aug	Sept	Totals May-Sept
Georgetown DE (Southern)	Evap.	6.51	7.64	8.24	7.24	5.39	35.02
	Rain**	3.47	3.66	4.57	4.82	3.56	20.08
Caribou ME (Northern)	Evap.	4.65	5.41	5.71	4.91	3.03	23.71
	Rain	3.03	4.07	4.04	3.67	3.53	18.34
Beltsville MD (S. Central)	Evap.	5.72	6.64	7.47	6.05	4.92	30.08
	Rain**	3.71	3.85	4.07	4.72	3.29	19.64
Chestnut Hill MA (Central)	Evap.	4.55	4.89	6.44	5.86	3.39	25.13
	Rain	3.51	3.61	3.28	3.81	3.87	18.08
Canoe Brook NJ (Northern)	Evap.	4.58	5.26	5.82	5.32	3.74	24.72
	Rain	4.17	3.53	4.84	4.81	3.84	21.19
Seabrook Farms NJ (Southern)	Evap.	6.41	7.41	7.69	6.68	4.92	33.11
	Rain**	3.51	3.42	5.13	4.53	3.30	19.89
Lockport NY (Great Lakes)	Evap.	4.23	5.48	6.39	5.02	3.51	24.63
	Rain	3.19	2.37	2.61	3.02	2.93	14.12
Landisville PA (Southeast)	Evap.	5.47	6.00	6.41	5.45	4.02	27.35
	Rain	3.79	3.56	4.40	4.02	3.35	19.12
Kingston RI	Evap.	4.87	4.97	5.66	5.04	3.68	24.22
	Rain	3.49	3.06	2.57	4.66	3.74	17.52
Holland VA (Southeast)	Evap.	6.91	7.56	7.74	6.77	5.41	34.39
	Rain	3.51	4.51	5.90	6.25	4.14	24.31

[1] *Evaporation and rainfall data are from* Climatological Data, *National Oceanic and Atmospheric Administration, U.S. Department of Commerce. Evaporation means are for the period 1968–77. Rainfall data are long-term normal 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′ × 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 0.52 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.

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 surface 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.

Pumps

The total pressure of the system, volume of water required, and type of power unit must be known to select a pump. The total dynamic head or pressure that the irrigation system will impose on the pump depends upon these factors:

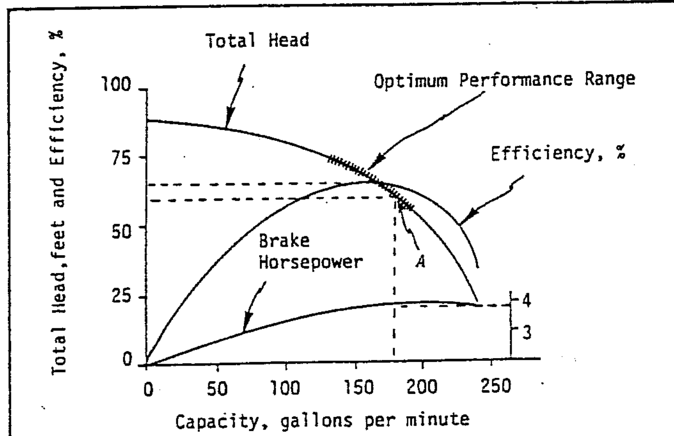
Elevation Head - difference in elevation between the water source and the highest emitter or land to be irrigated.

Friction Head - the loss in pressure due to friction of water flowing in the pipe and fittings.

Pressure Head - the pressure required at the most distant emitter.

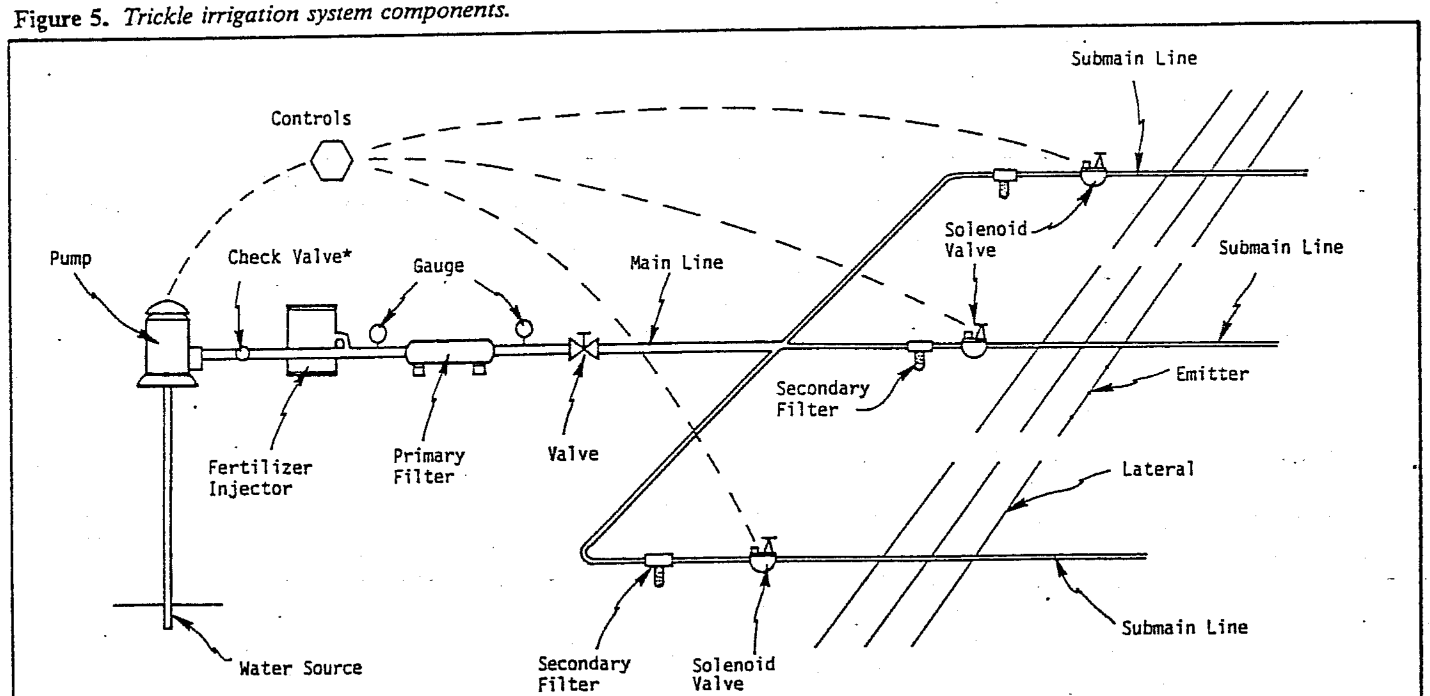
The performance of a centrifugal pump can be illustrated by a typical pump test plot shown in Figure 6. The three curves show how the pump performs at different flow rates or capacities. An important factor of concern is that the discharge decreases as the operating pressure increases.

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



EXAMPLE: The total head curve of this pump shows that if it operates at point A it will deliver 180 GPM at 58 feet of head. By drawing a vertical line through point A the efficiency and brake horsepower may be determined. The pump requires about 4 brake horsepower and operates at about 63% efficiency.

