DRIP IRRIGATION CHAPTER

INTRODUCTION

This chapter of the Irrigation Guide for New Mexico is intended to supplement the forthcoming Drip Irrigation Chapter of the National Engineering Handbook. The following data, compiled from the ASAE Monograph No. 3, "Design and Operation of Farm Irrigation Systems," is intended to familiarize the reader with the principles of drip irrigation.

Specific design procedures are currently available from area and state specialists and will become available in NEH 15.

Drip or trickle irrigation is the newest of all commercial methods of water application. It is described as the frequent, slow application of water to soils through mechanical devices called emitters or applicators located at selected points along the water delivery lines. The emitters dissipate the pressure from the distribution system by means of orifices, vortexes, and torturous or long flow paths, thus allowing a limited volume of water to discharge. The emitted water moves within the soil system largely by unsaturated flow. The wetted soil area for widely-spaced emitters (point source) will normally be eliptical in shape as illustrated in Figure 1. Since the area wetted by each emitter is a function of the soil hydraulic properties, one or more emission points per plant may be necessary.

ADVANTAGES OF DRIP IRRIGATION

Initially, many claims of advantages for drip irrigation compared to conventional methods were made. Several of the currently recognized advantages are:

1. Application of water at slow rates to limited areas around a plant improves water penetration on problem soils. Field trials have shown that the depth of water penetration can usually be improved appreciably.

2. Only small areas around the plants are wetted, thus water savings usually result by reducing the total evaporative surface, reducing runoff, and controlling deep percolation.

3. Further water savings with drip irrigation are obtained when plants are young because only a small area is wetted.

4. Weed growth is reduced because a limited soil surface is wetted.

5. Limited soil wetting also permits uninterrupted cultural operations and minimizes labor scheduling problems.

6. Fertilizers can be injected in the irrigation water.

7. Considerable evidence supports the concept that water availability to plants enhances plant growth and yield.

8. Frequent or daily application of water keeps salt in the soil water more dilute and on the outer limits of the wetting pattern, making the use of saline water practical.

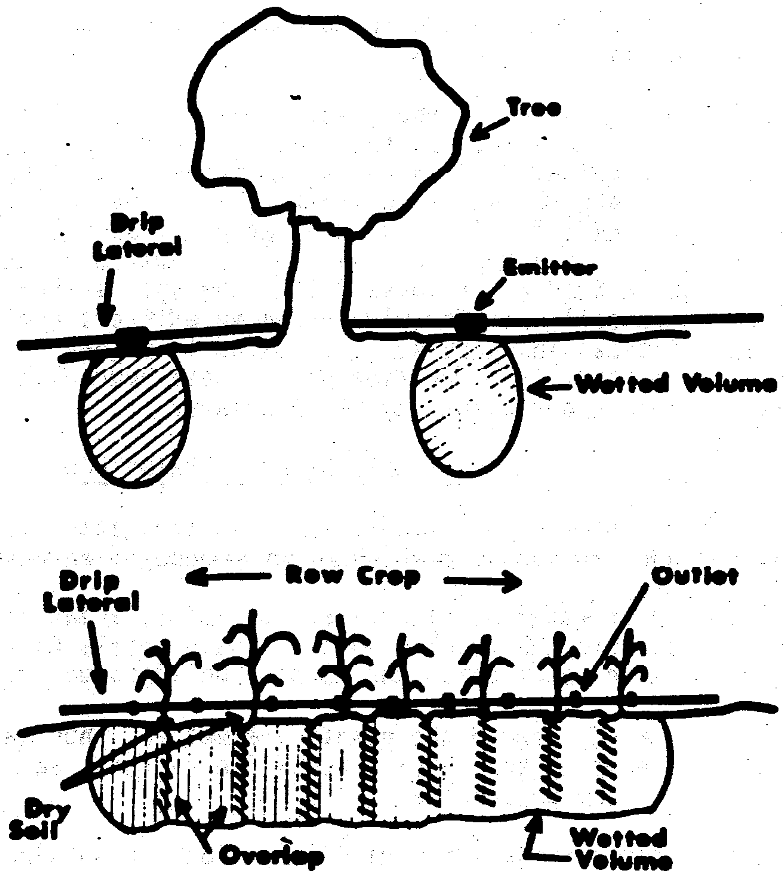


Figure 1

Trickle Irrigation Wetting Patterns

Drip irrigation, like other irrigation methods, will not fit every agricultural crop, specific site, or objectives. It is being used for a variety of crops, climate, and soils. Among these crops are almonds, grapes, citrus, stone fruit, avocados, walnuts, pistachios, olives, pecans, apples, pears, figs, vegetable crops, nursery plants, berries, tropical fruit, sugar cane, windbreaks, and others.

DISADVANTAGES OF DRIP IRRIGATION

Several problems are associated with drip irrigation methods. Emitter clogging is considered the most serious problem in drip irrigation. The causes of clogging are attributed to physical, chemical, and biological factors. When clogging occurs, the emission uniformity is greatly reduced and crop damage may occur before the clogging is detected. Improvement in the filtration process and chemical treatment of the water can reduce clogging problems. Rodents, coyotes, dogs, rabbits, etc., present a problem by damaging the plastic pipe. For crops with high plant densities requiring large amounts of pipe per land unit, drip irrigation may not be economical. In some areas, excess salts accumulate at the soil surface and toward the fringes of the wetted soil. Rain may leach harmful amounts of surface salts in the root zone, thus drip irrigation should continue during rains to prevent this problem.

FUTURE OF DRIP IRRIGATION

The drip method is an acceptable method of irrigating many crops, yet drip irrigation should not be expected to replace other irrigation methods, or in some cases, to even compete with conventional irrigation methods. The potential for using less water per unit of production may provide the motivation for changing irrigation methods whenever and wherever water costs have a very significant impact on profit margins. Most of the crops irrigated by the drip method yield higher cash returns per unit area compared to some of the crops under conventional irrigation. Developments in the future will probably continue to be concentrated on high value crops, on extending limited water supplies, and on the utilization of relatively low-quality waters. It is unlikely that expansion of drip irrigation will include solid stand, large area plants such as forages and cereals, because the system has little or no advantage compared with conventional sprinkler or surface systems on these types of crops.

SYSTEM COMPONENTS

From the water source to the farm, canals and pipelines are the main components of any irrigation system. Auxiliary components for drip irrigation systems include various combinations of sand separators, screening equipment, intakes, flow regulators or pressure reducers. Booster pumps are used where gravity pressure is inadequate, and equalizing reservoirs are used in mountainous terrain. Stilling or settling basins, chlorinators, water meters, valves, gauges, fertilizer injectors and controls are all parts of drip system components.

Between the farm delivery and the field ditch system, some type of fine filtration is required. Most of the filtering devices are simple but some are elaborate, complete with automatic back-flush devices. The filtering devices must have the capacity for the required flow of water and the ability to remove fine particles down to a size somewhat smaller than the emitter pathways and orifices. Clean water is essential for satisfactory, trouble-free operation of the drip systems.

Field systems vary considerably in physical arrangements but basically consist of a mainline, submains or manifolds, laterals and emitters. Line sources applicators are laterals and emitters combined in one unit. Submains provide a means of grouping laterals into zones, the number of which depend on the area, shape of field, topography, number of settings per day, or per interval, and limitations as to length of either submains or laterals. On small areas, a single submain may suffice or may be omitted if the main line can substitute for the submain, but generally cyclical flow will require submains. For the sake of minimizing pipe sizes, both submains and laterals can be arranged to split the flow of water in two directions to minimize friction losses.

