Lecture 19

Water Requirements in Trickle Irrigation

I. Trickle Irrigation Requirements

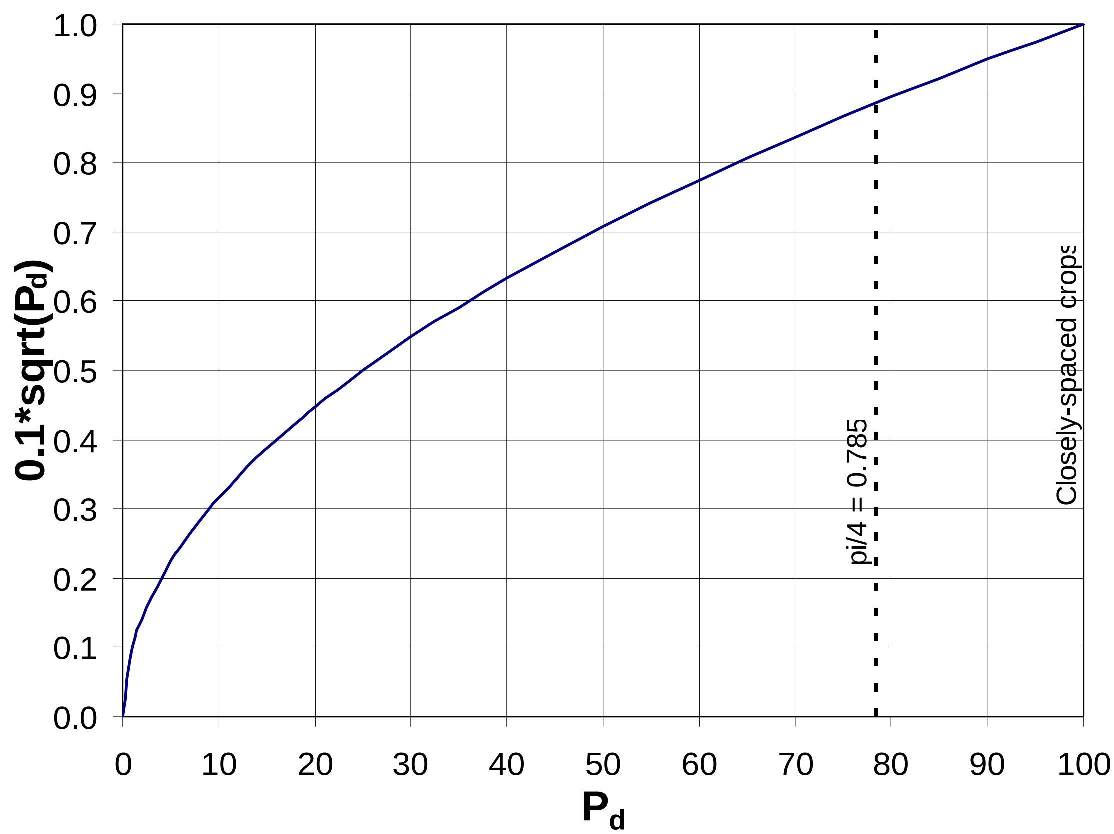
1. Daily Use Rate

- The daily transpiration rate under a trickle system is based on U_d and the percent area shaded (covered) by the plant leaves. Eq. 19.9:

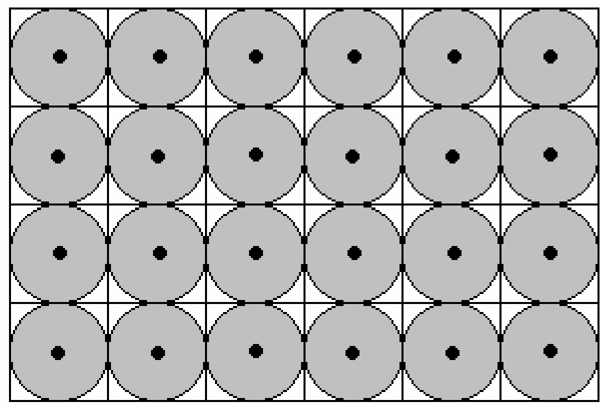
$$T_d = 0.1\,U_d\sqrt{P_d} \tag{349}$$

where U_d is as previously defined and P_d is the percent (0 to 100) shaded area when the sun is overhead (or most nearly overhead, in temperate zones)