Figure 5. *Trickle irrigation system components.*



* A backflow preventer or vacuum breaker is required in some areas.

A simple test for calcium carbonate is to stir 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 if an almost white, sparkling crystalline precipitate forms on the bottom of the container and it can neither 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. Glycero-phosphoric 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 micron 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 150 feet of lateral.[3]

[3]This accumulation time is based on sedimentation beginning when the Reynolds number drops below 4,000; 300 ft. of ½ in. lateral carrying 4 gpm; 3 gph outlets spaced at 10 ft.; a sedimentation time of $T = 250d^2$ (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 the material in lines. Particles may also combine with some types of bacterial slimes to form larger agglomerations that cause emitter clogging.

Periodic flushing will eliminate this buildup. Mains and submains 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 submains 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 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, where 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 (agglomerate) and rapidly clog lines and orifices. A chemical dispersant, such as a hexametaphosphate, or a settling basin normally solves the problem. Flushing the lines and using 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, emission points at low elevations may drain the system quite rapidly and create a suction on 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, it helps to 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 the algae and any slime producing bacteria without having to worry about harming fish. If desired, flocculants such as alum or organic polymers, can be added to precipitate the finest particulate matter.

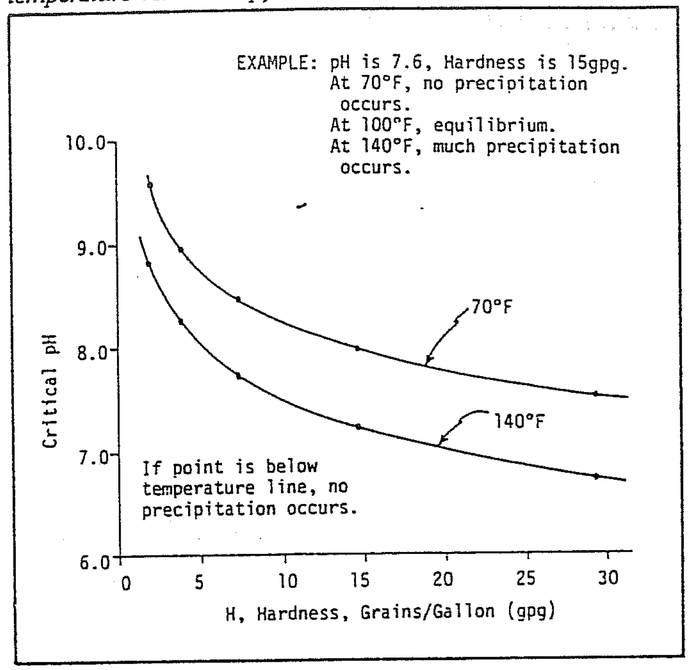
Because open basins accumulate floating debris, it is very important to use a coarse screened floating intake located one to two feet below the surface (Figure 7). A rope attached to its anchor allows it to be pulled over to the shore for periodic inspection and cleaning.

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 pipes. The relative effects of temperature, pH and hardness for some typical water are shown in Figure B-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 blocked 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

Figure B-1. *Carbonate precipitation chart. (Typical pH-hardness-temperature relationship).*



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 like a food grade phosphoric acid. Acid injection for a short duration, followed by a rinse period, has not been found harmful to drip systems. 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.

PH 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 lines, or the pH is raised with the addition of lime (CaO) or a fertilizer such as anhydrous ammonia.

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 lateral.

Also, examine narrow passageways in emitters. If calcium carbonate accumulations are visible, flush the system out with a strong acid and start a pH control program. 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 at 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 at 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 end of the range. 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 to automate with time clocks and other controls. They also operate quietly and need little maintenance. Single phase electric lines will usually handle up to 7½ horsepower 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 or diesel engine driven pump can be operated over a range of speeds, so the output volume and/or pressure can be varied slightly.

Filters

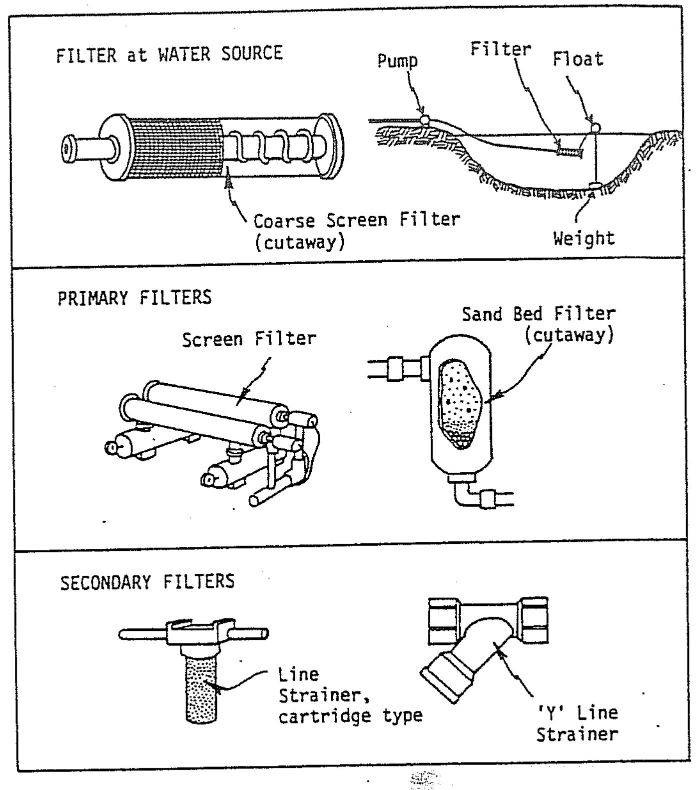
Filters are required to some degree in every drip irrigation system. They are useful in removing sand and the larger organic suspended particles. Filters cannot remove dissolved minerals, algae cells, or bacteria.

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 material 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 finer the screen the faster the filter loads 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 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 disassembly. Filter screens, such as nylon mesh, that either flutter during flushing or expand slightly during back-flushing are generally more effective in dislodging collected material than rigid screens.

Figure 7. *Types of filters.*



If much organic matter must be filtered out, **sand filters** are more effective than screen 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 holding capacity.

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 backwash water that is produced, as it is of 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 aerating well water containing hydrogen sulfide, ferrous iron or is high in carbonates. These elements tend to dissipate 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 algae 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 down to 250 microns. 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.