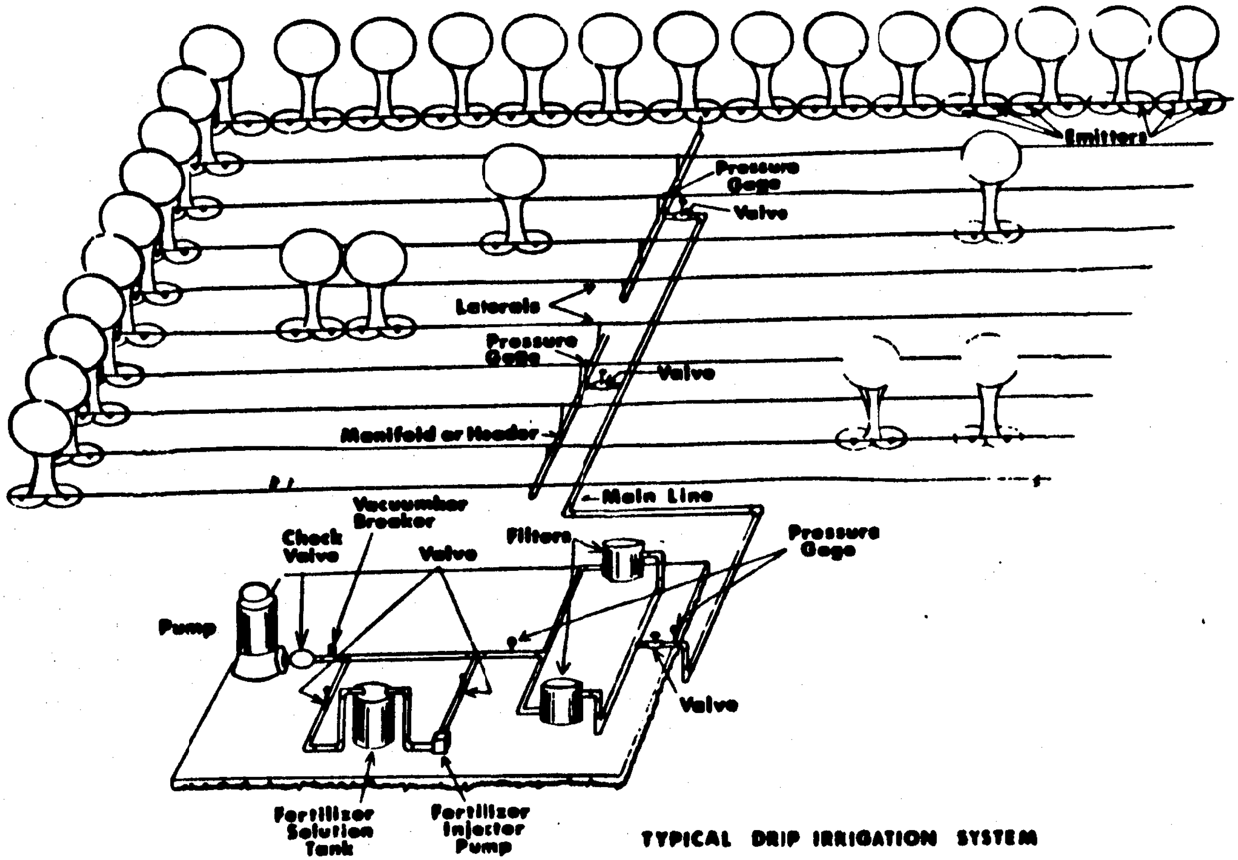
SYSTEM LAYOUT

Layouts of the drip emitters are generally simple pipe arrangements as seen in Figure 2. The decision as to number and spacing of laterals is governed by the nature of the crop. Each row of plants, whether trees, vegetables, or others, will usually require a lateral. In some horticultural crops, double row planting allows two crop rows to be served by one lateral. The in-row placement of emitters has the distinct advantage of minimum interference with other cultural operations such as cultivation, mowings, spraying, and picking. If adequate wetting is not achieved by one lateral line, emitters may be installed on a double line or loop (sometimes called a pigtail) around the base of the tree.

EMITTERS

Decisions about the type of equipment, field layout of equipment, and operation and maintenance of the system become a matter of choice and technical skill. Numerous types of emitters are manufactured. Several types are shown in Figure 3. The five distinct emitter types are:

1. Long path emitters
2. Short orifice emitters
3. Vortex emitters
4. Pressure-compensating emitters
5. Porous pipe or tube emitters



TYPICAL DRIP IRRIGATION SYSTEM

Figure 2

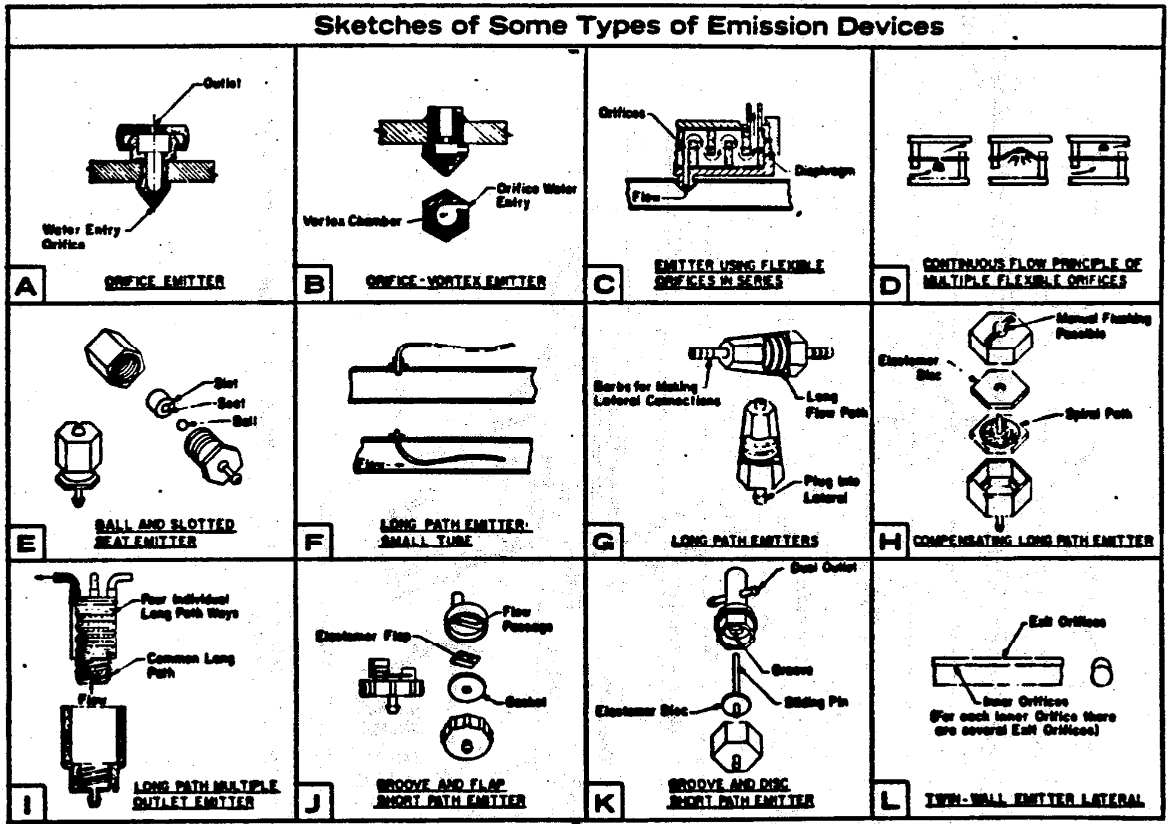


Figure 3

Emitter Examples

A miscellaneous group that includes such things as spitters, foggers, etc., could be added, but these are neither point nor line source applicators, resembling instead small sprinklers. Each of the first four groups includes the point source emitters. The fifth group includes the line source applicators and includes all double walled pipes, soaker hose types, and porous plastic tubes. The fourth group includes relatively new manufactured equipment which offers the advantage of constant flow with changing pressures but discards the advantage of increasing and decreasing irrigation applications simply by alterations of line pressures.

A few of the point source emitters are adjustable up to a maximum flow. While the principle is good, the practice of having to adjust many outlets offers the farmer a formidable task in both effort and time.

Emitters should offer a number of features that appeal to the designer and the farmer. These are: (a) each emitter should be available in a range of sizes in terms of flow rates, preferably over narrow increments; (b) flow rates should be within narrow tolerance limits (uniformity) for the operating pressure; (c) flow rates should be consistent and reproduciable for long time periods; (d) emitter flow should be insensitive to temperature changes; (e) emitters must withstand sunlight and general weathering to give a specific service life; (f) emitters should have a large flow area to reduce clogging potential. No single emitter can usually meet all the above criteria, thus, a wide diversity exists for drip emitters. Note also that a large flow area and low flow rate characteristics are incompatible.

LATERAL LINES

The emitters are connected to the lateral line, or in some cases are a part of the lateral line, as in the case of twin wall pipe and simple orifices. The lateral lines are usually polyethylene (PE) plastic and range in diameter from 8 to 20 mm with 14 mm (1/2 inch) being the most common. Two types of PE pipe fittings, barbed and compression, are commonly used. The barbed fittings fit inside the pipe while compression fit over the outside of the pipe. Earlier types of PE developed stress cracks where the pipe fit over the barbed connection. The emitters are either connected in the line or on the line through punched or drilled holes. The lateral downstream end is plugged with a pipe fitting or simply crimped over. Provisions for periodic flushing of the lateral line are necessary. Spring-loaded flushing valves which allow water passage when the pressure is less than some threshold pressure can be used to automatically flush the lines.

