# Trickle Irrigation Design Parameters

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TRICKLE irrigation is a system for supplying filtered water (and fertilizer directly on or into the soil Spraying is eliminated and water is allowed to dissipate under low pressure in an exact predetermined pattern. The outlet device which emits the water into the soil is known as an "emitter." Emitters dissipate the presssure in the pipe distribution networks by means of a narrow nozzle or long flow path, thereby decreasing the water pressure to allow discharge of only a few liters per hour (gallons per hour). After leaving the emitter water is distributed by its normal movement through the soil profile; therefore, the area which can be watered from each emission point is limited by the constraints of the water's horizontal flow.

In trickle irrigation the objective is to provide each plant with a continuous readily available supply of soil moisture which is sufficient to meet transpiration demands. Trickle irrigation offers unique agronomical, agrotechnical, and economical advantages for the efficient use of water. The main disadvantages of trickle irrigation systems are sensitivity to clogging, salinity build up, and poor soil moisture distribution.

Numerous papers and several regional, national and international conferences have been devoted to trickle irrigation and related crop performance (Black et al. 1970, DeRemer 1972, Hanks and Keller 1972, Edwards 1972, Karmeli et al. 1973 and Nortion 1972). Unfortunately most of the current information and design procedures are quite general and/or incomplete DeRemer 1972, Hanson 1973, Howell and Hiler 1972, Kramer 1971, and Meyer and Bucks 1972). The material which follows provides an outline and sufficient detail for trickler system design using the limited knowledge currently available.

## IRRIGATION DEPTH AND INTERVAL

Since only part of the soil volume is wetted, the determination of the amount (depth or volume) of application per trickle irrigation cycle and irrigation interval, are unique.

### Depth

Expressing the maximum application amount as a volume to apply per unit of total land area which is equivalent to the average depth of application gives:

$$I_{dx} = Y \cdot (FC - WP) \cdot Z \cdot P/100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [1]$$

in which

$I_{dx}$ is the maximum net depth of each irrigation application over the whole area, mm (in.)

Y is the portion of available moisture depletion allowed or desired

FC is the volumetric moisture at field capacity, mm/m (in./ft)

WP is the volumetric moisture at wilting point, mm/m (in./ft)

z is the soil depth to be considered, m (ft).

P is the area wetted as a percent of the total irrigated area, percent

The volume of water applied per irrigation cycle, $V_I$, can be determined by multiplying the total area to be irrigated by the depth per irrigation. Where hectares (acres) are the unit of land measure mm = 10 $m^3$/Ha (in = 27,154 gal per Ac). The root depth of major interest for tree crops is 1.0 to 1.2 m (3.3 to 4.0 ft), for vine and bush crops 0.8 to 1.0 m (2.7 to 3.3 ft), for wide spaced vegetable 0.4 to 0.6 m (1.3 to 2 ft), and for the close spaced vegetable 0.2 to 0.4 m (0.7 to 1.3 ft).

The moisture content at which the irrigation should be started depends on the soil, crop and water-yield-economic factors. Since this relationship is not quantitatively expressed, the portion of allowable moisture depletion, Y, is usually taken as 0.3 for drought-sensitive crops and up to 0.6 for non-sensitive crops.

The percentage of wetted area as compared to the whole irrigated area, P, depends on emitter discharge and spacing and the soil type. Quantitative relations have not been developed; however, Karmili and Peri, 1972, have presented a table similar to Table 1 as a guide for estimating the average percentage of coarse (C), medium (M), or fine (F) textured soils which can be wetted by various emitter discharges and spacings.

A "right or proper" minimum value for P has not been established. However, one can conclude that systems with high P values: provide more insurance in case of system failures; should be easier to schedule; and bring more of the soil systme into action for nutrient storage and supply. Considering the current state of knowledge a reasonable design objective is to wet at least one-third (P – 33 percent) of the potential root volume of soil. In areas with considerable supplemental rainfall, lower P values may be acceptable. On the other hand, P should be held below 50 percent in wide spaced crops since many of the advantages of trickle irrigation depend on keeping the strips between rows relatively dry.