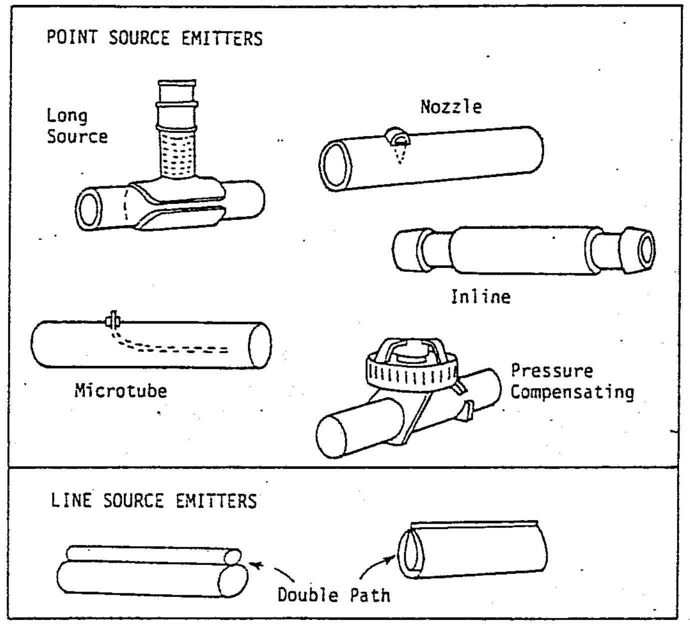
Filter Maintenance

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 any screen damage, separations of the screen mesh where it is joined to the support tube and problems with gasket or 0-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 screen more difficult to clean because 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.*



The **line-source** emitter is used for closely spaced row crops such as vegetables and some small fruit. It can also be used in greenhouses for irrigation on a mat. The emitter is a series of equally spaced holes along a **single** or **double chamber** tube or small openings in **porous** tubing. The discharge rate is usually given in gallons per minute (gpm) per unit length and ranges from 0.1 to 1.0 gpm per 100 feet of line. The length of tube effectively irrigating each plant determines the water delivered to each plant.

Operating pressure of line-source emitters range from 2 to 30 psi with the majority operating at less than 15 psi. The tubing is installed in rows up to 300 feet long as limited by water carrying capacity and slope of the ground.

Line-source emitters should only be used on level ground contours or on gentle slopes to maintain uniform discharge. Because the operating pressure is low, a moderate elevation change causes a large variation in discharge. Consult with a qualified engineer or specialist when designing systems for rolling terrain.

The **point-source** emitter is used for tree crops, ornamental shrubs and some fruit crops where plants are not closely spaced in the row. It is also used for container grown nursery

APPENDIX B: Preventing Line Clogging

Chemical Treatment

Water sources vary considerably in quality depending on the season, demand, rainfall, etc. Water contaminants include both inorganic and organic materials that can be categorized as in Table B-1.

Table B-1. *Water Quality Factors.*

Suspended Particles	Biochemical Factors
Inorganic	
Sand	Chemical Precipitates:
Silt	Calcium Carbonate
Clay	Ferric Iron
	Other reactions cause by injection of biocides
Organic	
Moss	Algae Growth
Aquatic Weeds	Bacterial Slime Production
Algae	Bacterial-caused Precipitates
Fish	Bacterial Slimes in association with filtered particles
Snails	

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, precipitates, 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 encourage its growth. Algae even grows in water that stands in an emitter after the system is turned off. Once algae gets into the line it is almost impossible to remove. Screening it 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; so 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.[1]

Generally a dosage of one to two parts per million of copper sulfate (1 to 2 ppm $CuSO_4$)[2] is sufficient and safe. The higher rate is 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 at intervals of two to four weeks. 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.

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. Floating 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 46°F; organic matter; dissolved (ferrous) iron in concentrations 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 it is installed. Slime buildup can then be checked by periodically cutting a small section from the extra tubing. The slime often has the same color as 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 since most of the bacterial slime develops during the off-cycle. Chlorine must be injected during the last 30 minutes of irrigation (or for the time required to fill all lines) so that 1 ppm of free residual chlorine remains at the end of the line.

[1]Most states require a permit to add chemicals to water supplies.

[2]One ppm is 2.7 lbs. per acre foot.

In example 1 it may be less expensive to run two submain lines into the field so ⅜" instead of ½" laterals can be used (Figure A-1). If the field is fairly large, it pays to look at several combinations to see which is the most economical.

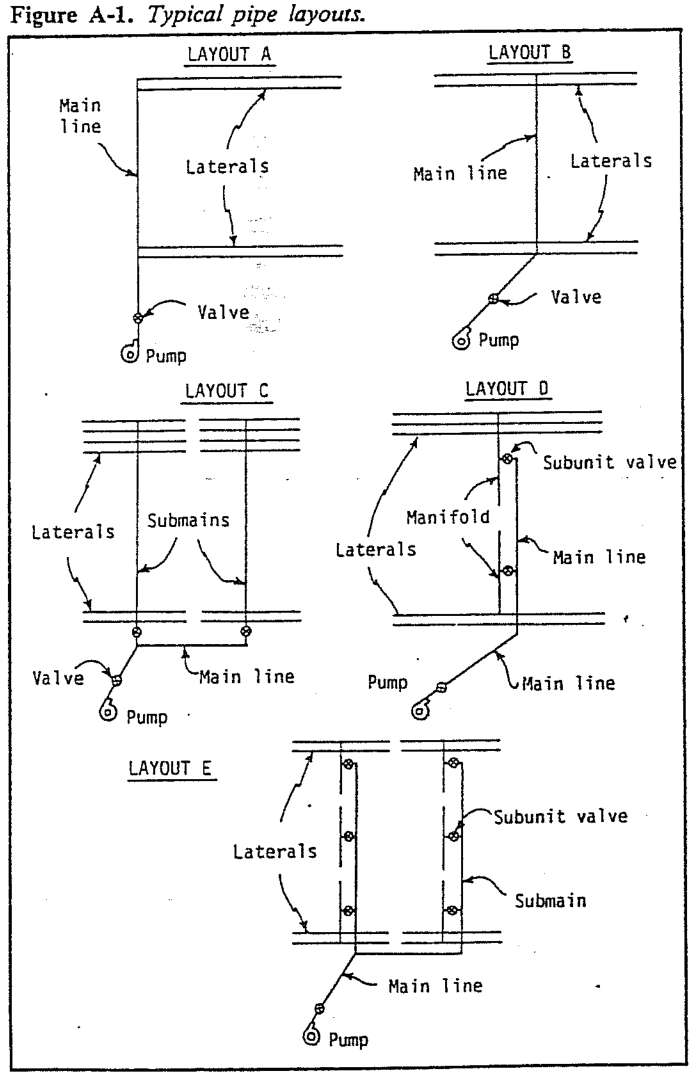
Example 1: What diameter lateral should be used in a 20 acre orchard with dwarf apples spaced 6' apart in 822' long rows. A 1 gph emitter operating at 15 psi waters each tree.

Pipelines may be laid out in several ways as shown in Figure A-1. If Layout A in the figure is chosen, 822' laterals 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', ½" diameter line 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' of ½" pipe is 1.1 psi or 1.5 psi in 15mm pipe. If the row is divided into 4 laterals as in layouts C, D and E, 200' of ⅜" pipe may be used with a pressure drop of 1.9 psi. More manifolds and valves will be required for ⅜" tubing; but in some situations, it may still be more economical than ½" or larger pipe.

Figure A-1. *Typical pipe layouts.*



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 lost 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 2: What is the pressure drop in the lateral in example 1 if it is on a uniform 2% (2' per 100') slope.

Total elevation drop = $\frac{2 \times 411}{100'}$ = 8.2' = 3.6 psi

Friction loss in 400 feet of ½" pipe is only 1.1 psi, so the pressure is greater at the bottom end of the lateral than at the top by 3.6 - 1.1 = 2.5 psi.

Except on small plots less than a quarter acre or so, it is better to divide the field into several subunits or blocks. Valves control watering so each subunit is watered in sequence during the day. A smaller water supply, pump and piping is required if water can be applied over a longer period instead of all at once over the entire field.