SUBMAIN LINES

The lateral lines are connected to a submain, or in some cases, directly to a main line. Normally these lines are polyvinyl-chloride (PVC) pipe. Occasionally, asbestos cement pipe is used for the main line. The laterals are connected to the submain using various techniques including: undersized drilled holes in PVC submains; saddle connections; various adapters and pipe T's. The main line and submain should have valve exits to allow periodic flushing. Small screens (80 to 100 mm) are used as safety devices to further protect the

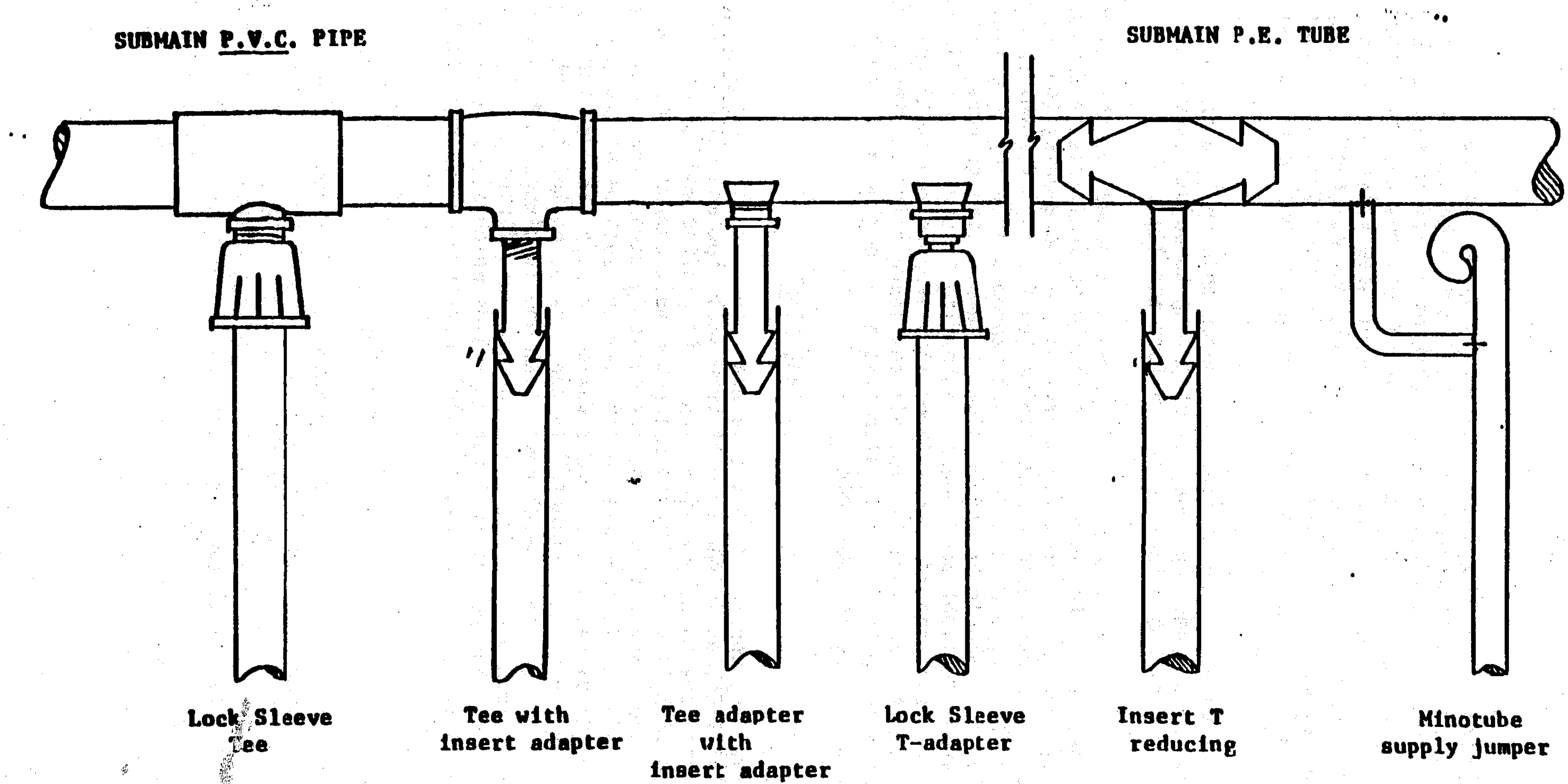
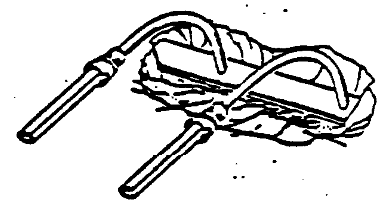