Fig. 1 shows the type of relationship that may exist between relative potential production and P. While there is insufficient data upon which to base specific curves, from current experience it seems logical to assume that: curves must start near the origin where there is little or no rainfall; significant production will be achieved when only a relatively small portion of the soil volume receives water; maximum potential

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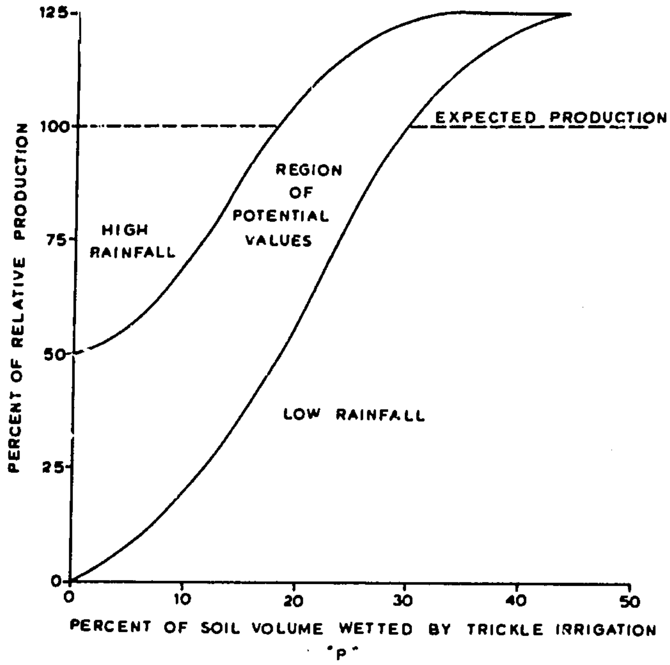

FIG. 1 Relative production as a percentage of the expected production from current surface or sprinkler irrigation practices for various amounts of potential soil root volume wetted by trickle irrigation.

production will be achieved with considerably less than full wetting; and there may be significant variations between different crop-soil-climate systems.

If yields under trickle irrigation can potentially be higher than are now being obtained by current practices, then systems which seem adequate may in fact be underdesigned. This is demonstarated in Fig. 1. For example, a system with P = 20 percent may appear to be doing as well as expected from current knowledge, however, increasing P to 40 percent may increase production by 25 percent.

The depth of irrigation obtained from equation [1] is the maximum depth that should be considered. Smaller depths at more frequent intervals are often recommended for increased productivity. Where there is experience with flood or sprinkler irrigation, a comparable trickle irrigation depth can be obtained by multiplying the net flood or sprinkler depth by P/100.

### Interval

The irrigation interval depends on the rate at which water is consumed by the plants and the depth of irrigation applied by each cycle. In addition, the emission uniformity and a minimum 10 percent excess water for leaching, unavoidable deep percolation and evaporation should be taken into account, thus:

$$I_i = \frac{I_{dn}}{T} = 0.9 \cdot \frac{EU}{100} \cdot \frac{I_d}{T} \quad \ldots\ldots\ldots\ldots\ldots\ldots [2]$$

in which

$I_i$ is the irrigation interval, days

$I_{dn}$ is the net depth of each irrigation application over the whole area, mm (in.)

T the average transpiration rate of the plant based on the whole area, mm/day (in./day)

EU is the emission uniformity, percentage

$I_d$ is the gross (or average) depth of irrigation over the whole area, mm (in.)

TABLE 1. PERCENTAGE OF SOIL WETTED BY VARIOUS DISCHARGES AND SPACINGS FOR EMISSION POINTS IN A STRAIGHT LINE APPLYING 40 mm (1.6 IN.) OF WATER PER CYCLE OVER THE WETTED AREA

| Effective spacing between laterals, m* (1.0 m = 3.3 ft) | Effective emission point discharge rate† | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | under 1.5 lph (0.4 gph) | | | 2 lph (0.5 gph) | | | 4 lph (1 gph) | | | 8 lph (2 gph) | | | over 12 lph (3 gph) | | |
| | Soil texture and recommended emission point spacing on the lateral - m‡ | | | | | | | | | | | | | | |
| | C 0.2 | M 0.5 | F 0.9 | C 0.3 | M 0.7 | F 1.0 | C 0.6 | M 1.0 | F 1.3 | C 1.0 | M 1.3 | F 1.7 | C 1.3 | M 1.6 | F 2.0 |
| | Percentage of soil wetted§ | | | | | | | | | | | | | | |
| 0.8 | 36 | 88 | 100 | 50 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1.0 | 33 | 70 | 100 | 40 | 80 | 100 | 80 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1.2 | 25 | 58 | 92 | 33 | 67 | 100 | 67 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1.5 | 20 | 47 | 73 | 26 | 53 | 80 | 53 | 80 | 100 | 80 | 100 | 100 | 100 | 100 | 100 |
| 2.0 | 15 | 35 | 55 | 20 | 40 | 60 | 40 | 60 | 80 | 60 | 80 | 100 | 80 | 100 | 100 |
| 2.5 | 12 | 28 | 44 | 16 | 32 | 48 | 32 | 48 | 64 | 48 | 64 | 80 | 64 | 80 | 100 |
| 3.0 | 10 | 23 | 37 | 13 | 26 | 40 | 26 | 40 | 53 | 40 | 53 | 67 | 53 | 67 | 80 |
| 3.5 | 9 | 20 | 31 | 11 | 23 | 34 | 23 | 34 | 46 | 34 | 46 | 57 | 46 | 57 | 68 |
| 4.0 | 8 | 18 | 28 | 10 | 20 | 30 | 20 | 30 | 40 | 30 | 40 | 50 | 40 | 50 | 60 |
| 4.5 | 7 | 16 | 24 | 9 | 18 | 26 | 18 | 26 | 36 | 26 | 36 | 44 | 36 | 44 | 53 |
| 5.0 | 6 | 14 | 22 | 8 | 16 | 24 | 16 | 24 | 32 | 24 | 32 | 40 | 32 | 40 | 48 |
| 6.0 | 5 | 12 | 18 | 7 | 14 | 20 | 14 | 20 | 27 | 20 | 27 | 34 | 27 | 34 | 40 |