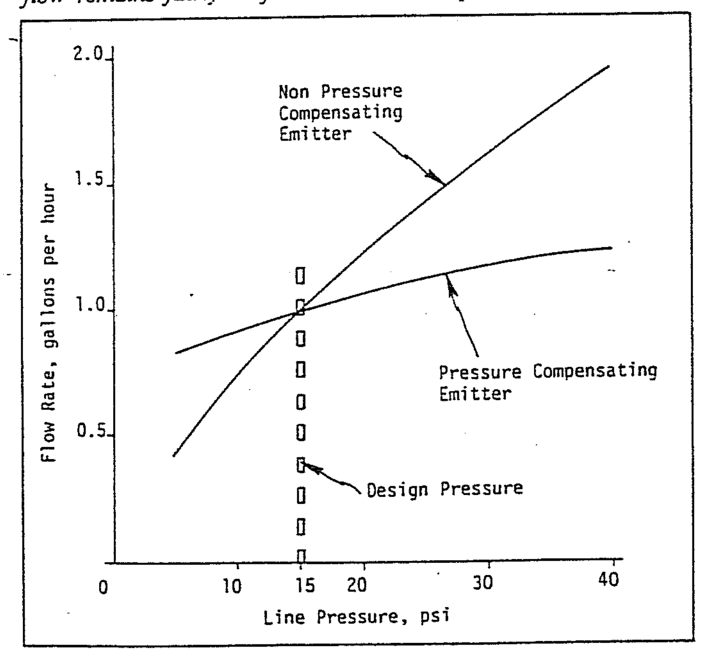
or greenhouse crops. The point-source emitter is an individual emitter that typically is connected to a plastic pipe.

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-flush 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 0.75 to 1.6 gph over that same pressure range.

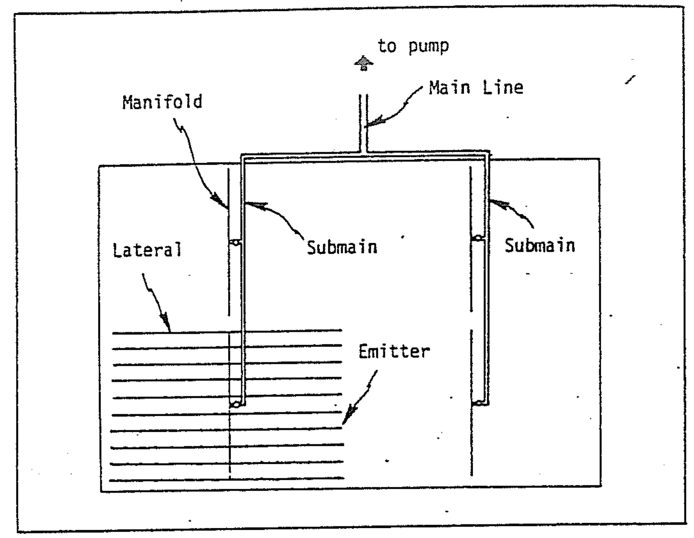
Figure 9. *Typical flow rates for point source emitters. The pressure compensation emitter is useful in hilly terrain because the flow remains fairly uniform over a wide pressure range.*



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.** Smaller **submains** or manifolds carry the water to **lateral** lines, from which it is applied to the plants from emitters.

Figure 10. *Water distribution lines for a typical field.*



The main lines may be rigid PVC, galvanized steel, or asbestos-cement pipe. Rigid PVC, layflat hose or polyethylene pipe is generally used for submains. The main lines should be buried at least two feet deep to prevent mechanical damage during field operations.

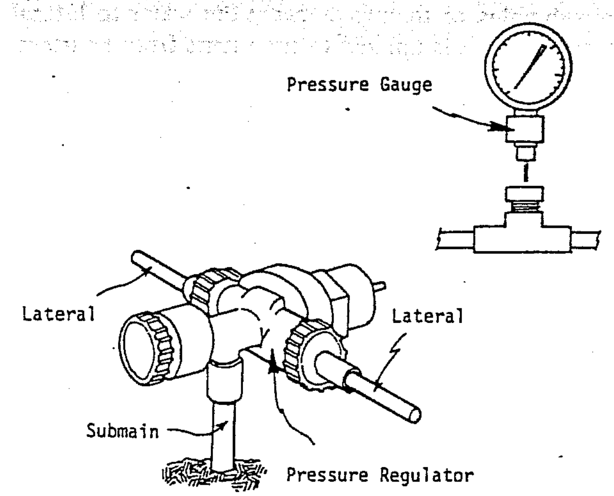
Polyethylene (PE) pipe, nominally ½" diameter, is commonly used for laterals in tree crops and many small fruit or shrub plantings. The laterals lie on the surface near the individual plants; so the pipe must withstand weathering. Polyethylene pipe is available in several grades and some manufacturers have weather resistant grades specifically suited to trickle applications. Smaller (⅜" diameter) pipe is large enough for many fields but may not be stocked by suppliers.

Monitoring and Control Equipment

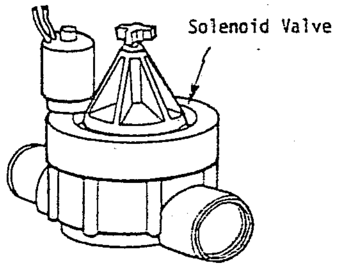
Flow meters are particularly important to monitor and manage permanent systems. Daily logging of the flow to various sections of the field allows discovery of problems before they become serious. A gradual decrease in flow, for example, may indicate a clogged filter or emitters. A sudden increase can signal a line break.

Pressure gauges are recommended to check pressure throughout a trickle system. They are especially important when the emitter does not compensate for pressure changes. Install gauges to monitor pressure losses across filters and the operating pressure at each submain. The pressure range of the gauge should match the system pressures, so it can be easily read.

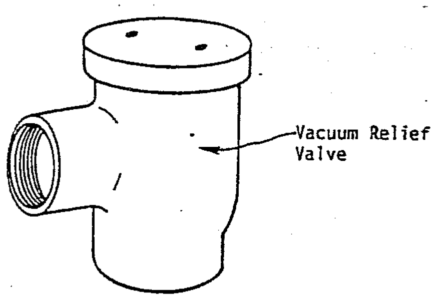
Pressure regulators, installed at the head of submains, compensate for elevation changes or pipe friction losses. Pressure regulators may be fixed or adjustable.



Manual **valves**, timed solenoid valves, or automatic flow valves are also recommended for submains. Small automatic flow valves are designed to allow a set flow rate and are used to reduce pressure variations between laterals in steep terrain. Combination pressure regulators and flow control valves are also available.



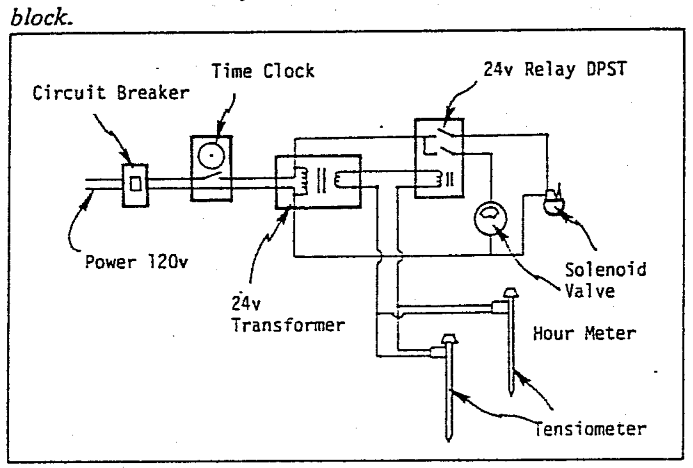
Vacuum relief is important for trickle irrigation systems. Negative pressures that develop when the system is turned off can clog emitters if dirty water is pulled back into the system. A one-inch vacuum relief valve for each 25 gpm of flow is recommended. Install the valve down-stream from the valve that controls water into a block.