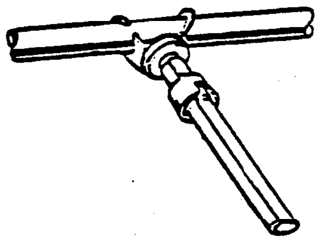
Figure 4

Typical Submain to Lateral Connections

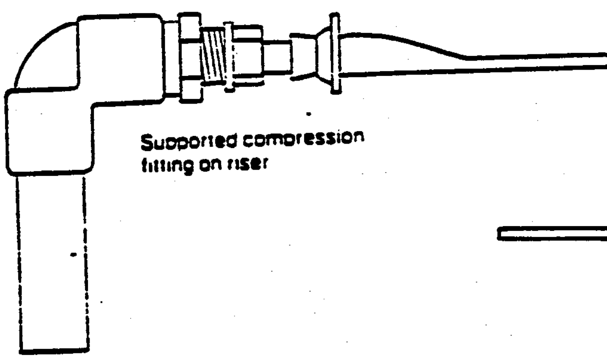
Typical Submain to Lateral Connections

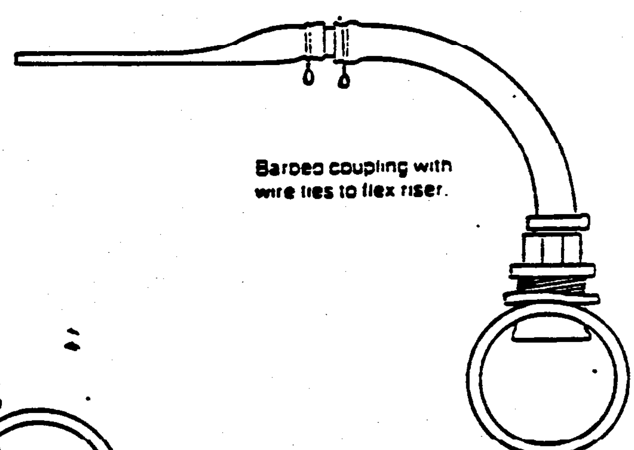


Permanent above-ground connection



Subsurface permanent connection





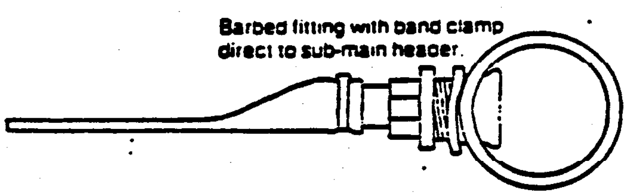
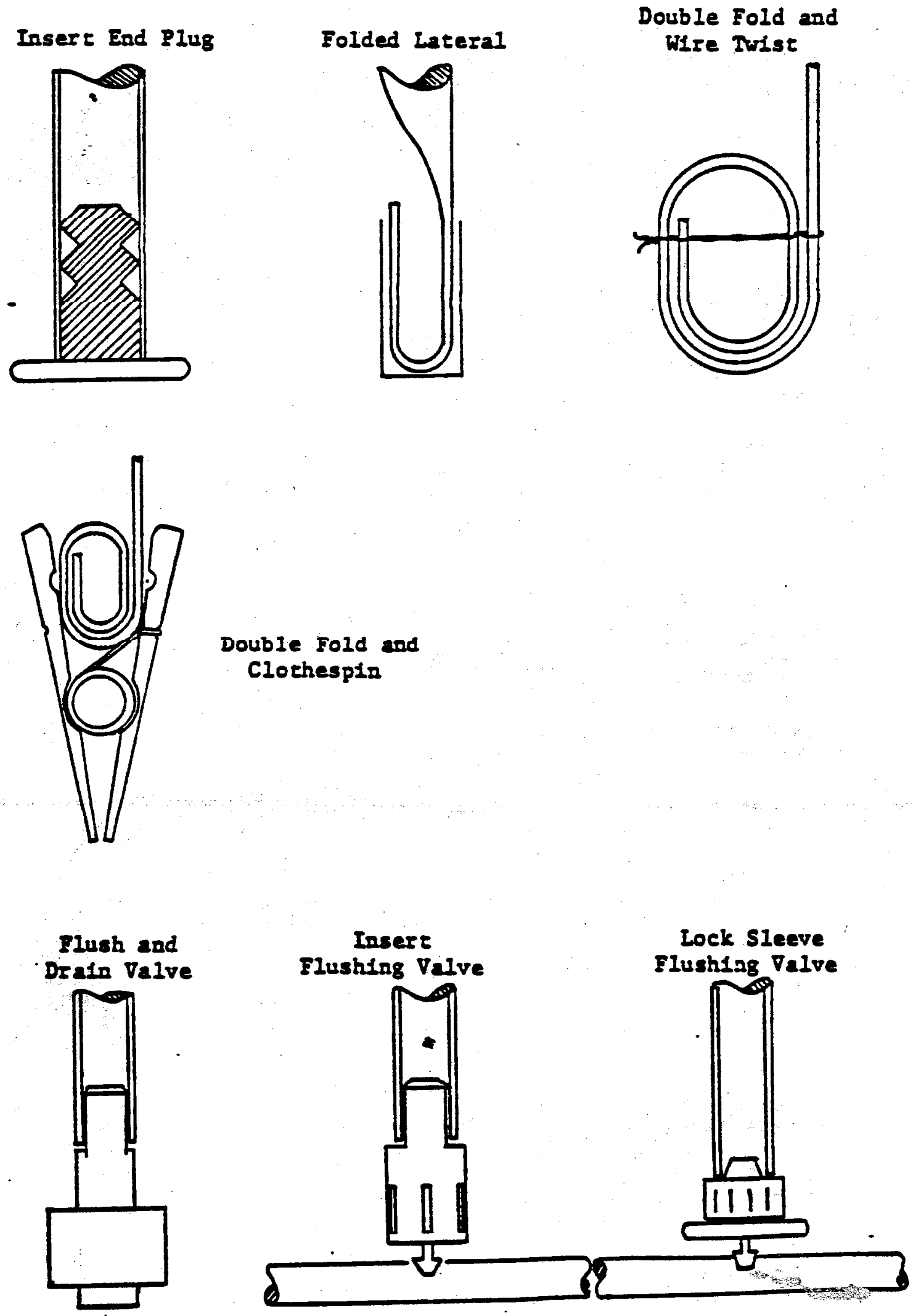


Figure 5



Lateral line and fittings.

Figure 6

laterals in case of pipeline breaks, etc. The submain may also contain pressure-regulating valves, flow control valves, manual or automatic control valves, water meter and pressure gauges. Additional manual valves should be located along the main line to help isolate certain areas of a system so that irrigation with part of the system is possible even when part of the system may be broken.

TRANSPIRATION RATES AND SOIL MOISTURE

For given climatic conditions, the major factor prohibiting a plant from transpiring at its potential rate is the resistance restricting the movement of water from the soil to the leaves. This resistance will depend on the particular plant, the soil, the moisture content of the soil, and the rate of movement (rate of transpiration) itself.

Experiments have shown that if the transpiration rate is low, a reduction in soil moisture (increase in soil suction) offers very little resistance to the slow movement of water and transpiration is unrestricted until moisture content of the soil is quite low. However, if the transpiration rate is very high, then a very small reduction in soil moisture (increase in soil suction) imposes a significant resistance to the high flow rate and transpiration is impeded.

The characteristics of the soil which will be most pertinent to its behavior in this process will be the variation of soil suction and hydraulic conductivity with moisture content. Soils which do not have a sharp increase in soil suction, nor a sharp decrease in hydraulic conductivity when their soil moisture is reduced will allow potential transpiration even at higher rates, to persist over a greater range of soil moisture content. Sandier soils will release most of their moisture content at soil suctions below 1 atmosphere, while the heavier clayey soils retain a great percentage of their water up to this suction. Hydraulic conductivity of the sandier soils can be 100 times greater than that of the heavier soils near saturation, but at field capacity, where the sandier soils have retained very little moisture, the hydraulic conductivity of clay can be greater than the sandy soils.

The above statements show why the clays and clay loams are most suitable for conventional irrigation (high water-holding capacity and maintenance of reasonable hydraulic conductivity between field capacity and wilting point) and also highlight the advantage of the sandier soils, providing the moisture content is maintained well above field capacity so that benefit can be derived from their high hydraulic conductivity in this state. Provided the moisture status is kept high, as can be done with trickle irrigation by frequent application of small quantities of water, sandier soils will allow more rapid movement of water to the plant roots than will heavier soils.

Experiments with drip irrigation have found that there is no fixed optimum interval between irrigations nor any fixed soil suction at which to irrigate, but rather that irrigations should be applied so that the soil suction should be kept sufficiently low to allow transpiration to persist up to the design rate under the prevailing atmosphere conditions. This will mean short intervals and low suction between irrigations in the hot, dry summer and long intervals and much higher suctions allowable between irrigations during cooler months. It is suggested, therefore, that ideally timing of irrigation should be determined according to soil suction and that the value of soil suction at which irrigation is to be applied not be a fixed value but rather predetermined according to the expected transpiration rate.

CROP WATER REQUIREMENTS

The crop water requirements under drip irrigation may be different from crop water requirements under surface and sprinkler irrigation primarily because the land area wetted is reduced, resulting in less evaporation from the soil surface. Most methods of estimating crop water requirements, presently utilized provide estimates of evapotranspiration, which probably contain a significant soil evaporation component. The evaporation of water from the soil surface is implicitly related to method of irrigation application and irrigation scheduling.

Crop water requirements are usually expressed in units of water volume per land area per unit time. Drip irrigation application rates are usually expressed in units of water volume per plant per unit time. (Gal./Plant/Day)

SCHEDULING

Irrigation scheduling involves two decisions. (A) When to irrigate (timing), and (B) How much to apply (quantity). These decisions are critical to the management of any irrigation system. The concept of drip irrigation implies a rather high irrigation frequency compared to conventional methods. The key principle of drip irrigation is to maintain a moist segment of the root zone with relatively small applications of water applied continuously or intermittently.

The system must be designed to meet the peak crop use demands. Initially as drip irrigation was being practiced, a flow rate just large enough to meet plant requirements on a continuous basis was deemed desirable. These small flow rates required small orifices or emitters which were susceptible to clogging problems. To minimize clogging, emitter diameters were increased, which increased emitter flow rates and changed the irrigation duration from continuous to intermittent. The system application rate must be maintained less than the soil infiltration rate to avoid excessive ponding or runoff.

INSTRUMENTATION

Since crop water requirements under drip irrigation contain at least some uncertainity, and since the system operation contains some uncertainity with regard to emitter flow variations and plugging, the system operator or manager must have means to insure that the crop is receiving a proper amount of water. Instruments that can sense soils or plant parameters have been utilized to check the performance of drip irrigation systems. Other types of instruments have been used to schedule irrigation and/or control system functions.

Various types of soil moisture instruments (tensiometers, Buoyoucous blocks, heat dissipation blocks, soil psychrometers, etc.) have been used in drip irrigation. Tensiometers, because of their simplicity, availability, and the lower range, are well adapted to the drip irrigation work.

Soil moisture devices are used to determine the water movement patterns in the soil and, in some cases, to initiate the irrigation cycle. With proper placement, tensiometers can show locations of over or under irrigation. The manager can then adjust the irrigation program to compensate. This system operational check is extremely important since the amount of water in soil storage is usually small and water deficits can develop quickly.

Soil moisture devices are commonly used on automated systems. Usually the soil moisture device is used to override a system controller. The controller will be preset to actuate a selected valve for a determined amount of time. If the soil at that station is too wet, the sensor device opens the valve circuit (no water discharge) and the station is then bypassed.

MAINTENANCE FILTRATION AND FLUSHING

Plugging of emitters caused by physical, chemical, or biological contaminates is universal and is considered the largest maintenance problem with the drip irrigation systems. The design of emitters has been conditioned by recognition of the axiom that the smaller the emitter opening, the more closely the flow rate can be matched with the soil infiltration rates, but result in greater plugging probability. Most emitters have been designed with some degree of compromise between these two diverse features.

A method of evaluating water quality in terms of emitter clogging has not been developed. Many water quality parameters are dynamic and cannot be predicted from selected measurements. The attached classification system for water analysis to indicate clogging potential is currently the best available data.

MECHANICAL FILTRATION

Mechanical filtration including settling basin, screens, centrifigal sand separators, cartridge and/or sand filters are used to reduce suspended particulate matter. These devices are used singularly or in series. Filtration units may require the addition of booster pumps for the proper backwash and flush operations. Table 2 presents filtration medium size openings equivalent to selected particles.

