Edição especial – 9º INOVAGRI International Meeting

ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

MÉTODO PARA PROJETAR LINHAS LATERAIS PAREADAS DE MICROIRRIGAÇÃO COM VARIAÇÃO DE DIÂMETROS COMERCIAIS

JOÃO AUDIFAX CÉZAR DE ALBUQUERQUE FILHO[1]; JOSÉ LUCAS PEREIRA DA SILVA[2]; CERES DUARTE GUEDES CABRAL DE ALMEIDA[3]; MANASSÉS MESQUITA DA SILVA[4]; JOSÉ AMILTON SANTOS JÚNIOR[5] E ALEXSANDRO OLIVEIRA DA SILVA[6]

[1] *Prof. Doutor, Depto de Engenharia Agrícola, Universidade Federal Rural de Pernambuco - UFRPE, Rua Dom Manuel de Medeiros, s/n - Dois Irmãos, Recife – PE, Brasil. E-mail: joao.albuquerquefo@ufrpe.br; ORCID (https://orcid.org/0000-0002-5064-3237).*

[2] *Doutorando do programa de Engenharia Agrícola, UFRPE, Rua Dom Manuel de Medeiros, s/n - Dois Irmãos, Recife – PE, Brasil. E-mail: jose.lucaspereira@ufrpe.br; ORCID (https://orcid.org/0000-0001-5566-4144).*

[3] *Prof(a). Doutora, Colégio Agrícola Dom Agostinho Ikas (CODAI) da UFRPE, Av. Dr. Francisco Correia, 643 - Centro, São Lourenço da Mata - PE, Brasil. E-mail: ceres.cabral@ufrpe.br; ORCID (https://orcid.org/0000-0001-6073-3853).*

[4] *Prof. Doutor, Depto de Engenharia Agrícola, Universidade Federal Rural de Pernambuco - UFRPE, Rua Dom Manuel de Medeiros, s/n - Dois Irmãos, Recife – PE, Brasil. E-mail: manasses.mesquita@ufrpe.br; ORCID (https://orcid.org/0000-0002-3892-3076).*

[5] *Prof. Doutor, Depto de Engenharia Agrícola, Universidade Federal Rural de Pernambuco - UFRPE, Rua Dom Manuel de Medeiros, s/n - Dois Irmãos, Recife – PE, Brasil. E-mail: joseamilton@ufrpe.br; ORCID (https://orcid.org/0000-0002-1656-7103).*

[6] *Prof. Doutor, Depto de Engenharia Agrícola, Universidade Federal Rural de Pernambuco - UFRPE, Rua Dom Manuel de Medeiros, s/n - Dois Irmãos, Recife – PE, Brasil. E-mail: alexsandro.osilva@ufrpe.br; ORCID (https://orcid.org/0000-0001-5528-9874).*

1 RESUMO

Este estudo tem como objetivo avaliar um método mais abrangente, simples e muito preciso para projetar linhas laterais pareadas de microirrigação com diâmetro constante ou misto em terrenos com inclinação uniforme. Com base em um novo princípio de se igualar as diferenças de pressão nas laterais de cada lado, a equação final do método apresentada num formato padrão e adimensional também facilitou o processamento de outros métodos já consagrados na literatura, bastando substituir a constante que caracteriza cada método. Um teste comparativo foi realizado com outros dois modelos com princípios de que se igualem as pressões mínimas ou pressões médias das laterais pareadas. A aplicação em um exemplo de projeto cobrindo várias condições indicaram resultados mais precisos para as linhas laterais pareadas, com menor diferença de desempenho entre os trechos em aclive e declive.

Palavras-Chave: Taxa de pressão, uniformidade de distribuição, linha do gradiente de energia.

ALBUQUERQUE FILHO, J. A. C.; SILVA, J. L. P.; ALMEIDA, C. D. G. C.; SILVA, M. M.; SANTOS JÚNIOR, J. A.; SILVA, A. O.

