Agricultural Water Management 191 (2017) 173–183

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Design of concave and convex paired sloped drip laterals

Giorgio Baiamonte*

Dipartimento di Scienze Agrarie, Alimentari e Forestali, Università degli Studi di Palermo, viale delle Scienze, 13, Edificio 4, Ingresso E, 90128 Palermo, Italy

ARTICLE INFO

Article history:
Received 20 February 2017
Received in revised form 19 June 2017
Accepted 20 June 2017
Available online 26 June 2017

Key-words:
Concave/Convex drip laterals
Microirrigation
Paired laterals
Sloped laterals
Optimal design

ABSTRACT

Properly designed microirrigation plants allow water use efficiency to be optimized and quite high values of emission uniformity to be obtained in the field. Disposing paired laterals so that two distribution pipes extend in opposite directions from a common manifold contributes to provide more uniform pressure to all laterals in thesystem. Towards this end, an analytical procedure to optimize the uniform pressure when designing paired drip laterals on uniform slopes has recently been proposed, based on the assumption that the variations of the emitters' flow rate along the lateral and the local losses due to the emitters' insertions could be neglected. More recently, an easy method to fix the best position of the manifold (BMP) equal to 24% of the optimal lateral length was introduced. The mentioned procedures are valid under the assumption that the paired laterals are laid on straight slopes; however, real microirrigation units rarely follow an even gradient, whose topography is characterized by equally spaced contour lines. The objective of this study was to extend the analytical procedure to optimally design paired sloped drip laterals to the case in which the shape of the field is concave or convex. Results showed that the position where the minimum occurs in the downhill laterals and the optimal pressure head distribution lines vary with the shape of the drip lateral and that the easy method to fix the BMP = 24% cannot be applied for paired sloped laterals laid on complex topography. Accordingly, a BMP relationship as a function of the curvature parameter of the lateral profile is proposed. Moreover, it is demonstrated that the optimal length of the paired lateral has achieved its minimum value, for a particular concave shape, at what corresponds to a paired lateral length 6.6% lower than that for straight paired laterals. By varying the curvature parameter, and for an inside diameter value equal to 17.6 mm, some practical solutions are presented. The proposed procedure was successfully compared with that derived by the step-by-step exact procedure.

1. Introduction

Drip irrigation, also called trickle irrigation, saves water by allowing water to drip slowly to plants' roots. A network of valves, pipes, tubing, and emitters deliver the water directly to the base of the plants, either on the soil surface or directly near the root zone. Thus, drip irrigation is considered a convenient and effective means to supply water directly along individual crop rows and to maintain the current levels of crop production; as a consequence, microirrigation can reduce water requirements and operation costs, in respect to other irrigation systems (Keller and Bliesner 1990) and evapotranspiration losses (Rallo et al., 2014). Microirrigation could require high initial investment cost for the equipment, which may be higher than that of traditional methods. However, in the long term, costs can be reduced through a substantial reduction in labor cost. In fact, water only needs to be regulated, which usually can be done via automatically timed devices.

Many studies focused on finding easy methods to their design, when laterals are laid on horizontal fields. Wu et al. (2010) developed a simple gravity-fed drip irrigation system design procedure for low-cost, single-manifold subunits with multiple pressure sections, by assuming that the laterals are laid along elevation contours so that the ground slope along the lateral is equal to zero. Moreover, it required iterative calculation process for determining the number of emitters per lateral and the lateral length. Under the assumption of the Darcy–Weisbach friction factor, Sadeghi et al. (2015) suggested a technique simple to use that not requires iteration, allows determining the maximum lateral length for horizontal laterals, and providing errors that generally does not exceed 1.1%.

Design criteria were also introduced for straight laterals laid on uniform slopes (Kang and Nishiyama, 1996; Jiang and Kang, 2010; Wu, 1975; Wu and Gitlin, 1975; Wu et al., 1986; Keshtgar et al., 2013). Keshtgar et al. (2013), in particular, took emitter uniformity to extremes for a drip irrigation system, presenting a design

