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Evaluation of drip irrigation: Selection of emitters and hydraulic characterization of trapezoidal units

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ABSTRACT

The primary focus of this paper is on the estimation of potential application efficiency in drip irrigation units. For this purpose, a new procedure for field evaluation of water distribution in trapezoidal drip irrigation units is proposed. It consists of measurement of flow discharged by a sample of emitters whose location in the unit is selected to assure that the sample has the same mean flow and the same flow variation as all the drippers in the unit. Several emitters at each location are considered to separate the variations due to manufacture and wear from those due to differences in pressure. As an additional aim, a simplified hydraulic analysis is proposed based on known expressions to characterize hydraulically the irrigation unit and also to separate the causes conditioning irrigation performance. This analysis requires data of the unit (lengths, diameters, spacings and elevations) and of the emitters (discharge equation exponent). In addition, variables such as inlet pressure head, total emitter flow, pressure heads at the downstream end of the submain and laterals, are also to be measured. These measurements are required to calibrate unknown parameters (emitter discharge coefficient, equivalent lengths of emitter or lateral insertion) to estimate their variation due to wear. Field evaluations were performance on rectangular and trapezoidal units. Emitters were selected following the proposed method as well as the one developed by Merriam and Keller [Merriam, J.L., Keller, J., 1978. Farm Irrigation System Evaluation: A Guide for Management. Utah State University]. Experimental results confirm the theoretical analysis. Finally, for practical purposes, an index and a unitary distribution curve of emitter discharge during irrigation are proposed to characterize the performance of level irrigation units, independently of their operating inlet pressure.

1. Introduction

The method of evaluation proposed by Merriam and Keller (1978), adopted by FAO (1986), is based on the discharge measurements of a sample of emitters. This sample is selected from four laterals located at the inlet, at a third and two-thirds of the length of the submain and at its downstream end. Four pairs of emitters are selected along each lateral, located at the inlet, at a third and two-thirds of the length of the lateral and at its downstream end. Aspects of this procedure, which can be improved deserve some comments. On the one hand, the selected locations represent, from the viewpoint of mathematical probability, neither the mean flow of all the unit emitters nor, above all, their variance. On the other hand, no reason is given for the recommendation on averaging out each pair's discharge. This can be justified from a statistical viewpoint if more uniform results are desired such as in the case of units with two emitters per plant or other special circumstances.

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Likewise, as each pair of emitters has approximately the same pressure, the difference between the two can serve to evaluate the variation due to manufacture and wear.

Bralts and Kesner (1983), Bralts and Edwards (1986), Bralts et al. (1987) and ASAE (1998) presented an alternative method, with a statistical approach: 18 points or locations were selected at random, to measure both their discharge and their pressure. From an operational viewpoint, random selection of emitters is more laborious than the above approach, and measurement of pressures at disperse points is not always a practical issue. Additionally, the extreme locations in the lateral and submain suggested by Merriam and Keller (1978) provide useful information on head losses in laterals and submain, and it seems unreasonable to disregard their potential contribution to the hydraulic analysis of the unit. A recent approach by Burt (2004) includes a practical methodology for field evaluation.

Hydraulic-statistical analysis of drip irrigation units is based on the works of Wu and Gitlin (1975), Karmeli and Keller (1975), Bralts et al. (1987), and Kang and Nishiyama (1996), Valiantzas (1998). Hydraulic analysis of Juana et al. (2002a,b, 2004, 2005) can be considered as a more specific application. The ideas from the above references underlying this paper are stated below.

The flow discharge q from an emitter working at a pressure head h can be written as:

$$q = (1 + u\,\mathrm{CV_m})kh^x = (1 + u\,\mathrm{CV_m})q_h \qquad (1)$$

Eq. (1) makes a distinction between two causes of variation determining differences in flow between emitters: a hydraulic variation and a random variation. The first one can be explained by a hydraulic analysis that determines the different emitter pressure heads, and the second one is due to causes not analyzed in the previous variation, such as manufacture and wear, and even small differences of elevation.

Parameters k and x determine the emitter discharge equation $q_h = kh^x$, which yields the flow discharge q from an emitter under pressure head h. Each emitter also has the unknown random term $uq_h\mathrm{CV_m}$, which can be assumed to obey a normal distribution whose mean is zero and standard deviation, $\sigma = q_h\mathrm{CV_m}$, where $\mathrm{CV_m}$ is the coefficient of variation that characterizes the variation of the emitters' manufacture. The random variable $u = (q - q_h)/\sigma_q$ belongs to the standardized normal distribution.