METHOD FOR DESIGNING PAIRED MICROIRRIGATION LATERALS WITH VARIABLE COMMERCIAL DIAMETERS

Recebido em 05/11/2025 e aprovado para publicação em 10/12/2025
DOI: http://dx.doi.org/10.15809/irriga.2025v30p29-38

2 ABSTRACT

This study aims to evaluate a more comprehensive, simple, and highly accurate method for designing paired microirrigation sides with constant or mixed diameters on uniformly sloped terrains. On the basis of a new principle of equalizing pressure differences between the sides on each side, the final equation of the method, which is presented in a standard and dimensionless format, also facilitates the processing of other well-established methods in the literature by simply replacing the constant that characterizes each comparative method. tests were performed with two other models based on the principles of equalizing either the minimum or average pressures of the paired sides. Application to a design example covering various conditions indicated more accurate results for paired sides, with reduced performance differences between upslope and downslope segments.

Keywords: Pressure rate, distribution uniformity, energy gradient line.

3 INTRODUCTION

Most lateral lines under microirrigation are paired to balance differences in elevation and pressure loss in uphill and downhill sections (Keller & Bliesner, 1990). An important component in designing paired laterals is determining the best submain position (BSP). Therefore, *on the basis of different* definitions, several methods have been proposed for designing paired laterals (Keller & Bliesner, 1990; Jiang & Kang, 2010; Ju *et al.*, 2015). These methodologies, which are already established in the literature and use the energy gradient line approach (Wu & Gitlin, 1975), likely do not allow for a better balance of elevation differences and pressure losses along the maximum length in uphill and downhill sections, as defined by BSP definitions that equalize minimum or average pressures. Given the circumstances presented and considering that the coefficients describing the adequacy of water distribution are affected by the pressure distribution that occurs along the maximum length of the sides on each side, Albuquerque Filho *et al.* (2025) devised a new principle in the definition of the BSP (Basic Pressure System) that equalizes the pressure differences in uphill and downhill sections. On the basis of the energy gradient line approach (Wu; Gitlin, 1975), this study aims to evaluate a simple, precise, and more comprehensive solution for better BSP location and considers two alternative commercial diameters, single or mixed, indicated for uphill and downhill sections.

4 MATERIALS AND METHODS

In accordance with Albuquerque Filho *et al.* (2025), in the present study, the following assumptions were made: the lateral line has an infinite number of equally spaced emitters (*N*), with constant discharge and hydraulic characteristics (friction factor and lateral diameter) along the entire length of the paired laterals, the flow is hydraulically smooth turbulent, the velocity energy along the lateral line can be neglected, the slope (*s*) of the terrain is uniform, and the coefficient of variation of emitter manufacturing was considered less than or equal to 5%.

To simplify the procedure for dimensioning the sides, it BSP was expressed, according to Ju *et al.* (2015), by the ratio between the length of the side on the slope (L_a) and the total length (L). of the unique paired sides, as per equation (1):

$$BSP = \frac{L_a}{L} \cong \frac{N_a}{N} \tag{1}$$

In which,
Na = number of emitters on the uphill slope*;*
N = total integer number of emitters.

According to Monserrat, Barragan, and Cots (2018), calculating the maximum length of a paired lateral line involves a high degree of mathematical complexity and, for this reason, has only recently been addressed (Baiamonte; Provenzano; Rallo, 2015; Ju *et al.*, 2015). Baiamonte, Provenzano, and Rallo (2015) reported that the total length of paired lateral lines is quite similar, regardless of the slope of the terrain. Therefore, it is possible to perform a simple calculation of the maximum length of the single lateral line, which is half the maximum length of the pair of lateral lines (L), assuming flat terrain so that the total head loss ($h'f_{(L)}$) is equal to the change in the pressure head (ΔH). The total integer number of emitters (N) on a single lateral with a constant diameter and slope and a variable BSP can be observed in equation (2).

$$N = Int\left(\frac{2^{2,75}}{k_1} \cdot q_{vh} \cdot \frac{PS}{x \cdot s^{2,75}}\right)^{\frac{1}{2,75}} + 1 \tag{2}$$

Given the total length (L) of the paired sides estimated according to equation (3).

$$L = N \cdot s \tag{3}$$

In which,
$Int(\cdot)$ represents the integer part of the function; q_{vh} *is the* allowable flow variation of the emitter*; PS is the* service pressure of the design emitter*; x is the* discharge exponent of the flow-pressure equation of the emitter*; s is the* uniform spacing between emitters; and k_1 is the constant of the total head loss equation (Melo *et al.*, 2019).