* Where double laterals (or laterals with multiple outlet emitters) are used in orchards, enter the table with both the spacing between outlets to either side of the tree row and across the space between the rows and proportion the percentages

† Where relatively short pulses of irrigation area applied, the effective emission point discharge rate should be reduced to approximately half of the instantaneous rate for safety

‡ The texture of the soil is designated by C, course; M, medium; and F, fine. The emission point spacing is equal to approximately 80 percent of the largest diameter of the wetted area of the soil underlying the point. (Closer spacings on the lateral will not affect the percentage area wetted)

§ The percentage of soil wetted is based on the area of the horizontal section approximately 0.30 m (1.0 ft) beneath the soil surface. Caution should be exercised where less than 1/3 of the soil volume will be wetted.

Howell and Hiler, 1972, suggest multiplying a standard value for the consumptive use of the crop by a coverage factor (fraction of the field area covered or shaded by the crop) to arrive at T. For mature crops, Karmeli and Peri, (1972), recommended using the standard values of net consumptive use developed under sprinkler or flood irrigation for T. Tscheschke (1973) found that the 10 percent excess water eliminates potential salt buildup problems in the wetted soil volume.

## SYSTEM CAPACITY

The emitter discharge rate and duration of irrigation must be selected so runoff does not occur. Caution should be exercised when attempting to use emitters having dishcarge rates exceeding 6.0 to 8.0 lph (1.5 to 2.0 gph) per outlet on medium and fine textured soils (especially on steep slopes). Field tests should be run to determine the duration (depth) of irrigation which can be applied without creating runoff problems or excessive deep percolation.

Wider emitter spacings can be used where higher discharge rates are utilized, see Table 1. The P values in Table 1 are based on gross irrigation depths in the neighborhood of 40 mm (1.6 in.) on the wetted strip. When more frequent irrigations are utilized, the P values should be selected for an emitter discharge rate in the next lower discharge category.

The time each emitter is operated during each irrigation is determined from:

$$I_t = K \cdot \frac{I_d \cdot S_e \cdot S_L}{q_a} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3]$$

in which

$I_t$ is the time each emitter is operated during each irrigation application, hr
K is a constant equal to 1.00 for the Metric System and 0.623 for the English System
$S_e$ is the emitter spacing on the lateral, m (ft)
$S_L$ is the average lateral spacing m (ft)
$q_a$ is the average emitter (or emission point) discharge, lph (gph)

System capacity requirements are usually based on the maximum transpiration or consumptive use rate expected during peak periods. Before determining the system capacity, the potential number, N, of operational units into which the system will be divided must be determined by:

$$N \leq \frac{I_i \cdot 24}{I_t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [4]$$

For economic reasons it is normal to operate the system nearly full time, thereby using the highest N possible. The required system capacity is then found by:

$$Q = K' \cdot \frac{A \cdot I_d}{N \cdot I_t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [5]$$

in which

Q is the system capacity, lps (gpm)
K' is a constant equal to 2.78 for the Metric System and 453 for the English System
A is the area to be irrigated, Ha (Ac)
N is the number of operational units or segments

## EMITTER FLOW CHARACTERISTICS AND UNIFORMITY

The uniformity of the trickle irrigation systems is dependent on the flow characteristics of the emitters, emitter manufacturing tolerances and pressure variations in the system. To achieve uniformity the emitters must fulfill the following requirements: (a) give relatively low, but uniform and constant discharges, which do not vary significantly because of minor differences in pressure; (b) have relatively large flow cross-sections in order to reduce clogging problems; and (c) be inexpensive, compact and accurately made.