- Note that when $P_d = 0$, $T_d = 0$
- Note that when $P_d = 100\%$, $T_d = U_d$
- Note that T_d is called "transpiration," but it really includes evaporation too



- The reduction from U_d is justified by considering the typical reduction in wet soil evaporation with trickle irrigation
- The maximum P_d for a mature orchard is usually about $\pi/4$ (0.785), which is the ratio of the area of a square and the circle it encloses:



- Tree spacing is generally such that the trees do not compete for sunlight, and the area of each tree is equal to the square of the spacing between them (for a square spacing)

2. Seasonal Water Use

- This is calculated as for the peak daily use in Eq. 19.9:

$$T_s = 0.1\,U\sqrt{P_d} \tag{350}$$

3. Seasonal Water Deficit

- To determine the seasonal water deficit, to be supplied from the irrigation system, consider effective rainfall and initial soil moisture, in addition to percent shaded area:

$$D_n = \left(U - P_e - M_s\right)\left(0.1\sqrt{P_d}\right) \tag{351}$$

where U is used instead of T_s because P_e (effective precipitation) and M_s (initial soil water content) are over the entire surface area

4. Net Depth per Irrigation

- This is the same as for sprinkle irrigation (or surface irrigation), but with an adjustment for percent wetted area. Eq. 19.12 is:

$$d_x = \frac{MAD}{100}\frac{P_w}{100}W_a Z \quad (352)$$

- Essentially, the same net volume of water is applied as with other irrigation methods, but on a smaller area of the surface (and subsurface)
- Then, the maximum irrigation interval is:

$$f_x = \frac{d_x}{T_d} \quad (353)$$

and f' (round down from f_x to get whole number of days) is less than or equal to f_x, but often assumed to be 1 day for trickle system design purposes. Then,

$$d_n = T_d f' \quad (354)$$

II. Gross Irrigation Requirements

- The transmission ratio (peak use period) takes into account the two-dimensional infiltration pattern, or bulb shape, under trickle irrigation
- Even if the net depth is exactly right, there will almost always be some deep percolation (more than that which may be required for leaching purposes)
- The transmission ratio, T_r, is used as a factor to increase required gross application depth from d_n
- The transmission ratio is equivalent to the inverse of the distribution efficiency, DE_{pa}, as given in Chapter 6 of the textbook
- The transmission ratio is lower for heavy-textured ("fine") soils because there is more lateral water movement in the soil, and the bulb shape is flatter; thus, potentially less deep percolation losses
- Table 19.3 gives approximate values of T_r for different soil textures and root depths ($1.0 < T_r < 1.1$) – obtain more representative values from the field, if possible
- Then, for $LR_t < 0.1$, or $T_r > 1/(1-LR_t)$, Eq. 19.15a:

$$d = 100\left(\frac{d_n T_r}{EU}\right) \quad (355)$$

where EU is the *emission uniformity* (%), which can be taken as a field-measured value for existing trickle systems, or as an assumed design value

- EU takes into account pressure variations due to friction loss and elevation change, and the manufacturer's variability in emitter production
- If f' = 1 day, then d_n can be replaced by T_d in Eq. 19.15a

- For $LR_t > 0.1$, or $T_r < 1/(1-LR_t)$, Eq. 19.15c:

$$d = \frac{100\, d_n}{EU\left(1.0 - LR_t\right)} \tag{356}$$

- The difference in the above two equations is in whether LR_t or T_r dominates
- If one dominates, it is assumed that the other is “taken care of” automatically

Gross Volume of Water per Plant per Day

- Equation 19.16:

$$G = \frac{d}{f'} S_p S_r \tag{357}$$

with d in mm; S_p and S_r in m; and G in liters/day

- Note that millimeters multiplied by square meters equals liters
- This equation does not use P_w because d is calculated for the entire surface area, and each plant occupies an S_pS_r area
- Other versions of this equation are given in the textbook for gross seasonal volume of water to apply

Required Application Time During Peak-Use Period

- Equation 20.11:

$$T_a = \frac{G}{N_p q_a} \tag{358}$$

where T_a is the required application (irrigation) time during the peak-use period (hr/day), with G in litres/day, and q_a in litres/hr