FIELD INSPECTION

The drip system must be inspected to detect clogged emitters and pipeline leaks or breaks. Filters must be routinely checked (weekly or more often). Water meters can indicate when emitter flow is reduced due to clogging. Flow changes as low as ten percent should be investigated.

FLUSHING

Flushing individual laterals has been successful in some systems, but flushing tends to be an attempt to cure rather than prevent clogging, and if not carried out with careful timing, will not always be successful. The lateral itself is a sort of filter since it has much smaller effluent openings than influent openings, and with a gradual reduction in the flow velocity towards the end of the line, particulate precipitation will increase. In addition, there can be mechanical agglomeration of particulates in the lateral and/or growth of micro-organisms, particularly algae, that increase plugging in the lateral. Removing these particles before they are drawn into the lateral will greatly reduce the probability of plugging and lengthen the life of the lateral for irrigation.

Table 1. Tenative Criteria For Classifying Potential Clogging Hazard of Irrigation Waters To Be Used in Trickle Systems (after Bucks and Nakayama, 1980)

	Clogging hazard		
	Slight	Moderate	Severe
Physical			
Suspended solids (Max. ppm)*	< 50	50-10	> 100
Chemical			
pH	7.0	7.0-8.0	> 8.0
Dissolved solids (Max. ppm)*	< 500	500-2000	> 2000
Manganese (Max. ppm)*	< 0.1	0.1-1.5	> 1.5
Iron (Max. ppm)*	< 0.1	0.1-1.5	> 1.5
Hydrogen sulfide (Max. ppm)*	< 0.5	0.5-2.0	> 2.0
Biological			
Bacteria populations (Max. no./mL)+	<10,000	10,000-50,000	>50,000

*Maximum measured concentration from a representative number of water samples using standard procedures for analysis.
+Maximum number of bacteria per milliliter can be obtained from portable field samplers and laboratory analysis.

Table 2. Filter Media Opening Size Equivalents (after Wilson, 1977)

Standard Soil Particle Categories	Millimeters	Inches	Micrometers	Screen Mesh*	Stand+
Very coarse sand	1.00 -2.00	0.0393 -0.9786	1000-2000	18-10	Approx.
Coarse sand	0.50 -1.00	0.0197 -0.0393	500-1000	35-18	1/10.
Medium sand	0.25 -0.50	0.0098 -0.0197	250- 500	60-35	the
Fine sand	0.10 -0.25	0.0039 -0.0098	100- 250	160-60	particle
Very fine sand	0.05 -0.10	0.0020 -0.0039	50- 100	270-160	size
Silt	0.002 -0.05	0.00008-0.0020	2- 50	400+270	
Clay	Less than 0.002	Less than 0.00008	Less than 2	–	

*Using market grade wire cloth.
+Assuming round sand; sharp sand approximately 1/12 the particle size.

Flushing can be done manually, lateral-by-lateral, by opening the end of the line. Flushing valves are available that can be operated using the irrigation water pressure. Any number of laterals can be flushed from one flushing control valve depending on the system capacity. Flushing velocity should exceed one foot per second.

Frequency and timing of flushing should be established in each individual case. These practices will depend on water quality, irrigation frequency and amount, as well as the limitation in pressure or flow rates of the system. Reasonable flushing frequencies can vary from more than once per irrigation to once a month.

CHEMICAL TREATMENT

Most surface water supplies for irrigation contain a wide variety of particulate matter ranging from very coarse floating organic materials to very fine mineral sediments. Filtration alone is usually not sufficient to prevent emitter clogging. Such waters will also contain living algae, bacteria, and probably a host of flora and fauna that frequent open ponds, reservoirs, and lakes. All of these materials, some of which may continue to grow in slow moving water of lateral lines, particularly if nutrients are present, are potential hazards to a drip system since, in the right amounts and conditions, they will plug almost any type of emitter. Subsurface waters, namely deep well waters, are normally free of most of these particulates except the troublesome iron and sulphur bacteria.

ACIDS

Precipitation of calcium or magnesium carbonate can occur in drip lines and emitters if the water pH is over 7.5. Chemical precipitation can be reduced by adding acids, usually sulfuric or hyperchloric acid, to lower the pH. Phosphoric acid can also be used as water treatment fertilizer. A reduced pH also aids in bacterial control with chlorination.

ALGAECIDES

Algaecides are commonly used to prevent the growth of algae in water. The most common algaecides are copper sulfate, sulfuric acid, and chlorine. Since algae is a photosynthetic plant and must have sunlight, it will not grow in the pipeline and algaecide treatment in the flow system will be of no value unless it disintegrates the algae plant. The treatment may kill the algae that has passed the filtering system, but the algae is still a potential plugging hazard.

BACTERIACIDES

Bacterial slimes which form within closed pipelines, as well as in open water, are a hazard in themselves, and as a potential coagulant of fine particles. Both algae and bacteria require adequate nutrition and any water that is impoverished of nutrients will exhibit much less of a growth problem than waters carrying loads of nutrient elements.

CHLORINE

Chlorine is the most effective and inexpensive treatment for bacterial slimes. Chlorine can be introduced at low concentrations (1 ppm) or as slug treatments at intervals as necessary at much higher concentrations (10-20 ppm) for only a few minutes at a time. Most specialists favor slug treatments over continuous treatments. The chlorine is introduced into the system upstream from the filters and can be either sodium hyperchloride (the ingredient in common bleach) or as chlorine gas. The gas treatment is usually more expensive, more difficult, and potentially more hazardous to the operator than sodium or calcium hyperchloride at similar concentrations. The use of chlorine gas must conform to regulations regarding the safe handling of liquid and gaseous chlorine under high pressure. Calcium hyperchloride (a solid) can also be used, but the calcium tends to produce precipitates that may cause plugging without pH adjustment.

OXIDENTS

Calcium hyperchloride acts as an oxident for precipitation of troublesome iron in the water. It can be used deliberately to precipitate iron, allowing it to settle out before the water is introduced into the system. Chlorine also destroys the iron bacteria in lines preventing the formation of iron preciptates and slimes within the system. Other oxidents include bromine, iodine, bromine chloride, hydrogen-, calcium-, and sodium-peroxides. Most of these are relatively more expensive than the chlorine compounds.

FLOCCULANTS

Flocculants are used largely in conjunction with settling basins. The flocculation of fine materials into large aggregates permits many of them to settle out. With some materials, the floccules may be less dense than the individual particles in which case the foccules are screened or filtered off.

REFERENCES

1. ASAE, 1980. Design and Operation of Farm Irrigation Systems. ASAE Monograph No. 3.

2. New Zeland Agricultural Engineering Institute, 1974. Trickle Irrigation Design Manual.

3. Keller, J. and D. Karmeli, 1974. Trickle Irrigation Design. Rain Bird Sprinkler Mgf. Corp.

4. USDA-SCS, 1981. Trickle Irrigation. Chapter 7, NEH 15.

APPENDIX I

FIELD EVALUATION PROCEDURES

FOR TRICKLE IRRIGATION SYSTEMS

Field Evaluation - Trickle Irrigation System

Successful operation of trickle irrigation requires that the frequency and quantity of water application be accurately scheduled. The field emission uniformity, EU', must be known in order to manage the quantity of application. Unfortunately, EU' often changes with time; therefore, periodic field checks of system performance are necessary.

The data needed for fully evaluating a trickle irrigation system are available by determining:

1. Duration, frequency, and sequence of operation of normal irrigation cycle.

2. The S_{md} and M_{ad} in the wetted volume where

S_{md} - Soil moisture deficit is the difference between field capacity and the actual soil moisture in the root zone soil at any given time. It is the amount of water required to bring the soil in the root zone to field capacity.

M_{ad} - Management allowed deficit is the desired soil moisture deficit at the time of irrigation. It is expressed as a percent of the available water capacity (W_a) or the corresponding soil moisture deficit (S_{md}) related to the desired soil moisture stress for the crop-soil-water-climate system. Sprinkle and surface irrigation is usually scheduled when S_{md} equals M_{ad} but trickle irrigation is often scheduled with a much lower S_{md}. However, in humid areas supplemental irrigation depths are often applied to only partly replace S_{md} in order to leave some root zone capacity for storage of anticipated rainfall.