### Flow Characteristics

In order to produce a large pressure drop (to offset minor differences in pressure due to topography and friction loss) and still have a low discharge the cross-section of the flow paths must be between 0.3 mm and 1.5 mm (0.01 and 0.06 in.). These narrow paths are easily clogged. Enlarging the flow corss-section permits less of a drop in pressure and an increase in flow. However, the requirements for low discharges with a high pressure drop and for a large flow cross-section are contradictory. This has led to the diversity of available emitters.

The two major methods for dissipating the pressure are by means of long flow paths or through nozzles or orifices. Emitters can be characterized by:

$$q = K_d \cdot H^x \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [6]$$

in which

q is the emitter discharge, lph (gph)
$k_d$ is a constant of proportionately which characterizes each emitter
H is the pressure head at which the emitter operates, m (ft)
x is an exponent which is characterized by the flow regime

To determine $K_d$ and x the discharges for at least two different operating pressure heads must be known for each emitter. The value of x is of greatest importance for system design purposes as will be discussed later. The value of x can be determined by plotting H versus [illegible] on log-log paper and measuring the slope of the line.

The value of x characterizes the flow regime of emitters. For fully turbulent flow $x = 0.5$, for partially turbulent flow $0.5 < x < 0.7$, for the unstable flow regime $0.7 < x < 1.0$ and for laminar flow $x = 1.0$. The flow from orifice and nozzle emitters is always fully turbulent ($x = 0.5$). However, long-path emitters may have exponents which vary anywhere from 0.6 to 1.0.

Some emitters provide varying degrees of flow regulation and x may be less than 0.5. With absolute flow regulation, $x = 0.0$. This may be undesirable, however, if it ever became necessary to compensate for underdesign or emitter flow rates decreased due to slow clogging or deterioration since pressure increases would not increase flow. With x ranging between 0.3 and 0.4, considerable regulation is acheived (i.e., a 50 percent head differential would only cause a 13 to 18 percent flow variation) while some compensating capability is also maintained.

Throughout the laminar and unstable flow regime the discharge is a function of water temperature as well as pressure head. Where calibrations were made with a water temperature of 20 C (68 F) the discharges should be multiplied by the following factors: (assuming the same pressure head and laminar flow)

| Temperature | | Factor | Temperature | | Factor |
|---|---|---|---|---|---|
| 5C | 41F | 0.63 | 25C | 77F | 1.13 |
| 10 | 50 | 0.75 | 30 | 86 | 1.28 |
| 15 | 59 | 0.87 | 35 | 95 | 1.43 |
| 20 | 68 | 1.00 | 40 | 104 | 1.56 |

### Emission Uniformity

The emission uniformity, EU, of the laterals is a function of: (a) the expected discharge variations due to pressure variations and (b) the variation in discharge between emitters operating at the same pressure head.

The EU is used in determining the gross depth of irrigation, irrigation interval and system capacity. It is useful in both the design and management of trickle irrigation systems. Basically, EU is the ratio of the minimum emitter discharge to the average discharge expressed as a percentage.

To calculate the EU from design data:

$$EU = 100\,(1.0 - u + u \cdot \frac{q_{rn}}{q_{ra}})\,\frac{q_n}{q_a} \qquad \text{. . . . . . . . . . . . . . . . . . . . . . . [7]}$$

or from field test data

$$EU = 100\,\frac{q_n}{q_a} \qquad \text{. . . . . . . . . . . . . . . . . . . . . . . [8]}$$

in which

$u$ is a weighting factor dependent on the number of emitters per plant, e.

$q_{rn}$ is the average emission point discharge of the low 1/4 of a test sample operated at the reference pressure head, lph (gph)

$q_{ra}$ is the average emission point discharge of a test sample operated at the reference pressure head, lph (gph)

$q_n$ is the minimum emitter discharge when using design data and the average of the lowest 1/4 of the emission point discharges for field data, lph (gph)

| e | u | e | u |
|---|---|---|---|
| <1 | 1.00 | 4 | 0.50 |
| 2 | 0.71 | 6 | 0.41 |
| 3 | 0.58 | 8 | 0.35 |