* Corresponding author.
E-mail address: giorgio.baiamonte@gmail.com

http://dx.doi.org/10.1016/j.agwat.2017.06.015
0378-3774/

List of symbols

a [−] Shape parameter of the Fréchet EV2 CDF
b [−] Scale parameter of the Fréchet EV2 CDF
D [m] Internal pipe diameter
g [m^2/s] Acceleration of gravity
h_i [m] Pressure head of the generic emitter i
$h_{min}^{(u)}$[m] Minimum pressure head in the uphill lateral
$h_{max}^{(u)}$ [m] Maximum pressure head at the manifold connection
$h_{min}^{(d)}$ [m] Minimum pressure head in the downhill lateral
$h_{max}^{(d)}$ [m] Maximum pressure head at the downhill end of the lateral
h_n [m] Nominal emitter's pressure head
h_{*n} [m] Dimensionless emitter's pressure head
H(.,.) Generalized harmonic number
i [−] Generic emitter of the lateral counted from the manifold connection
i_{min} [−] Number of emitters in downhill lateral, from the manifold connection to the section with minimum pressure head
K [−] Friction loss parameter
L_{opt} [m] Optimal length of the lateral
$L_{opt,min}$ [m] Minimum of the optimal length of the lateral
m [−] Location parameter of the Fréchet EV2 CDF
n_u [−] Optimal number of emitters in the uphill lateral
n_d [−] Optimal number of emitters in the downhill lateral
n_{opt} [−] Optimal number of emitters in the entire lateral
q_n [$m^3 s^{-1}$] Nominal emitters' flow rate
r [−] Flow rate exponent of the resistance equation
s [−] Diameter exponent of the resistance equation
s [−] Diameter exponent of the resistance equation
S [m] Emitter spacing
S_0 [−] Optimal slope of the lateral
x [−] Exponent of the flow rate-pressure head relationship
x_L [m] Abscissa of the paired sloped lateral measured from its top.
z_i [m] Elevation of the generic emitter, i, in respect to the lateral's bottom
z_M [m] Elevation of the manifold, M, in respect to the lateral's bottom
Z [m] Elevation of the paired sloped drip lateral
β [−] Curvature parameter
$\beta_{Lopt,min}$ [−] Curvature parameter corresponding to the minimum optimal length of the lateral
δ [−] Pressure head tolerance
Δz_i [m] Elevation variation of the generic emitter i in respect to the manifold
ν [$m^2 s^{-1}$] Kinematic water viscosity
ζ Riemann Zeta function

procedure based on variable length microtubes as emitters along the laterals, thus attaining total emission uniformity. However, the suggested criterion might be difficult to use in practice.

In designing drip irrigation laterals with traditional emitters, a well-accepted practice consists in limiting the variation of the pressure head to about ± δ of its nominal value along the lateral, where the pressure head tolerance, δ, can be assumed to be around to 10%, depending on each design and on the accepted flow rate variability of the emitters installed along the laterals.

The criteria of fixing the pressure head tolerance agrees with the hypothesis to neglect the variation of emitters' flow rates, which in many papers was considered to simplify deriving of design procedures of sloped and horizontal laterals. In fact, when design procedures are developed under limited pressure head variations, only a narrow range of the flow rate-pressure head relationship of the emitters is involved in the operating pressures of the laterals (Karmeli and Keller, 1975; Wu and Giltin, 1975; Wu, 1975; Wu et al., 1983; Wu et al., 1986; Baiamonte et al., 2015; Baiamonte 2016a,b,d).

Using paired laterals, in which two laterals pipes extend in opposite directions from a common inlet point on manifold, provide more uniform pressure to all the laterals and allows the lateral length to be maximized (Keller and Karmeli, 1974; Al-Samarmad, 2002; Baiamonte, 2017; Goldammer, 2017). An important component of designing paired laterals is to determine the best manifold position, *BMP* (Keller and Bliesner, 1990; Kang and Nishiyama 1996; Baiamonte et al., 2015). Contrarily to horizontal laterals for which, because of the symmetry, the length of both laterals is equal (*BMP* = 0.5), for sloped laterals, the manifold has to be shifted uphill, so to balance differences in elevation and pressure losses on both uphill and downhill laterals, by imposing the same minimum pressure in the uphill and in the downhill laterals (Keller and Bliesner, 1990).

Under the Blasius resistance equation and by fixing a pressure head tolerance equal to 10%, Baiamonte et al. (2015) presented an analytical approach to evaluate the optimal length of paired drip laterals placed on uniformly sloped grounds by assuming that: i) the variations of emitters' flow rate along the lateral, as well as ii) the local losses due to emitters' insertions could be neglected. Although the latter assumption can be accepted only in some cases, and can be fully relaxed in the exact step-by-step (SBS) procedure, which provides complete and exact solutions on its own, the usefulness of analytical solutions is also important to consider. They do not need iterations to be coded into computer programs and they make it easy to understand how the factors affecting the studied feature influence the output variables and serve a useful pedagogical purpose (Anderson and Woessner 1992; Giraldez and Woolhiser 1996; Baiamonte and Singh, 2016a; Baiamonte and Singh 2016a; Baiamonte, 2016c).

The analytical solution of Baiamonte et al. (2015) provided the maximum number of emitters in the uphill and downhill sides of the lateral and, therefore, the optimal lateral length by imposing constant emitter flow rates and a pressure head tolerance, δ = 10%, of its nominal value along the entire lateral. More recently, Baiamonte (2016a) simplified the analytical design procedure introduced by Baiamonte et al. (2015), which required solving a system of four implicit equations, by deriving simple explicit relationships as a function of 16 calibration constants. This simplified procedure derived the design variables required for the optimal paired lateral, with a relative error less than 2%. Moreover, the author exactly identified the *BMP* value associated with the optimal paired lateral design in a sloping field, which is equal to 0.24. It was shown that this choice for any sloped laterals allows optimizing lateral uniform pressure and the energy efficiency (Baiamonte, 2017).

The previously mentioned procedures are valid under the assumption that the paired laterals are laid on straight slopes, however, real microirrigation units rarely follow an even gradient, whose topography is characterized by linear and equally spaced contour lines. On the contrary, real microirrigation units often have very complex shapes (Fig. 1). In the past, several works have been carried out about the effect of profile field shape on different physical processes. In two different works, Philip analyzed the effect of convergent and divergent slopes (Philip, 1991b) and of concavity/convexity of the hillslope profile (Philip, 1991c) on the hillslope infiltration and downslope subsurface unsaturated flow. The solution of the unsaturated flow equation suggested that, with respect to the case of the planar hillslope (Philip, 1991a), the integrated