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).

Figure 11. *Wiring diagram for automatic irrigation control (mixed voltages). Tensiometers measure moisture in one block of a field. A time clock with multiple switches or several time clocks may be set so each block of a field is irrigated in sequence. Tensiometers and relays are then wired to control water for each block.*



Time clocks may also be used to sequence the system to run water to part of the field for a set time. At the end of each set the clock controls valves to route water to another part or block.

A **tensiometer** with electrical switch or other device which senses soil moisture can be used as a control device. It may be installed in series with a clock and solenoid valve.

Two tensiometers should be installed to monitor both the top and bottom of the active root zone. Locate the units near one another a short distance from an emitter and in the crop row. The distance from the emitter to the tip of the tensiometer determines how long the system will operate. The exact distance must be found by trial and error for each situation.

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.

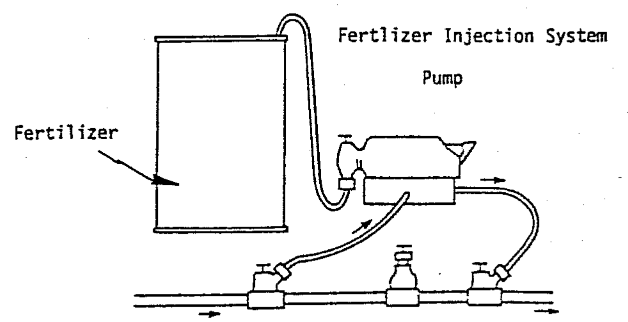


Table A-4. *Pressure Loss in Polyethylene Emitter Lines. Average emitter flow rate = 1 gallon per hour.*

Approx. line length, feet	Line Pressure Loss, psi — Emitter Spacing 4'		6'		8'		10'		12'		16'	
	Nominal Pipe Diameter 15mm	1/2"	15mm	1/2"	15mm	1/2"	15mm	1/2"	15mm	1/2"	15mm	1/2"
200	.46	.32	.23	.16	.14	0.10						
250	.9	.61	.44	.31	.25	0.18	.17	.12	.13			
300	1.4	1.0	.67	.47	.44	0.31	.28	.20	.20	.15	.13	.10
350	2.2	1.5	1.0	.71	.65	0.46	.43	.31	.30	.22	.19	.17
400	3.1	2.2	1.5	1.1	.9	0.62	.62	.44	.44	.31	.27	.25
450	4.3	3.0	2.0	1.4	1.2	0.85	0.8	.58	.64	.46	.37	.33
500	5.7	4.0	2.7	1.9	1.6	1.2	1.1	.77	.8	.60	.49	.46
550		5.3	3.6	2.5	2.1	1.5	1.4	1.0	1.0	.73	.63	.57
600		6.6	4.5	3.2	2.7	1.9	1.8	1.3	1.3	.9	.85	.75
650			5.6	3.9	3.3	2.3	2.2	1.6	1.6	1.1	1.0	.85
700				4.9	4.2	2.9	2.7	1.9	1.9	1.4	1.3	1.1
750				5.9	5.0	3.5	3.3	2.4	2.4	1.7	1.4	1.3
800					5.9	4.2	4.0	2.8	2.9	2.0	1.7	1.5
850						4.9	4.7	3.3	3.4	2.4	2.0	1.9
900						5.9	5.5	3.9	3.9	2.8	2.3	2.1
950						6.7	6.3	4.5	4.6	3.2	2.7	2.5
1000								5.2	5.2	3.7	3.2	2.8
1050								5.9	6.1	4.4	3.7	3.3
1100								6.7		4.9	4.2	3.8
1150										5.5	4.7	4.2
1200										6.2	5.2	4.8

Table A-5. *Pressure Loss in Polyethylene Emitter Lines. Average emitter flow rate = 2 gallons per hour (gph)*[1].

Approx. line length, feet	Line Pressure Loss, psi — Emitter Spacing 4'		6'		8'		10'		12'		16'	
	Nominal Pipe Diameter 15mm	1/2"	15mm	1/2"	15mm	1/2"	15mm	1/2"	15mm	1/2"	15mm	1/2"
100	.24	.17	.13									
150	.77	.54	.35	.25	.23	.16	0.15	.11	.12			
200	1.5	1.1	.76	.53	.46	.33	.31	.22	.25	.18	.16	.11
250	2.9	2.0	1.5	1.0	.84	.59	.57	.41	.42	.30	.28	.20
300	4.7	3.3	2.2	1.6	1.5	1.0	.9	.67	.68	.49	.45	.32
350		5.1	3.4	2.4	2.2	1.6	1.4	1.0	1.0	.73	.64	.45
400			5.0	3.5	2.9	2.1	2.1	1.5	1.5	1.0	.9	.64
450			6.9	4.8	4.0	2.9	2.7	1.9	2.2	1.5	1.2	.9
500				6.4	5.6	3.9	3.7	2.6	2.8	2.0	1.6	1.2
550						5.1	4.7	3.4	3.5	2.5	2.1	1.5
600						6.4	6.0	4.3	4.4	3.1	2.9	2.0
650								5.3	5.4	3.8	3.5	2.5
700								6.5	6.5	4.6	4.3	3.0
750										5.8	4.9	3.5
800										6.9	5.8	4.1
850											6.8	4.8

[1] *Either one 2 gph emitter or two 1 gph emitters.*

Table A-6. *Pressure Loss in 3/8" diameter Polyethylene Emitter Lines.*

Approx. line length, feet	Average Emitter flow rate = 1 gph — Pressure Loss, psi — Emitter Spacing 4'	6'	8'	10'	12'	16'
50	.11					
100	.64	.33	.20	.13		
150	2.0	.9	.57	.37	.29	.15
200	4.1	1.9	1.2	.77	.61	.38
250		3.7	2.1	1.4	1.0	.68
300		5.7	3.7	2.3	1.7	1.1
350			5.5	3.6	2.5	1.5
400				5.2	3.6	2.2
450				6.8	5.3	3.0
500						4.0
550						5.1

Approx. line length, feet	Average Emitter flow rate = 2 gph — Pressure Loss, psi — Emitter Spacing 4'	6'	8'	10'	12'	16'
50	.4	.2	0.1	.1		
100	2.1	1.1	0.7	.4	.3	0.2
150		3.0	1.9	1.2	1.0	.5
200		6.5	3.9	2.6	2.1	1.3
250				4.8	3.5	2.3
300					5.6	3.7
350						5.2

APPENDIX A: Designing Laterals and Submains

Design Formulas

Friction loss in a lateral or up to 1½" manifolds can be calculated by the formula[1]:

$$P = 0.0006\ Q^{1.75}\ D^{-4.75}\ (L + N\ L_e)\ F \ldots\ldots\ [1]$$

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 multiplied by the average flow rate per outlet.