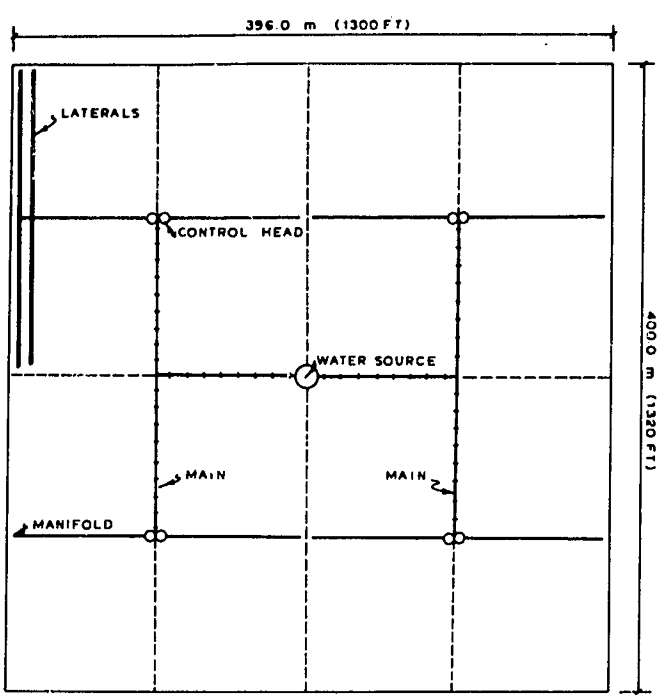

FIG. 2 Typical trickle irrigation system layout. (The dimensions which are not necessarily typical are given for use in an example which follows.)

When calculating EU by Equation 7 the values for $q_a$ and $q_n$ should be based on $q_{ra}$. When using Eq. 8 to evaluate field performance adjacent pairs of emission point discharges should be averaged before computing $q_n$ if: (a) there are two or more emission points for each tree, vine, or bush; or (b) more than half of the surface area is wetted. The field evaluation of EU should be made from emitter discharges taken from three to five locations along four different lateral lines equally spaced throughout a representative area. The selected locations should include the extremes.

Friction causes decreasing pressures and consequently decreasing discharges from the emitters along the lateral lines. A general rule of thumb is to limit the flow differential so the minimum emitter discharge, $q_n$, is at least 90 percent of the average discharge. With precision manufacturing, sufficient filtering to eliminate clogging and uniform topography, EU values in the neighborhood of 90 percent are practical.

The overall efficiency of trickle irrigation systems is equal to the EU multiplied by the portion of the application not lost to deep percolation since evaporation losses are minimum. Under good management approximately 0.9 of the water applied remains in the root zone in the lesser watered areas. Therefore, the "overall application efficiency" should approach 0.9 EU.

## HYDRAULIC DESIGN CONSIDERATIONS

The pipe which supplies water to the individual emitters is called the lateral, and the pipe which serves a number of laterals is the manifold, as shown in Fig. 2.

The important functions of water filtration, volume control,automatic control, fertilizer injection and pressure or flow regulation, are often grouped together in trickle irrigation. The equipment that collectively performs these functions is called the "control head." Since emitter discharge is very sensitive to pressure fluctuations, aging, temperature, plugging and slow clogging by particles or deposits, it is recommended that the system controls be either volumetric or incorporate volumetric monitoring with time sequencing.

The hydraulic design considerations which follow are based on the current common practice of using a constant emitter spacing and one size of emitters. Although a higher degree of uniformity could be achieved by varying the emitter size along the lateral as suggested by Meyers and Bucks (1972) this practice is not common due to design, installation, and maintenance complications.

### Laterals

The diameter of the typical lateral pipe is less than 25 mm (1.0 in.). The

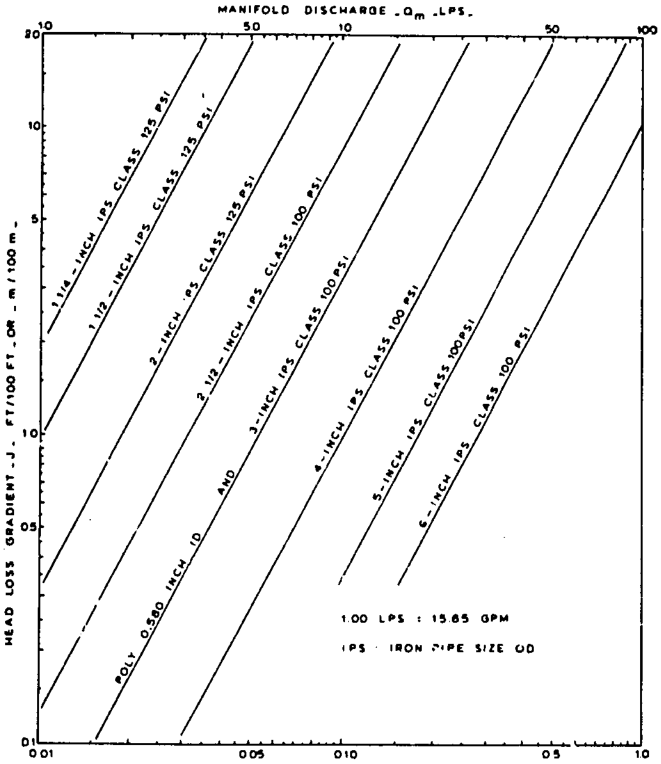

FIG. 3 Head loss gradient in lateral hose and manifold pipe based on Hazen-Williams formula with C = 150.

pipe is usually flexible hose (soft polyethylene or PVC) laid on the ground; however, sometimes buried rigid PVC with the emitters on risers extending above ground is used.