III. Coefficient of Variation

- This is a statistical index to quantify discharge variations in emitters, at the same operating pressure, due to differences in the emitter construction
- The coefficient of variation is important in trickle system design and evaluation because it can significantly affect the adequacy of the system to irrigate the least watered areas of a field
- For statistical significance, there should be at least 50 measurements of discharge from 50 individual emitters of the same design and manufacture

$$\nu = \frac{\sqrt{\sum_{i=1}^{n}\left(q_i^2\right) - \frac{1}{n}\left(\sum_{i=1}^{n} q_i\right)^2}}{\sqrt{n-1}\left(\frac{1}{n}\sum_{i=1}^{n} q_i\right)} = \frac{\sigma}{q_{avg}} \tag{359}$$

or,

$$\nu = \frac{1}{q_{avg}}\sqrt{\frac{\sum_{i=1}^{n}\left(q_i - q_{avg}\right)^2}{n-1}} \tag{360}$$

where n is the number of samples; σ is the standard deviation; q_i are the individual discharge values; and q_{avg} is the mean discharge value of all samples

- Standard classifications as to the interpretation of ν have been developed (Soloman 1979):

Classification	**Drip & Spray Emitters**	**Line-Source Tubing**
Excellent	$\nu < 0.05$	$\nu < 0.1$
Average	$0.05 < \nu < 0.07$	$0.1 < \nu < 0.2$
Marginal	$0.07 < \nu < 0.11$	---
Poor	$0.11 < \nu < 0.15$	$0.2 < \nu < 0.3$
Unacceptable	$0.15 < \nu$	$0.3 < \nu$

- For a large sample (n > 50) the data will usually be normally distributed (symmetrical “bell-shaped” curve) and,

68% of the discharge values are within............... $(1\pm\nu)q_{avg}$
95% of the discharge values are within............. $(1\pm 2\nu)q_{avg}$
99.75% of the discharge values are within........ $(1\pm 3\nu)q_{avg}$

IV. System Coefficient of Variation

- The system coefficient of variation takes into account the probability that the use of more than one emitter per plant will cause an effective decrease in the combined discharge variability per plant due to differences in the emitters (not due to pressure variability due to pipe friction losses and elevation changes)
- On the average, discharge variability due to manufacturer tolerances will tend to balance out with more emitters per plant

$$\nu_s = \frac{\nu}{\sqrt{N_p'}} \qquad (361)$$

where N_p' is the minimum number of emitters from which each plant receives water (see page 493 of the textbook)

- For a single line of laterals per row of plants,

$$L_w = w + (N-1)S_e \qquad (362)$$

where L_w is the length of the wetted strip; and N is the number of emitters (assumed to be evenly spaced). Then,

$$N = 1 + \left(\frac{L_w - w}{S_e}\right) \qquad (363)$$

or,

$$N_p' \approx 1 + \left(\frac{S_p - w}{S_e}\right) \qquad (364)$$

V. Design Emission Uniformity

- In new system designs it is not possible to go out to the field to measure the EU' (Eq. 17.2) – a different approach is required to estimate EU
- The design EU is defined as (Eq. 20.13):

$$EU = 100\left(1 - 1.27\,\nu_s\right)\frac{q_n}{q_a} \qquad (365)$$

where q_n is the minimum emitter discharge rate in the system, corresponding to the emitter with the lowest pressure; and q_a is the average emitter discharge rate in the system, corresponding to the location of average pressure in the system

- q_n and q_a are calculated (not measured) in new system designs by knowing the topography, system layout, pipe sizes, and Q_s
- Note that the value in parenthesis in Eq. 20.13 corresponds to the low one-quarter emitter discharge

- EU gives a lower (more conservative) value than EU', and the equation is biased toward lower discharges to help ensure that the least watered areas will receive an adequate application
- Graphical interpretations of these relationships are given in Figs. 20.9 and 20.10