3. Rate of discharge at the emission points and the pressure near several emitters spaced throughout the system.

4. Changes in rate of discharge from emitters after cleaning or other repair.

5. The percent of soil volume wetted.

6. Spacing and size of trees or other plants being irrigated.

7. Location of emission points relative to trees, vines, or other plants and uniformity of spacing of emmision points.

8. Losses of pressure at the filters.

9. General topography.

10. Additional data indicated on Form 7-11.1.

Equipment needed

The equipment needed for collecting the necessary field data is:

1. Pressure gauge (0-50 psi range) with "T" adapters for temporary installation at either end of the lateral hoses.

2. A stopwatch or watch with an easily visible second hand.

3. Graduated cylinder with 250 ml capacity.

4. Measuring tape 10 to 20 ft long.

5. Funnel with 3- to 6-in diameter.

6. Shovel and soil auger or probe.

7. Manufacturer's emitter performance charts showing the relationships between discharge and pressure plus recommended operating pressures and filter requirements.

8. Sheet metal or plastic trough 3 ft long for measuring the discharge from several outlets in a perforated hose simultaneously or the discharge from a 3-ft length of porous tubing. (A piece of 1- or 2-in PVC pipe cut in half lengthwise makes a good trough.)

9. Copies of Form 7-11.1 for recording data.

Field Procedure

The following field procedure is suitable for evaluating systems with individually manufactured emitters (or sprayers) and systems that use perforated or porous lateral hose. Fill in the data blanks of Form 7-11.1 while conducting field procedure.

1. Fill in parts 1, 2, and 3 of Form 7-11.1 concerning the general soil and crop characteristics throughout the field.

2. Determine from the operator the duration and frequency of irrigation and his concept of the M_{ad} to complete part 4.

3. Check and note in part 5 the pressures at the inlet and outlet of the filter and, if practical, inspect the screens for breaks and any other possibility for contaminants to bypass the screens.

4. Fill in parts 6, 7, and 8 which deal with the emitter and lateral hose characteristics. (When testing perforated or porous tubing the discharge may be rated by the manufacturer in flow per unit length.)

5. Locate four emitter laterals along an operating manifold (See Figure 7-1.3); one should be near the inlet and two near the "third" points, and the fourth near the outer end. Try to select a manifold

which appears to have the greatest head differential for evaluation. Sketch the system layout and note in part 9 the general topography, manifold in operation and manifold where the discharge test will be conducted.

6. Record the system discharge rate (if the system is provided with a water meter) and the numbers of manifolds and blocks (or stations) in Part 10. The number of blocks is the total number of manifolds divided by the number of manifolds in operation at any one time.

7. For laterals having individual emitters, measure the discharge at two adjacent emission points (denoted as A and B in part 14) at each of four different tree or plant locations on each of the four selected test laterals. (See Figure 7-11.1) Collect the flow for a number of full minutes (1, 2, and 3, etc.) to obtain a volume between 100 and 250 ml for each emission point tested. Convert each reading to ml per minute before entering the data in part 14 on Form 7-11.1. To convert ml per minute to gallons per hour (gph), divide by 63.

These steps will produce eight pressure readings and 32 discharge volumes at 16 different plant locations for individual emission points used in wide-spaced crops with two or more emission points per plant.

For perforated hose or porous tubing, use the 3-ft trough and collect a discharge reading at each of the 16 locations described above. Since these are already averages from 2 or more outlets, only one reading is needed at each location.

For relatively wide-spaced crops such as grapes where one single outlet emitter may serve one or more plants, collect a discharge reading at each of the 16 locations described above. Since the plants are only served by a single emission point, only one reading should be made at each location.

8. Measure and record in part 15 the water pressures at the inlet and downstream ends of each lateral tested in part 14 under normal operation. On the inlet end, this may require disconnecting the lateral hose, installing the pressure gauge, and reconnecting the hose before reading the pressure. Some systems are equipped with tire valve stems at the inlet end and pressure can be read with the use of portable gauge. On the downstream end, the pressure can be read after connecting the pressure guage the simplest way possible.

9. Check the percentage of the soil that is wetted at one of the tree locations on each test lateral and record in part 16. It is best to select a tree at a different relative location on each lateral. Use the probe, soil auger, or shovel--whichever seems to work best--for estimating the area of the wetted zone in a horizontal plane about 6 to 12 inches below the soil surface around each tree. Determine the percentage wetted by dividing the wetted area by the total surface area represented by the tree.

10. If an interval of several days between irrigations is being used, check the soil moisture deficit, S_{md}, in the wetted volume near a few representative trees in the next block to be irrigated and record it in part 17. This is difficult and requires averaging samples taken from several positions around each tree.

11. Determine the minimum lateral inlet pressure, MLIP, along each of the operating manifolds and record in part 18. For level or uphill manifolds, the MLIP will be at the far end of the manifold. For downhill manifolds it is often about two-thirds down the manifold. For manifolds on undulating terrain it is usually on a knoll or high point. When evaluating a system with two or more operating stations, the MLIP on each manifold should be determined. This will require cycling the system.

12. Determine the discharge correction factor, DCF, to adjust the average emission point discharges for the tested manifold. This adjustment is needed if the tested manifold happened to be operating with a higher or lower MLIP than the system average MLIP. If the emitter discharge exponent, x, is known, use the second formula presented in part 19.

13. Determine the average and adjusted average emission point discharges according to the equations in parts 11 and 12 of Form 7-11.1.

Utilization of field data

In trickle irrigation all the system flow is delivered to individual trees, vines, shrubs, or other plants. Essentially, there is no opportunity for loss of water except at the tree or plant locations. Therefore, uniformity of emission is of primary concern, assuming the crop is uniform. Locations of individual emission points, or the tree locations when several emitters are closely spaced, can be thought of in much the same manner as the container positions in tests of sprinkler performance.

Average application depth. The average depth applied per irrigation to the wetted area, D_{aw}, is useful for estimating M_{ad}. It is computed from:

$$D'_{aw} = \frac{1.604\ e\ q'_a\ T_a}{A_w} \qquad \text{(eq. 7-11.1)}$$

in which

D'_{aw} is the average depth applied per irrigation to the wetted area (in)

q'_a is the adjusted average emission point discharge of the system for part 12 Form 7-11.1 (gph)

e is the number of emission points per tree

T_a is the application time per irrigation (hrs)

A_w is area wetted per tree or plant from part 16 (ft^2)

$$1.604 = \frac{gal}{hr} \times hrs \times \frac{ft^3}{7.48\ gal} \times \frac{12\ in}{ft} \times \frac{1}{ft^2}$$

The average depth applied per irrigation to the total cropped area can be found by substituting the plant spacing, $S_p \times S_r$, for the wetted area, A_w, in eq. 7-11.1. Therefore:

$$D'_a = \frac{1.604\ e\ q'_a\ T_a}{S_p \times S_r} \qquad \text{(eq. 7-11.2)}$$

in which

D'_a is the average depth applied per irrigation to the total cropped area (in)

S_p and S_r are plant and row spacing, ft.

Volume per day. The average volume of water applied per day for each tree or plant is:

$$G' = \frac{e\ q'_a\ T_a}{F_i} \qquad \text{(eq. 7-11.3)}$$

in which

G' is the average volume of water applied per plant per day (gal/day)

F_i is the irrigation interval (days)

Emission Uniformity. The actual field emission uniformity, EU', is needed to determine the system operating efficiency and for estimating gross water application requirements. The EU' is a function of the emission uniformity in the tested area and the pressure variations throughout the entire system. Where the emitter discharge test data is from the area served by a single manifold:

$$EU'_m = 100\ q'_n/q'_a \qquad \text{(eq. 7-11.4)}$$

in which

EU'_m is the field emission uniformity of the manifold area tested (percent)

q'_n and q'_a are the system low quarter and overall average emitter discharges, taken from Form 7-11.1, part 12 (gph)

Some trickle irrigation systems are fitted with pressure compensating emitters or have pressure or flow) regulation at the inlet to each lateral. Some systems are only provided with a means for pressure control or regulation at the inlets to the manifolds, others are provided with regulators at each lateral. If the manifold inlet pressures vary more than a few percent (due to design and/or management), the overall EU' (of the system) will be lower than EU'_m (of the tested manifold). An estimate of this efficiency reduction factor (ERF) can be computed from the minimum lateral inlet pressure along each manifold throughout the system by:

$$ERF = \frac{\text{average MLIP} + (1.5 \text{ minimum MLIP})}{2.5 \text{ (average MLIP)}} \qquad \text{(eq. 7-11.5a)}$$

in which

ERF is the efficiency reduction factor

MLIP is the minimum lateral inlet pressure along a manifold (psi)

Average MLIP is the average of the individual MLIP along each manifold (psi)

Minimum MLIP is the lowest lateral inlet pressure in the system (psi)

A more precise method for estimating the ERF can be made by:

$$ERF = \left(\frac{\text{minimum MLIP}}{\text{average MLIP}}\right)^{X} \qquad \text{(eq. 7-11.5b)}$$

x is the emitter discharge exponent

In cases where there are relatively small pressure variations and x = 0.5, the two methods for computing ERF give essentially equal results;

however, for pressure variations greater than 0.2 h_a or x values higher than 0.6 or lower than 0.4, the differences could be significant. Note - h_a is the average emitter pressure head.