The value u of each emitter can be generated at random to simulate flow of any drip irrigation unit. Having introduced the generated set of values of u, the computer simulation model yields flow distribution of all emitters. Slight differences are observed between different generated sets. They are negligible, because many emitters are considered.

The discharge distribution function q_h can be considered together with the flow distribution function q. If $\mathrm{CV_m}$ is known, the expected value of the last one can be obtained from the first. One benefit of this procedure is that it yields a single result.

A precise determination of the random variation needs to consider enough points, but their location is, in principle, indifferent. To characterize the hydraulic variation, knowledge of the characteristics of the unit (as diameters, lengths, heights, emitter equation, spacings, and local head losses) and also inlet pressure is likely to suffice. Apart from inlet pressure, however, it is advisable to measure total emitter flow and pressure at the downstream end of the submain and several laterals. It will be used either to check or to calibrate any hydraulic parameters (such as local head losses in insertions of emitters and laterals) that are frequently not known or may have changed (such as emitter parameters). Using hydraulic data, the head loss equations can quite reliably ascertain the piezometric distribution, as well as, by subtracting the elevation at each point from this distribution, the pressure profile in both the laterals and the submain. This can be changed to the hydraulic flow distribution through the emitter flow equation.

Hydraulic variation would determine the final distribution if there were no random variation. In general, one and other cause of variation lead to independent differences in flow. The statistical analysis can relate $\mathrm{CV_m}$ to the coefficients of variation of the hydraulic distribution, CV_{qh}, and global distribution, CV, as follows:

$$\mathrm{CV} \cong \sqrt{\mathrm{CV_m^2} + \mathrm{CV}_{qh}^2} \cong \sqrt{\mathrm{CV_m^2} + x^2\,\mathrm{CV}_h^2} \qquad (2)$$

The pressure distribution and its coefficient of variation CV_h can be used to further generalize the analysis, without introducing the exponent x until the end. The approximate relationship between the two is: $\mathrm{CV}_{qh} \cong x\mathrm{CV}_h$.

A unit is composed of laterals and, consequently, the final distribution is the sum of their distributions. From a hydraulic viewpoint, the distribution of any lateral is determined by ascertaining its inlet head h_0. But different laterals may have identical distributions. Hence, the pressure distributions of any two laterals, laid on uniform slopes (not necessarily equal) will be identical in practice, if their inlet head h_0, their head losses hf_L and the difference in elevation between their ends $\mathrm{SL_L} = S_0L$ are the same. The pressure head h at a point located at a distance from the inlet given by the fraction f of length L would be (Wu and Gitlin, 1975):

$$\begin{aligned} h &= h_0 - hf_\mathrm{L}(1 - (1-f)^{m+1}) + \mathrm{SL_L}f \\ &= h_0 - hf_\mathrm{L}(1 - f'^{m+1}) + \mathrm{SL_L}(1 - f') \\ &= h_1 + hf_\mathrm{L}f'^{m+1} - \mathrm{SL_L}f' \end{aligned} \qquad (3)$$

The value m is the flow exponent in the friction loss formula. Additionally, the fraction from the downstream end $f' = 1 - f$ is sometimes more efficient for the description of the problem, in which case the pressure head at the downstream end h_1 can also be used.

Although Eq. (3) was developed assuming a continuous and steady discharge, in practice it can be used for many irrigation systems. Juana et al. (2004) showed that the pressure head distribution in that equation has the following mean and variance:

$$\begin{aligned} \bar{h} &= \int_0^1 h\,\mathrm{d}f = \int_0^1 h\,\mathrm{d}f' = h_0 - \frac{m+1}{m+2}hf_\mathrm{L} + \frac{1}{2}\mathrm{SL_L} \\ &= h_1 + \frac{1}{m+2}hf_\mathrm{L} - \frac{1}{2}\mathrm{SL_L} \end{aligned} \qquad (4)$$

$$\begin{aligned} \sigma_h^2 &= \int_0^1 (h - \bar{h})^2\,\mathrm{d}f \\ &= \frac{1}{2m+3}\left(\frac{m+1}{m+2}\right)^2 hf_\mathrm{L}^2 + \frac{1}{12}\mathrm{SL_L^2} - \frac{1}{m+3}\frac{m+1}{m+2}hf_\mathrm{L}\mathrm{SL_L} \end{aligned} \qquad (5)$$