For the uphill (a) and downhill (d) sections, the total number of emitters (N) and the maximum lengths (L) are in accordance with equations (4), (5), (6) and (7), respectively.

$$N_a = Int(BSP \cdot N) \tag{4}$$

$$L_a = (N_a + u) \cdot s \tag{5}$$

$$N_d = N - N_a \tag{6}$$

$$L_d = (N_d - u) \cdot s \tag{7}$$

In which,
N _a = number of emitters on an uphill slope*; L _a* = maximum length on an uphill slope (m); u = ratio of the initial segment to the uniform spacing (0.5 of s)*; N _d* = number of emitters on a downhill slope*; L _d* = maximum length on a slope (m);

The kinematic viscosity of the irrigation water (v; $m^2 \cdot s^{-1}$), a function of temperature (T; °C), was calculated using equation (8) according to Rodríguez-Sinobas, Juana and Losada. (1999), using the simple potential relationship adjusted with a coefficient of determination $R^2 = 0.99$.

$$v = 0{,}000006177 \cdot T^{-0{,}603} \tag{8}$$

Given that a microirrigation water distribution system is a hydraulic structure limited by irrigation uniformity and, consequently, by head loss, knowledge of lateral line hydraulics and emitter characteristics is fundamental. In general, the emitters are identical and installed at uniform spacing along the lateral line, whose flow characteristics are normally described by the following mathematical function (Keller; Karmeli, 1974).

$$q_n = K \cdot H_n^x \tag{9}$$

In what way:
q_n is the emitter discharge (m ^{3} s $^{-1}$), H_n is the pressure head at the emitter inlet (m), K is the emitter discharge coefficient, and x is the discharge exponent that characterizes the flow regime and emitter type.

Assuming uniform spacing between emitters (*s), a* constant inner diameter of the lateral line (*D*) and emitter discharge (*q), Wu and* Gitlin (1975) proposed the final simplified equation for total single lateral head loss ($h'_{f(L)}$), with the same total length (*L*) as the paired laterals, which can be rewritten in the form of equation (10) and equation (11) to estimate the dimensionless unit head loss (*j'*):

$$h_f^{'} = k_1 \cdot L^{(3-b)} \tag{10}$$

$$j^{'} = k_1 \cdot L^{(2-b)} \tag{11}$$

where k_1 is a constant originally presented by Melo *et al.* (2019), according to equation (12):

$$k_1 = 2{,}8311 \cdot 10^{-2}\, \frac{a \cdot v^{0{,}25} \cdot \lambda \cdot q^{1{,}75}}{s^{1{,}75} \cdot D^{4{,}75}} \tag{12}$$

In what way:
a is the Blasius method adjustment constant for b=0.25; v is the kinematic viscosity of the irrigation water (m ^{2} s $^{-1}$) as a function of the water temperature (°C); λ is the increase factor for localized head loss, which occurs at the emitter insertion point, based on the equivalent length method (l_e) (m); q is the average emitter discharge (m ^{3} s $^{-1}$); and D is the commercial internal diameter of the single paired lateral line (m).

To estimate the localized head loss that occurs at the insertion points of the emitter connections, on the basis of the equivalent length method, Juana *et al.* (2004) proposed equation (13), which represents an increase in the maximum real length of the paired sides.

$$\lambda = 1 + \frac{l_e}{s} \tag{13}$$

In accordance with Ju *et al. (2015)*, the pressure loss rate (*J*) in equation (14) represents the relationship between two dimensionless values, the uniform slope gradient (*s0*) and the unit head loss $^{(j')\cdot}$, the method is valid for the pressure loss rate in the interval $0 < J < 1$. According to Melo *et al.* (2019), this interval is characterized by a pressure profile of type (IIa); that is, the minimum pressure must occur in the second half of the maximum length of the lateral line on a slope.