D = pipe inside diameter in inches (Table A-1).

L = total pipe length in feet.

L_e = an emitter equivalent length factor to correct for added resistance from the emitters. Table A-2 lists values for typical emitters.

N = Number of outlets or 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-1. *Plastic Pipe Diameters.*

Polyethylene (any grade)		PVC Pipe 160 psi (SDR 26)	
Nominal Diameter	Inside Diameter, in.	Nominal Diameter	Inside Diameter, in.
3/8"	0.375	2"	2.193
15mm	0.580	2 1/2"	2.655
1/2"	0.622	3"	3.230
16mm	0.630	4"	4.154
20mm	0.800	6"	6.115
3/4"	0.824		
1"	1.049		
1 1/4"	1.380		
1 1/2"	1.610		
2"	2.067		

[1]Formula derived from the equation $p = f\,(L/D)\ V^2/2g$

where p = pressure drop in feet

f = 0.32/ (Reynolds No.)$^{0.25}$ for smooth pipe as developed by Blasius.

v = average water velocity in feet per second

g = acceleration of gravity, 32.2 feet per second per second

Table A-2. *Equivalent Length Factors, L_e, for Typical Emitters.*

Nominal Pipe Diameter	Le, feet
3/8"	.9
12 mm	.6
15 mm	.4
1/2"	.3
3/4"	.2
more than 3/4"	0

Note: Assume L_e = 0 for emitter spacing 20 times L_e or greater. For example, assume L_e = 0 for ½" pipe when emitters are spaced 6' (20 × 0.3) or more apart.

Table A-3. *Outlet Correction Factor, F.*

Number of Outlets	F	Number of Outlets	F
1	1.00	7	0.44
2	0.65	8-11	0.42
3	0.55	12-19	0.40
4	0.50	20-30	0.38
5	0.47	31-70	0.37
6	0.45	more than 70	0.36

The friction loss in 1½" 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:

$$P = 4.53\ (Q/C)^{1.85}\ D^{-4.87}\ L \ldots\ldots\ [2]$$

where C = 140 for polyethylene pipe

C = 150 for PVC pipe

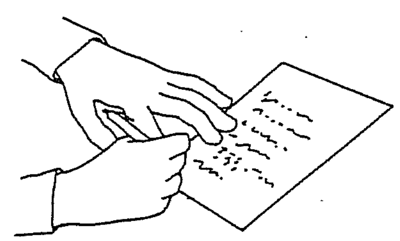
P = pressure drop in the pipe, psi

Q = flow rate, gpm

D = pipe diameter, inches

L = pipe length, feet

Pressure drops for 3/8", 15mm, and 1/2" polyethylene laterals with various emitter spacings and discharges have been calculated 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.



The injection methods in general use include:

- metering into the pump inlet or irrigation water
- venturi bypass
- metering pump
- proportionate controlled injectors

Metering the chemical from a tank with a drip valve into the irrigation water is the simplest method. A variation of this method is to install a suction feeder to the pump inlet. Injection rate is controlled by electrically timed cycles. This method is inexpensive, but an inaccurate way to meter. It is used on some large irrigation systems.

The **venturi bypass** connects a tank with a venturi and feeds the chemical into the main irrigation line. Water flowing through the venturi creates a suction that draws the chemical into the line. This method has been used on trickle systems. But, again, it is fairly inaccurate because pressure and flow rate varies.

The **metering pump** injects fertilizer directly into the line at a uniform rate. This equipment works well with trickle systems designed to deliver fairly constant flow. Diaphragm pumps are more reliable than piston pumps because the corrosive fertilizer solution does not contact any moving metal parts.

Various **proportioner injectors** sense the rate of water flow to control the amount of chemical injected. This equipment is useful in nurseries and greenhouses where varying flow rates are encountered. No electrical power is required to operate these injectors—a real advantage in isolated areas.

On all systems an **anti-syphon device** such as a vacuum breaker or a **backflow preventer** must be installed to protect water supplies. All units should be wired to the pump switch or a flow control switch in the main line to prevent the unit from running when no water flows in the system.

Any chemical should be checked to make sure it is compatible at the concentrations used with all the materials making up the drip system. Plastics manufacturers publish compatability charts for the plastics they make.

To calculate the injection rate of any source material use the following formula:

Gallons per hour of Source Material =

$$0.048 \times \frac{\text{System gallons per minute}}{\text{Percent of desired material in source material}} \times \frac{\text{Required parts/million of desired chemical}}{\text{Pounds of Source material per gallon}}$$

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

$$\text{Gal/hr. of bleach} = 0.048 \times \frac{200\ \text{gpm}}{5.25\%} \times \frac{33\ \text{ppm chlorine}}{8\ \text{lbs bleach/gal}}$$

$$= 0.69\ \text{gal/hr}$$

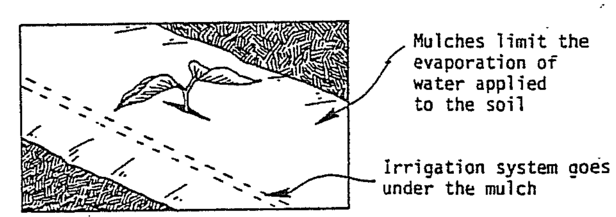
Mulches

Water use efficiency is increased when trickle irrigation is used under mulches because they limit the evaporation of water applied to the soil. The most popular types of mulches include clear and black, 1 to 1½ mil, polyethylene film, and aluminum foil. Clear polyethylene is used primarily on cucumbers, 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 length varies, 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 for the plant to grow through.

Polyethylene mulch (4' wide, 1½ mil) costs about $150 per acre (1979) for 6' row spacing; foil costs $400 per acre and line source emitter tubing costs approximately $200 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

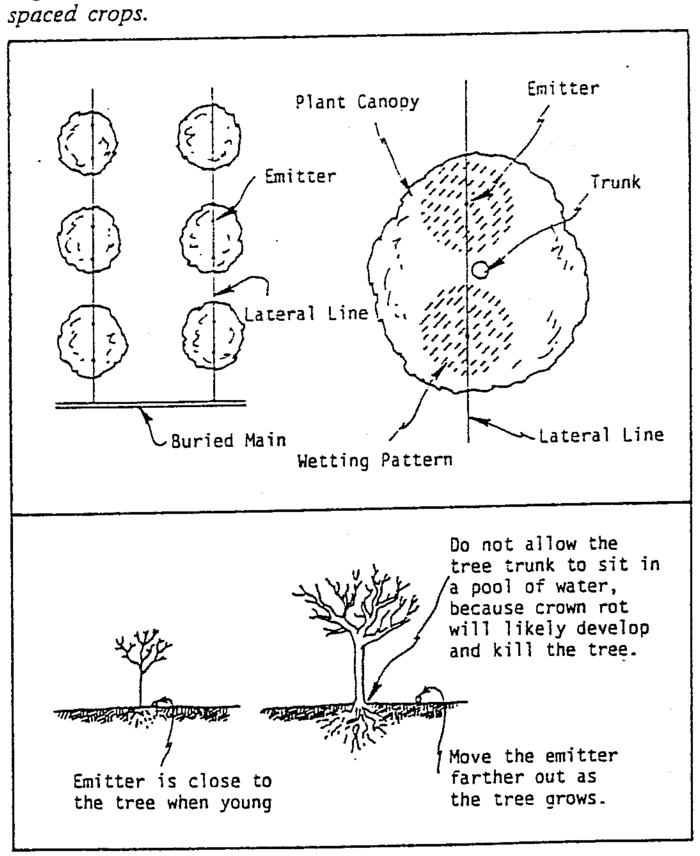
Tree Fruits, Thornless Blackberries and Grapes

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 nonirrigated 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 size. Peaches require adequate water two weeks before harvest for sizing fruit. 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 submains. 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.