The value of x can be estimated from field data as follows:

Step 1 Determine the average discharge and pressure of a group of at least 6 emitters along a lateral where the operating pressure is uniform.

Step 2 Reduce the operating pressure by adjusting the lateral inlet valve and again determine the average discharge and pressure of the same group of emitters.

Step 3 Determine x by Equation 7-4.9 using the average discharge and pressure head values found in Steps 1 and 2.

$$X = \frac{\log \frac{q_1}{q_2}}{\log \frac{h_1}{h_2}} \qquad \text{(eq. 7-4.9)}$$

Where

x = Emitter discharge exponent

q_1 = Average discharge of a group of emitters at pressure, h_1

q_2 = Average discharge of the same group of emitters at pressure, h_2

Step 4 Repeat steps 1, 2, and 3 at two other locations and average the x values for the three tests.

The ERF is approximately equal to the ratio between the average emission point discharge in the area served by the manifold with the minimum MLIP and the average emission point discharge for the system. Therefore, the system EU' can be approximated by:

$$EU' = ERF\ EU'_m \qquad \text{(eq. 7-11.6)}$$

General criteria for EU' values for systems which have been in operation for one or more seasons are: greater than 90% excellent; between 80% and 90%, good; 70 to 80% fair; and less than 70% poor.

Gross application required. Since trickle irrigation wets only a small portion of the soil volume, the S_{md} must be replaced frequently. It is always difficult to estimate S_{md} because some regions of the wetted portion of the root zone often remain near field capacity even when the interval between irrigation is several days. For this reason, S_{md} must be estimated from weather data or information derived from evaporation devices. Such estimates are subject to error and since there is no practical way to check for slight underirrigation, some margin for safety should be allowed. As a general rule, the minimum gross depth of application, I_g, should be equal to (or slightly greater than) the values obtained by eq. 7-3.10.

A bulbous tipped probe can be used to determine the area of the wetted bulb. If the wetted bulb increases over a series of irrigations, too much water is being applied. If the wetted bulb is decreasing in size, then there is underirrigation.

The gross depth per irrigation, I_g, should include sufficient water to compensate for the system uniformity and allow for unavoidable losses of the required leaching water. (Unavoidable losses can be used to satisfy leaching requirements or vice versa) To minimize the gross depth, systems should be well designed, accurately scheduled and carefully maintained. Where the unavoidable water losses are greater than the leaching water required, T_r $1/(1.0 - LR_T)$ or LR_t 0.1:

$$I_g = \frac{I_n \quad T_r}{EU/100} \qquad \text{(eq. 7-3.10)}$$

and where $T_r < 1/(1.0-LR_t)$ and $LR_t > 0.1$:

$$I_g = \frac{T_n}{EU/100 \ (1.0 - LR_t)}$$

in which

I_g is the gross depth per irrigation, inches

T_r is the peak use period transpiration ratio

EU is the emission uniformity, percentage

LR_t is the leaching requirment under trickle irrigation, ratio

I_n is the net depth to be applied per irrigation, in

The T_r is the <u>ratio</u> of the depth of water applied to the area where T_d is exactly satisfied <u>to</u> the depth of water transpired. It represents the extra water which must be applied, even during peak use period, to offset unavoidable deep percolation losses. These losses are due to excess vertical water movement below the active root zone which is unavoidable in porous and shallow soils when sufficient lateral wetting is achieved. With efficient irrigation scheduling and for design purposes, use the following peak use period T_r values:

i) T_r = 1.00 for deep (greater than 5 ft) rooted crops on all soils except very porous gravely soils; medium (2.5 to 5 ft) rooted crops on fine and medium textured soils; and shallow rooted (less than 2.5 ft) on fine textured soils.

ii) T_r = 1.05 for deep rooted crops on gravely soils; medium rooted crops on coarse textured (sandy) soils; and shallow rooted crops on medium textured soils.

iii) T_r = 1.10 for medium rooted crops on gravely soils; or shallow rooted crops on coarse textured soils.

T_d in the above discussion is the peak month average daily transpiration rate of a crop under trickle irrigation, in/day.

When estimating i_g by eq. 7-3.10 for managing (scheduling) irrigations let EU be the field EU' and estimate the net depth or irrigation to apply; I_n, as follows:

i) First estimate the depth of water which could have been consumed by a full canopy crop since the previous irrigation, I_n'. This can be done using standard techniques based on weather data or pan evaporation data.

ii) Next, subtract the depth of effective rainfall since the last irrigation, R_e'

iii) Then calculate I_n by:

$$I_n = (I_n' - R_e')\left[\frac{P_s}{100} + 0.15\left(1.0 - \frac{P_s}{100}\right)\right] \qquad \text{(eq. 7-11.7)}$$

P_s is the ground area shaded by the crop canopies at midday as a percentage of the total area, percentage

Using I_g (computed by eq. 7-3.10), the average daily gross volume of water required per plant per day, G, can be computed by eq. 7-3.11. The average volumn of water actually being applied each day is computed by eq. 7-11.3. If G G' the field is being overirrigated and if G G', it is underirrigated. This can be verified with the use of a neutron probe or similar equipment. The gross volume of water required per plant per day, G, is useful for selecting the design emitter flow rate:

$$G = 0.623\ S_p\ S_r\ I_g/F_i \qquad \text{(eq. 7-3.11)}$$

in which G is the gross water required per plant per day

S_p and S_r are the plant and row spacings, ft

I_g is the gross depth per irrigation, in

F_i is the irrigation interval (frequency), days

Application Efficiencies

A concept called potential application efficiency (of the low quarter), PE_{lq}, is useful for estimating how well a system can perform. It is a function of the peak use transpiration ratio, T_r, the leaching requirement, LR_t and EU'. When the unavoidable water losses are greater than the leaching water requirements., T_r $1/(1.0 - LR_t)$:

$$PE_{lq} = \frac{EU'}{T_r\ (1.0 - LR_t)} \qquad \text{(eq. 7-11.8a)}$$

and where $T_r < 1/(1.0 - LR_t)$:

$$PE_{lq} = EU' \qquad \text{(eq. 7-11.8b)}$$

The values for T_r are given in conjunction with eq. 7-3.10.

Leaching requirement, LR_t. In arid regions where salinity is a major importance, most of the natural precipitation is accounted for in R_e, W_a, nonbeneficial consumptive use, and/or runoff. There is usually very little additional natural precipitation, D_{rw}, that can add to deep percolation and consequently help satisfy the leaching requirements. Furthermore, since only a portion of the soil area is wetted and needs leaching under trickle irrigation, the effective additional precipitation is reduced to $(P_w/100)\ D_{rw}$; therefore, it can almost always be neglected. P_w is the average horizontal area wetted in the top part (6 to 12 in) of the crop root zone as a percentage of the total crop area.

Calculating the leaching requirement for trickle irrigation, LR_t is greatly simplified by neglecting $(P_w/100)D_{rw}$ and

$$LR_t = \frac{L_n}{I_n} = \frac{L_N}{I_N} = \frac{EC_w}{EC_{dw}} \qquad \text{(eq. 7-3.18)}$$

in which

LR_t is the leaching requirement under trickle irrigation, ratio

L_n and L_N are the net per irrigation application and net annual leaching requirements, in

I_n and I_N are the net per irrigation application and net annual irrigation depths to meet consumptive use requirements, respectively, in EC_w is the electrical conductivity of the irrigation water, mmhos/cm EC_{dw} is the electrical conductivity of the drainage (deep percolation) water, mmhos/cm

Equation 7-3.18 is based on a steady state salt balance condition, or in popular terminology, "what goes in, must come out and nothing comes from in between." It is important to understand the meaning of the number calculated for LR_t. It represents the minimum amount of water (in terms of a fraction of applied water) that must pass through the root zone to control salt buildup. The actual LR_t, however, is that amount of leaching water necessary to control salts in the root zone and this can only be determined by monitoring the soil salinity which is then related to field water management.

In a trickle irrigation system, there are no field boundary effects or pressure variations along the manifold tested which are not taken into account in the field estimate of EU'. Therefore, the estimated PE_{1q} is an overall value for the field except for possible minor water losses due to leaks, draining of lines, and flushing (unless leaks are excessive), with the system EU' (see eq. 7-11.6).