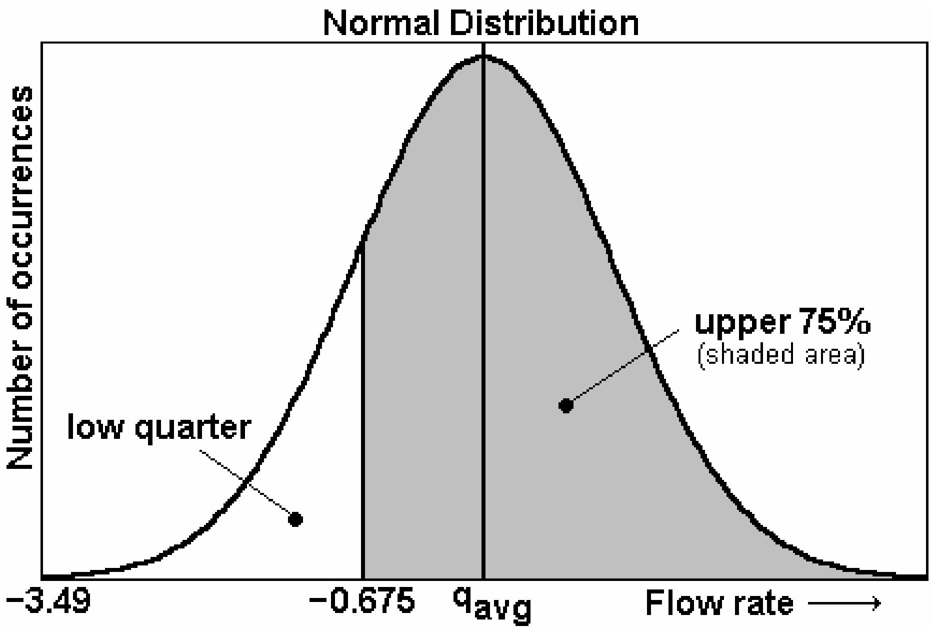
VI. Average of the low ¼

- Note that the inclusion percentages for 1, 2 and 3 standard deviations correspond to any normally distributed data
- Note also that $\nu \, q_{avg} = \sigma$
- The textbook says that for a normal distribution, the average flow rate of the low one-quarter of measured q samples is approximately $(1 - 1.27\,\nu)q_{avg}$
- The 1.27 coefficient can be determined from the equation for the normal distribution and tabular values of the area under the curve
- The equation is:

$$\text{occurrences} = \frac{e^{-\frac{1}{2}\left(\frac{q - q_{avg}}{\sigma}\right)^2}}{\sigma\sqrt{2\pi}} \tag{366}$$

- To use the tabular values of area under the curve (e.g. from a statistics book), it is necessary to use $q_{avg} = 0$ and $\sigma = 1$ (the alternative is to integrate the above equation yourself, which can also be done)
- Actually, q_{avg} never equals zero, but for the determination of the 1.27 coefficient it will not matter
- In the tables, for area = **75%**, the abscissa value (q, in our case) is about 0.675
- The same tables usually go up to a maximum abscissa of 3.49 (recall that 99.75% of the values are within $\pm 3\sigma$, so 3.49 is usually far enough)
- Anyway, for 3.49, the area is about **99.98%**, and that is from $-\infty$ to +3.49 (for $q_{avg} = 0$ and $\sigma = 1$), for the *high* ¼
- For the *low* ¼, take the opposite, changing to q = -0.675 and q = -3.49
- In this case ($q_{avg} = 0$ and $\sigma = 1$), the equation reduces to:

$$\text{occurrences} = \frac{e^{-0.5q^2}}{\sqrt{2\pi}} \tag{367}$$



- For q = 0.675, occurrences = 0.31766718
- For q = 3.49, occurrences = 0.0.00090372
- Finally,

$$\frac{0.31766718 - 0.00090372}{0.9998 - 0.7500} = 1.268 \tag{368}$$

- Therefore, $(1 - 1.268\ \nu)q_{avg}$ is the average of the lowest 25% of measured discharge values, for any given values of ν & q_{avg}, and given normally-distributed data

V. System Capacity

- The system capacity of a trickle system can be calculated by Eq. 20.15:

$$Q_s = 2.78 \frac{A}{N_s} \frac{N_p q_a}{S_p S_r} \tag{369}$$

where N_s is the number of stations (sets); and A is the <u>total</u> net irrigated area. Or,

$$Q_s = 2.78 \frac{A}{N_s} \frac{q_a}{S_e S_l} \tag{370}$$

where the coefficient "2.78" is for Q_s in lps; A in ha; q_a in lph; and S_p, S_r, S_e, and S_l in m (10,000 m^2/ha divided by 3,600 s/hr = 2.78)

VI. Operating Hours per Season

- The approximate number of hours the system must operate per irrigation season (or per year, in many cases) is equal to the required gross seasonal application volume, divided by the system flow rate:

$$O_t = K \frac{V_s}{Q_s} \quad (371)$$

where K = 2,778 for V_s in ha-m; and Q_s in lps; and V_s is gross seasonal volume of irrigation water