The lateral head loss based on the Hazen-Williams equation can be calculated by:

$$\Delta H_l = K'' \cdot F \cdot L \cdot (D)^{-4.87} \cdot \left(\frac{Q_l}{C}\right)^{1.852} \quad \ldots\ldots\ldots\ldots\ldots\ldots [9]$$

in which

$\Delta H_l$ is the pressure head loss in the lateral, m (ft)

K″ is a proportionately constant equal to $1.21 \times 10^{10}$ for Metric Units and 10.5 for English Units

F is a reduction coefficient to compensate for discharge from openings along the pipe

L is the pipe length, m (ft)

D is the inside diameter of the pipe, mm (in.)

$Q_l$ is the flow rate in the lateral, lps (gmp)

C is the Hazen-Williams friction coefficient for the pipe material

For plastic pipe C = 150 is normally used. However, Hanson (1973) found laterals with emitters spaced at 1.52 m (5 ft) intervals had equivalent C values between 98 and 136 (with the lowest values associated with the inline or bayonet type emitter connections to the lateral pipe). Most laterals have more than 20 emitters and for all practical purpose F = 0.36 can be used.

Instead of using equation [9], log-log plots of test data similar to Fig. 3 based on 100 m (ft) lengths of pipe without outlets are often employed. The friction loss, J, in m/100 m (ft/100 ft) can be used to simplify equation 9 as:

$$\Delta H_l = \frac{F \cdot L \cdot J}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots [10]$$

To adjust for C values of less than the C = 150 used in Fig. 3 multiply J by 2.11 for C = 100, 1.78 for C = 110, 1.51 for C = 120, 1.30 for C = 130 and 1.14 for C = 140.

The total lateral discharge is equal to the average emitter discharge, $q_a$, times the number of emitters on the lateral, $n_e$.

To compute EU by equation [7] the minimum discharge ratio, $q_n/q_a$, must be estimated. A theoretical analysis was made and verified by field testing to determine minimum discharge ratios. For single-sized pipe laterals on level ground the ratio is approximately:

$$\frac{q_n}{q_a} = 1.0 - 0.22 \cdot x \cdot H_R \quad \ldots\ldots\ldots\ldots\ldots\ldots [11]$$

in which

$H_R$ is the head loss ratio $\Delta H_l/H_a$

$H_a$ is the pressure head which will produce the average emitter discharge by equation [6], m (ft)

For multiple-sized (tapered) laterals the ratio may be approximated by:

$$\frac{q_n}{q_a} = 1.0 - 0.38 \cdot x \cdot H_R \quad \ldots\ldots\ldots\ldots\ldots\ldots [12]$$

An approximate equation was also developed for estimating the maximum discharge ratio, $q_x/q_a$. For a single or multiple-sized (tapered) lateral on level ground the ratio is:

$$\frac{q_x}{q_a} = 1.0 + 0.58 \cdot x \cdot H_R \quad \ldots\ldots\ldots\ldots\ldots\ldots [13]$$

in which

$q_x$ is the maximum emitter discharge, lph (gph)

It is important to determine $q_x$ to gain insight into potential runoff problems at the head of laterals especially when high values of $H_R$ are used.

In a single-sized lateral line the emitter having the average discharge (and pressure head) is located approximately 40 percent of the lateral length from the inlet end. For laterals on uniform slopes the lateral inlet pressure head, $H_l$, may be approximated by:

$$H_l = H_a + 0.77 \cdot \Delta H_l \pm \frac{\Delta EL}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [14]$$

in which

$\Delta EL$ is the difference in elevation between the ends of the lateral, m (ft)

Where the system design is based on the head loss, the minimum emitter discharge, $q_n$, and the minimum pressure head, $H_n$, for a single sized lateral:

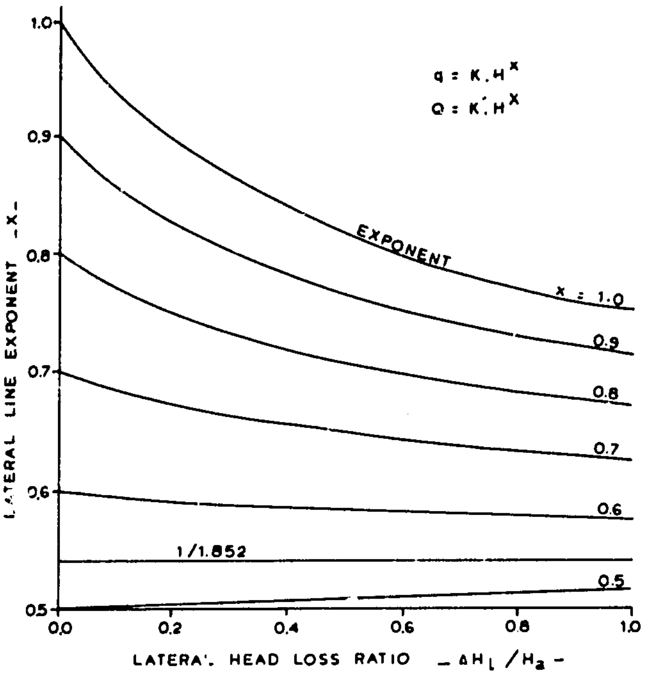

FIG. 4 Lateral line exponents as a function of lateral head loss for tricklers having various exponents.

$$H_l = H_n + \Delta H \pm \Delta EL \quad \ldots\ldots\ldots\ldots [15]$$

For fully tapered lateral lines (tapered to produce uniform friction slopes) the 0.77 in equation [14] approaches 0.50.

## Manifolds

The design of the manifold is similar to the lateral design. However, the spacing between outlets is greater and larger flow rates are involved. Pressure or flow regulation is usually provided at the head of the manifold. The manifold lengths are determined by the number of laterals served and the distance between laterals. The selection of the number of laterals depends on the following considerations: (a) keeping within the desired pressure differences; (b) economic trade-offs between the diameters of the laterals and the manifold; (c) the method of irrigation management; and (d) the degree of automation.

The maximum pressure head difference usually occurs between the pressure regulator at the inlet of each manifold and the furthest and/or highest emitter. Karmeli and Peri (1972) found the most economic division of the allowable head loss is approximately 55 percent in the lateral and 45 percent in the manifold.

The water supply to the manifold should be situated so the flow is split in the most opportune manner. In a flat area, the connection should be placed in the middle of the manifold line to split the flow evenly. On a sloping area, it should be placed so the uphill portion is shorter than the downhill portion to achieve equal pressures. (The same concept should be employed for the lateral layout.)

The hydraulic characteristics of manifolds also follows equations [9] through [15] presented for laterals by treating the laterals as "large emitters" on the manifold. However, from a theoretical analysis which was verified in the field, it was found that the lateral pipe friction modifies the emitter discharge exponent, x, from equation [6] as shown in Fig. 4. This modification is very significant for laminar flow emitters; however, for the more common emitters, having exponents $x < 0.8$ and moderate lateral friction losses the modification is relatively unimportant.

## Sub-Units

The general layout of a typical trickle irrigation system is shown in Fig. 2. Manifolds with the connected laterals form the sub-units into which the pipe system is divided. The minimum number and maximum size of sub-units depend on: the field geometry, the application rate, the desired depth of application, the irrigation interval, the maximum available system capacity, and the desired operating schedule.

In order to minimize mainline costs, it is often advantageous to use more than the minimum number of sub-units. This allows the flow to be split, thus reducing the mainline pipe sizes. Furthermore, small sub-units require small laterals and manifolds and the elevation differentials within them is reduced.

In some cases, the size of the sub-units is fixed by physical factors that cannot be changed by the designer. These factors include field dimensions and shapes, natural barriers, topography, etc. However, in most cases, there is some flexability in the layout. In general for optimum economics, the manifold lengths should be 1.5 to 3.0 times the lateral line lengths and the friction head losses should be about equally distributed between the manifold and laterals.

The minimum and maximum discharge ratios for the sub-unit can be estimated by using the head loss ratio for the entire sub-unit in equations [11], [12] and [13].

## SYSTEM DESIGN

A system was designed for the layout shown in Fig. 2 assuming a level field 396.0 m (1300 ft) wide by 400.0 m (1320 ft) long and using the following input considerations.

1 Well discharge of 9.16 lps (145 gpm) with a moderately saline water.

2 Medium textured soil over 2.0 m (6.6 ft) deep, with a moisture holding capacity of approximately 160 mm/m (2.0 in./ft) and 30 percent soil moisture depletion between irrigation ($y = 0.3$).