The system PE_{1q} may be low because the manifold inlet pressures are not properly set and ERF (see eq. 7-11.5) is low. In such cases, the manifold inlet pressures should be adjusted to increase the pressure uniformity and consequently ERF. When there is overirrigation, the actual application efficiency of the low quarter, E_{1q} will be less than PE_{1q}. In such cases the E_{1q} can be estimated by:

$$E_{1q} = \frac{100\ G}{G'} \qquad \text{(eq. 7-11.9)}$$

when there is underirrigation and G' G then E_{1q} will approach the system EU'. In such cases the LR_t and/or the I_r will not be satisfied. This may cause excessive salt buildup in the least interest areas and/or a reduced volume of wetted soil.

Form 7-11.1. TRICKLE IRRIGATION EVALUATION

1. Location __________, Observer ______, Date __________
2. Crop: type ________, age ____ years, spacing ____ -by ____ -feet
   root depth ____ ft, percent area covered or shaded ____ %
3. Soil: texture __________, available moisture ______ in/ft
4. Irrig: duration ____ hrs, frequency ____ days, M_{ad} ____ %, ______ in
5. Filter pressure: inlet ____ psi, outlet ____ psi, loss ______ psi
6. Emitter: make __________, type ______, point spacing ____ ft
7. Rated discharge per emission point ______ gph at ______ psi
   Emission points per plant ____, giving ____ gallon per plant per day
8. Lateral: dia. ____ in, ______ material ____ length ____ ft, spacing ____ ft
9. System layout, general topography, and test locations:

10. System discharge ____ gpm, No. of manifolds ____ and blocks ____
11. Average test manifold emission point discharges at ______ psi

    $$\text{Manifold} = \frac{\text{(sum of all averages \_\_\_\_\_\_ gph)}}{\text{(number of averages \_\_\_\_\_\_)}} = \text{\_\_\_\_\_\_ gph}$$

    $$\text{Low 1/4} = \frac{\text{(sum of low 1/4 averages \_\_\_\_\_\_ gph)}}{\text{(number of low 1/4 averages \_\_\_\_\_\_)}} = \text{\_\_\_\_\_\_ gph}$$

12. Adjusted average emission point discharges at ______ psi
    System = (DCF ____) X (manifold average ____ gph) = ______ gph
    Low 1/4 = (DCF ____) X (manifold low 1/4 ____ gph) = ______ gph
13. Comments: ____

Form 7-11.1 TRICKLE IRRIGATION EVALUATION (Cont.)

14. Discharge test volume collected in ____ min (1.0 gph = 63 ml/min)

Location on Lateral		Lateral Location on the Manifold							
		inlet end		1/3 down		2/3 down		far end	
		ml	gph	ml	gph	ml	gph	ml	gph
inlet end	A								
	B								
	Ave								
1/3 down	A								
	B								
	Ave								
2/3 down	A								
	B								
	Ave								
far end	A								
	B								
	Ave								

15. Lateral inlet ____ psi ____ psi ____ psi ____ psi
closed end ____ psi ____ psi ____ psi ____ psi

16. Wetted area ____ ft^2 ____ ft^2 ____ ft^2 ____ ft^2
per plant ____ % ____ % ____ % ____ %

17. Estimated average Smd in wetted soil volume ____________ in

18. Minimum lateral inlet pressures, MLIP, on all operating manifolds:

Manifold:	Test	A	B	C	D	E	F	G	Ave.
Pressure-psi:	____	____	____	____	____	____	____	____	____

19. Discharge correction factor, DCF, for the system is:

$$DCF = \frac{2.5 \times (\text{average MLIP } \_\_\_\_ \text{ psi})}{(\text{average MLIP } \_\_\_\_ \text{ psi}) + 1.5 \times (\text{test MLIP } \_\_\_\_ \text{ psi})} = \_\_\_\_$$

or if the emitter discharge exponent x = ________ is known

$$DCF = \left[\frac{(\text{average MLIP } \_\_\_\_ \text{ psi})}{(\text{test MLIP } \_\_\_\_ \text{ psi})} \right]^{x} = \_\_\_\_\_\_\_\_$$

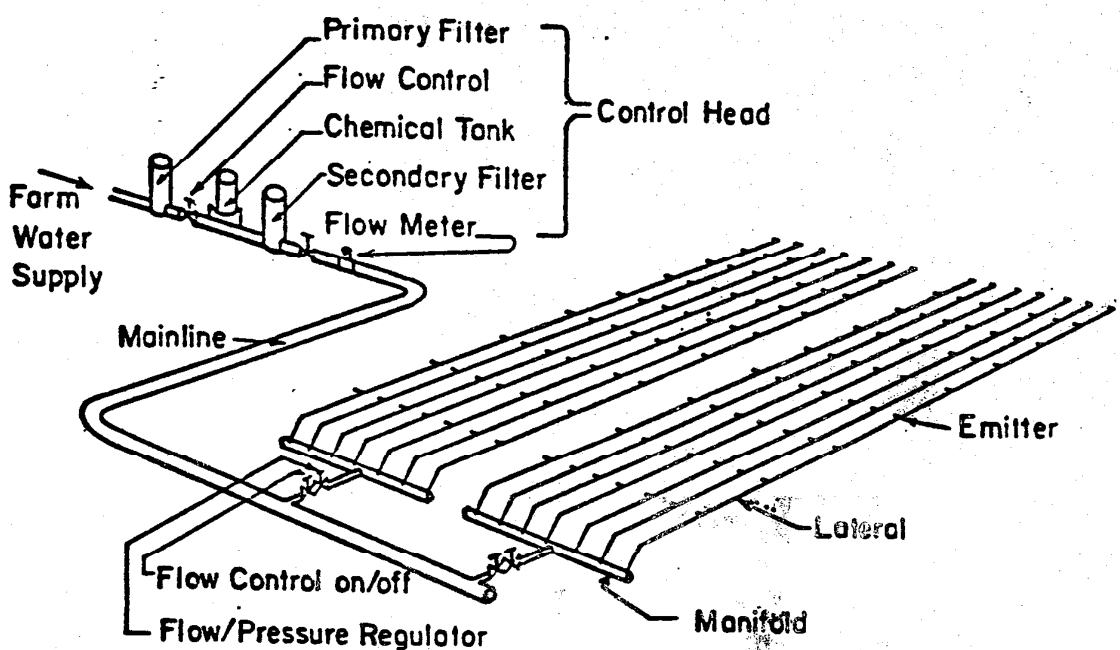


Figure 7-1.2.--Basic components of a trickle-irrigation system.

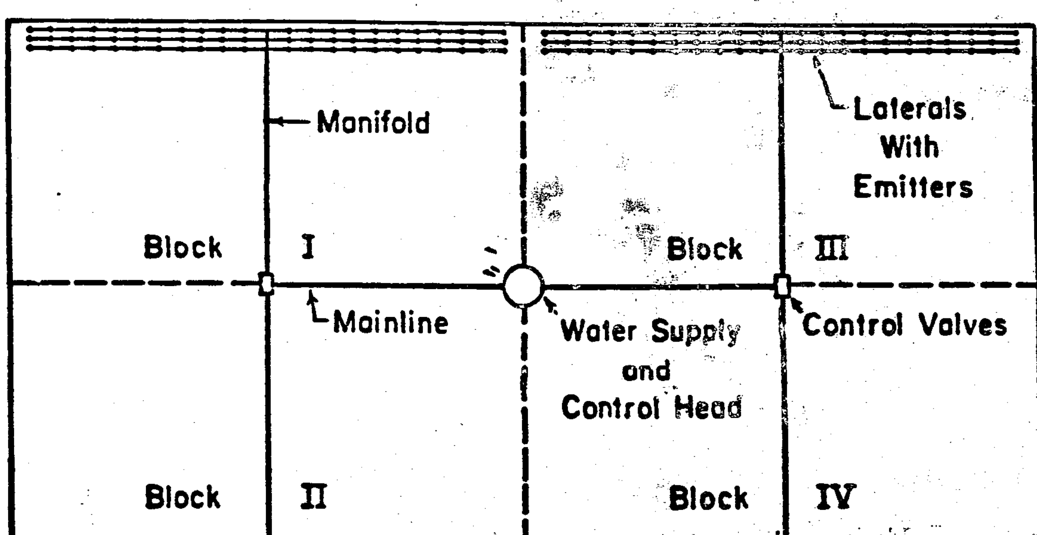


Figure 7-1.3.--Typical two station split flow layout for trickle irrigation system with Block I and III, or II and IV operating simultaneously.

*U.S. GOVERNMENT PRINTING OFFICE : 1980 O-310-944/SCS-155