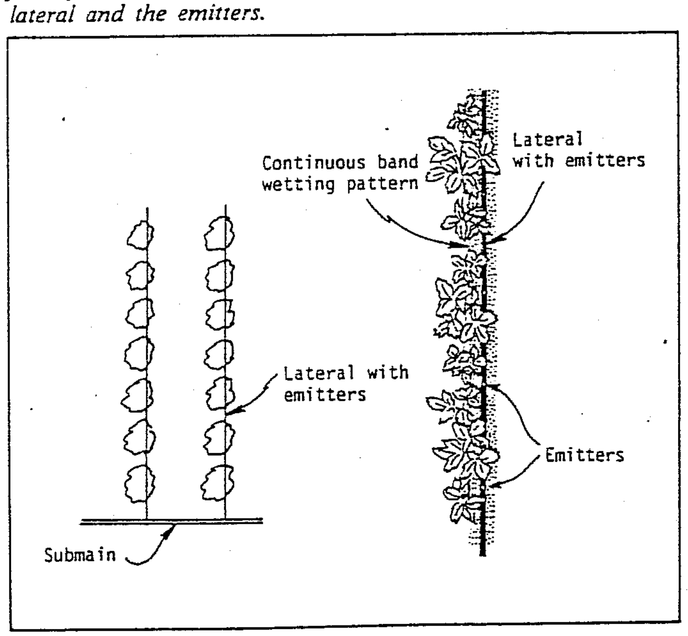
Trickle irrigation equipment installed in fields of tree crops or grapes is considered to be permanent for the life of the crop (10-20 years). Therefore main lines are buried for protection and convenience. Emitters and lateral lines should be compatible with cultural and harvesting activities to reduce 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 rainfall 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.*



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' long on a side).

Manufacturer specifications state that the tubing may be run 290 feet on the level. Thus the main line may be placed on one side of the field rather than down the middle. The flowrate is 0.52 gpm per 100 feet of run. What is the irrigation time?

$$\text{Irrigation time} = \frac{\text{Daily application}}{\text{Emitter application rate}}$$

$$= \frac{68 \text{ gal}/100'/\text{day}}{0.52 \text{ gpm}/100'}$$

$$= 131 \text{ min} = 2.2 \text{ hr}$$

There are 295/5 = 59 rows in the field, so the water demand for full operation will be 90.5 gpm (59 x 0.52 x 295/100). A pump that delivers 90.5 gpm through a large (2½" or 3") main could water the entire field at once. But it is better to divide the field into four zones or subunits because the main lines can be reduced to 1¼" - 1½" 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.

Emitter Location

Line-source emitters are either buried several inches deep or placed beside the plants in a row to wet the root zone. Initially point-source emitters should be close to the tree; but **do not let the trunk sit in a pool of water** because crown rot will likely develop and kill the tree. Ideally, the emitter should be moved farther from the trunk as the tree grows.

Sizing Laterals

After the emitters are selected and the amount of water to be applied is calculated the distribution lines must be designed. 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 20% or from 0.9 gph to 1.1 gph. Pressure may vary from 50% to 80% 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.

Table 6. *Recommended Maximum Pressure Variation for Typical Emitters.*[1]

	Non-pressure Compensating		Pressure Compensating	
Design pressure	15 psi	20 psi	15 psi	20 psi
Pressure variation[2]	13-17 psi	17-23 psi	11-20 psi	14-26 psi
Pressure range	4 psi	6 psi	9 psi	12 psi

[1] *Based on 20% flow rate variation.*

[2] *The allowable pressure variation is an estimate for typical point-source emitters. If available, manufacturer's discharge data should be used instead.*

In an optimum design, the total pressure loss in the subunit should be divided equally between the submain lines and the laterals. For example, if a total of 4 psi pressure variation is allowed, 2 psi should be lost in the submain and 2 psi in the laterals.

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, submains 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 about equals 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 plot* 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 plots 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 submains. 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 laterals 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 either 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).

Table 4. *Diameter and Area of Soil Wetted by a Single Emitter.*

Soil Texture	Wetted Diameter, ft	Wetted Area, sq ft
Coarse	2 - 4	4 - 12
Medium	4 - 5	12 - 20
Fine	5 - 7	20 - 60

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:

$$\text{Wetted area} = 0.2\ (\text{Diameter of root zone})^2$$

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 5. *Suggested Emitters for Crops in the Northeast.*

Type of Crop	Emitter Recommendations
Dwarf Trees	One or two 1 gph emitter per plant. Space 2' to 3' from the trunk.
Vine and berries	Normally one 1 gph emitter per plant. Use one emitter per 2 plants when closely spaced (3' to 4' apart).
Semi dwarf and standard trees	Two 1 gph emitters per tree. May need 3 emitters in sandy soils.
Vegetable crops	Calculate water requirements for line source emitter.

Example: At maturity apple trees spaced 18' apart in rows 26' wide should receive 18 gallons per day (Table 2). Several exterior factors may influence the irrigation design but several possibilities include:

a) use one 1 gph emitter for 18 hours
b) use two 1 gph emitters for 9 hours
c) use three 1 gph emitters for 6 hours
d) 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:

$$A = 0.2\ (9)^2 = 16 \text{ sq. ft.}$$

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.

$$\text{Hours per irrigation} = \frac{\text{Gallons of water per plant per day}}{\text{Application rate of emitters, gph}}$$

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 breakdowns, 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.

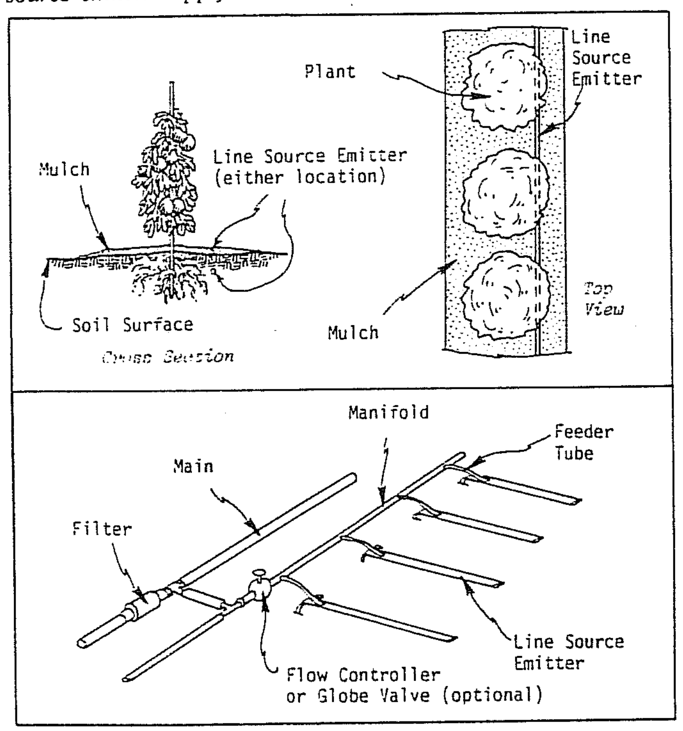
Vegetable Crops

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 rowcrops. Water is applied to a narrow band down each row and is not usually 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 to which the emission lines are attached can be 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 line.*



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.