3 Average transpiration rate T = 4.0 mm/day (0.16 in./day).

4 Citrus trees with a 4.0 m (13.1 ft) by 6.0 m (19.7 ft) spacing and a 1.0 m (3.3 ft) root depth.

5 The average discharge of test samples of emitters when operated at a standard head of 10.0 m (32.8 ft) at 20 C (68 F) was 4.0 lph (1.06 pgh). The emitter discharge exponent $x = 0.8$. The minimum discharge in the low 1/4 of the samples was found to be 3.7 lph (0.98 pgh) at standard conditions.

6 Laterals of 0.58 in. polyethylene hose and manifolds with 2 1/2-in. class 100 PVC pipe. For the manifolds C = 150. For the laterals C = 120 due to the roughness caused by the emitter connections.

7 Current irrigation practice is to apply 50 mm (2.0 in.) by undertree sprinkling on a 10-day cycle.

From Table 1, the spacing between emitters on the lateral was selected as 1.0 m (3.3 ft). With one lateral for each tree row spaced at 6.0 m (19.7 ft) P = 20 percent which is considerably less than the recommended 33 percent. Therefore, two laterals per tree row should be used which gives P = 40 percent. The laterals should be laid 0.6 m (2.0 ft) to either side of each tree row. This gives the widest spacing, 1.2 m (4.0 ft), which will wet 100 percent of the area along the tree rows. (Complete wetting in this area is necessary to reduce the hazards of salts accumulating around the wetted volume underlying each emitter.) However, there will still be a 6.0 m – 1.2 m = 4.8 m (15.8 ft) dry strip between the rows.

With P = 40 percent a 4-day trickle irrigation interval is comparable to the current practice of using a 10-day sprinkler cycle, equation [1]. Furthermore, the eight sub-units in Fig. 2 can be covered in four days with $I_t$ = 12.0 hr. The design rational is to have the least watered trees sufficiently irrigated. From equation [2] with an assumed EU = 95 percent, the gross (or average) depth of application $I_d$ = 18.7 mm (0.74 in.).

From equation [3] the average emitter discharge, $q_a$ = 4.7 lph (1.23 gph) and by equation [6] (or a plot of q vs. H) the pressure head which gives $q_a$ is $H_a$ = 12.2 m (40.1 ft). For the 100-meter (328-ft) long laterals with 100 emitters the lateral discharge is $Q_l$ = 0.130 lps (2.06 gpm). By equation [10] using F = 0.36, J = 5.3m/100m (ft/100 ft) from Fig. 3 and correcting for C = 120 the friction head loss in the lateral is $\Delta H_l$ = 2.9 m (9.4 ft).

In Fig. 2 each of the eight manifolds is a complete operating unit. The 99 m long (325 ft) manifolds cross 16.5 of the 6 m (19.7 ft) tree rows. Each tree row is supplied by two laterals and since the manifolds run through the middle of the unit and supply both sides, there are 66 laterals operating simultaneously, and the manifold flow rate is $Q_m$ = 8.58 lps (136 pgm). By equation 10 with J = 6.5 m/100 m (ft/100 ft) form Fig. 3, the friction head loss in the manifold is $\Delta H_m$ = 2.3 m (7.7 ft).

Adding the lateral and manifold head losses, the head loss ratio for the subunit is:

$$(H_R)_s = \frac{\Delta H_l + \Delta H_m}{H_a} = 0.43$$

Since both the lateral and manifold use single diameters of pipe the minimum discharge ratio can be approximated by equation [11] as:

$$\frac{q_n}{q_a} = 1.0 - 0.22 \times 0.8 \times 0.43 = 0.92$$

The EU can now be computed by equation [7] as:

$$EU = 100\,(1.0 - 0.35 + 0.35\,\frac{3.7}{4.0})\,0.92$$

$$= 90 \text{ percent.}$$

Since this EU value is considerably lower than the originally assumed value, i.e., 90 vs. 95 percent, the computations should be re-done. Beginning with an assumed EU = 90 percent, the computations can be made: $q_a$ = 4.9 lph (1.30 pgh) $H_a$ = 13.0 m (42.7 ft); $\Delta H_l$ = 3.2 m (10.3 ft); and $\Delta H_m$ = 2.7 m (8.7 ft). Therefore, $(H_R)_s$ = 0.45 and by equation [11] the minimum discharge ratio is still 0.92 and by equation [7], EU = 90 percent which is the same as the new assumed value. The system capacity is the same as the manifold flow rate which is $Q_m$ = 9.05 lps (144 gpm) and by equation [15], the manifold inlet pressure head is 17.5 m (57.5 ft).

To complete the design the mainline pipe sizer should be selected and the friction head losses in the mainlines, values and fillers should be taken into account.

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