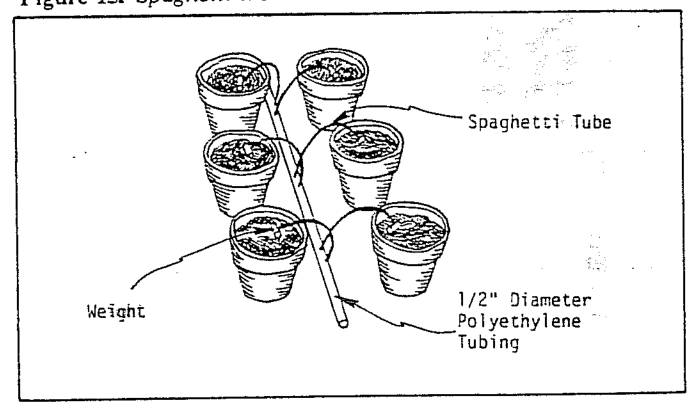
The free draining nonsoil mixes, in wide use commercially, allow automated water application. Even when watered 2-3 times a day, they drain excess water within 10 minutes of saturation to provide ample air in the media for excellent root growth.

Automated watering systems will fail with a soil mix (even with perlite) because it will not drain freely. On the other hand most bark 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 **spaghetti watering** systems do the most precise job of watering. They do not wet the foliage or flowers, and they leach 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 tubes.*



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 heat 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 (1:20) 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 $230 per acre (1978), 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.

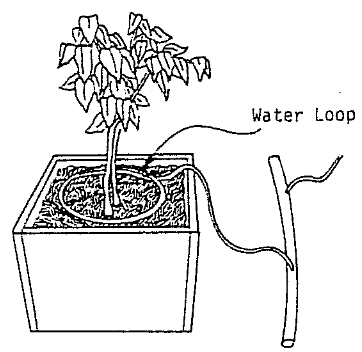
Trickle tubes buried 2" to 4" deep encourage the development of an excellent root system and insure good transplant survival. However, when the plant is dug a 3' to 4' long piece of tubing is left in the soil to complicate the planting of succeeding crops.

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.

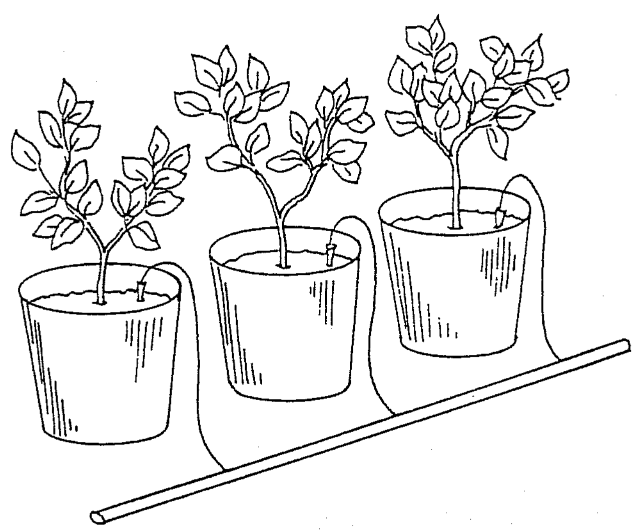
Placement above ground may work for some crops. Damage from cultivation tools could be a problem and the system must be secured from wind dislocation. A permanent system, above ground or buried 2" to 3" deep, should be excellent for bed-grown plants.

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.



The problems with these systems include worker abuse, rodent damage and plugging. A properly filtered water supply eliminates plugging. A good herbicide program reduces worker time around the container and, except for pruning, eliminates the need for workers around the plants.



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 first. There must be a sufficient supply of good quality water before any irrigation system can be planned. Evapotranspiration from a vegetable rowcrop is about 5400 gallons of water per acre per day (0.20 in./day × 27,160 gallons per acre-inch). An orchard may use 50 percent of this amount. The source must supply this quantity of water and at the designed application rate. For the above examples, the design application rates could range between 6 gpm and 90 gpm per acre, depending on length of application time and the emitter system.

The system can be designed to operate less frequently than daily, but the application per irrigation would be larger. The delivery system must either be sized for a larger flow rate or be operated longer to apply the necessary water.

Trees and Small Fruits

Water requirements for trees, small fruit and bush crops may be estimated from Table 2 and 3. The values consider that rainwater stored in the soil supplies part of the crop's water needs. This reliance on rainfall contrasts with designs for arid climates where rainfall and soil water holding capacity are considered relatively unimportant under trickle irrigation. The amount applied approximates the average daily evapotranspiration that occurs during summer drought periods lasting 20 to 30 days and that occur two or three times every 20 years in the Northeast.

Table 2. *Water Application Rates for Crops using Point Source Emitters[1].*

Crop (Spacing in feet)	Plant Age in Years					
	1	2	3	4	5	6-20
	--- Gallons per Day per Plant--------					
Apple						
M.9 Variety (6 × 14)	1.0	1.0	1.5	1.5	2.0	3.0
M.9 Variety (14 × 22)	1.0	2.0	3.0	4.0	6.0	12.0
M.111 Variety (18 × 26)	1.0	2.0	4.0	6.0	10.0	18.0
Peach, Nectarine, Plum Standard (18 × 24)	1.0	2.0	4.0	6.0	9.0	17.0
Grapes, Thornless Blackberry (8 × 10 or 6 × 12)	1.0	1.0	2.0	2.0	3.0	3.0

[1] *Assume pan evaporation averages 0.2" and evapotranspiration is 80% of pan evaporation.*

Table 3. *Water Application Rates for Row Crops[1]*

Crop (Spacing in feet)	Plant Age, Years		
	1-2	3-4	5-20
	Gallons per Day per 100 ft of row		
Strawberries (2 × 4)	18	18	
Raspberry & Blackberry[2]	18	27	27
Blueberry (5 × 10)	18	27	35

[1] *Assume water applied to root zone (canopy area at evapotranspiration rate of 0.15 inch per day from June 1 to September 1).*

[2] *Plant spacings are: Raspberry (2 × 12), thorny blackberry (3 × 12), and thornless raspberry (6 × 12).*

Vegetable and Melon

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

$$Q = 50 \times E_p \times S$$

Where: Q = Gallons required per 100' per day
E_p = 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 ½ gpm per 100 feet of row.

Example: Plant melons on 5 foot row spacing in southern Delaware on a two acre square field. The soil is coarse. 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:

$$Q = 50 \times E_p \times S = 50 \times 0.27 \times 5$$
$$= 67.5 \text{ gallon per 100' per day}$$

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.