$$J = \frac{s_0}{j^{'}} \tag{14}$$

In accordance with Albuquerque Filho *et al.* (2025), the new method presented by equation (15) was based on a new principle. to equalize the pressure differences on each side $\Delta H_a = \Delta H_d$. Therefore, to solve the implicit unknown *BSP* of this equation, the data were processed in the MATLAB ® computational environment following the iterative steps indicated by Jiang and Kang (2010) to increase the convergence speed of the solution closest to *the* $BSP_{(i)}$, also considering a tolerable relative error of 10 $^{-5}$ and a more suitable initial value of $BSP_{(1)}$ = 0.50.

$$BSP_{(i+1)} = 1 - \left[\left(CM + BSP_{(i)}^{2{,}75}\right) / K_D\right]^{\frac{1}{2{,}75}} \tag{15}$$

where *CM* is the constant for each method and K_D is a constant that relates the smaller commercial diameter indicated for the downhill section (D_d) and the larger commercial diameter for the uphill section (D_a), which is raised to the exponent of the diameter of the total head loss equation (-4.75) according to equation (16).

$$K_D = \left(\frac{D_d}{D_a}\right)^{-4,75} \quad (16)$$

To evaluate the performance of the studied methods, the authors verified which result of the relationship between the pressure differences of the uphill and downhill sections was closest to 1; that is, the method should represent the smallest difference in the variation in the emitter flow on the sides of each side. For the method of Albuquerque Filho *et al.* (2025), the dimensionless constant (CM_{AF}) of equation (15) should be estimated by equation (17). For the methods of Keller and Bliesner (1990) and Ju *et al.* (2015), the constants ($CM_{K\&B}$ and CM_{Ju}) should consider equations (18) and (19), respectively.

$$CM_{AF} = J \quad (17)$$

$$CM_{K\&B} = J - 0,36 \cdot J^{1,57} \quad (18)$$

$$CM_{Ju} = \frac{J}{1,466} \quad (19)$$

5. RESULTS AND DISCUSSION

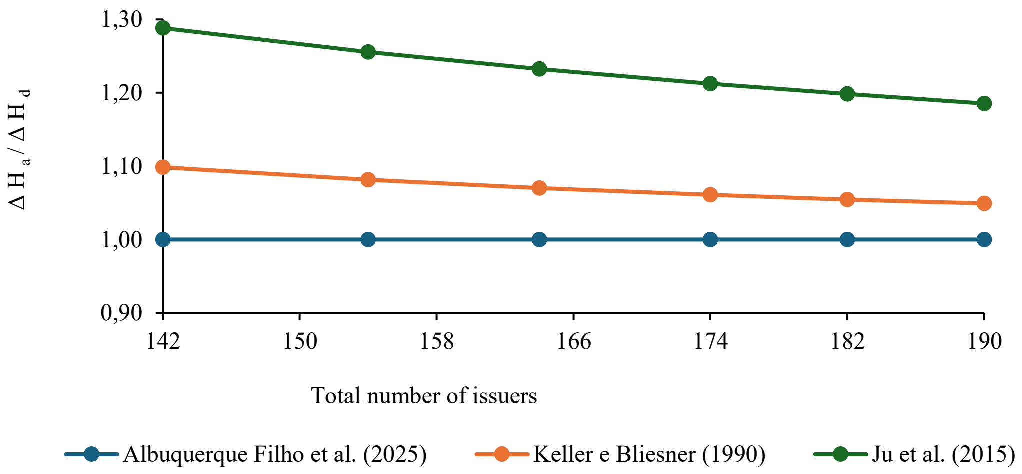
The methods were validated on the basis of several reference parameters considered in the study by Carrión *et al.* (2013), e.g., a polyethylene lateral line with a single commercial diameter of $D = 13.6$ mm; emitter spacing, s = 1.25 m; average emitter discharge, qa = 4.0 L $h^{-1;}$ corresponding average pressure, H_a = 10 m; emitter discharge exponent, x = 0.5; slope gradient, *s0* = ±1% (in the flow direction: (-) uphill and (+) downhill); equivalent length of the emitter connector, l *and* = 0.5 m; irrigation water temperature, considered standard, *T* = 20°C, for adjustment of kinematic viscosity, *v* (m^2 s^{-1}); and the adjustment constants of the Blasius equation (hydraulically smooth flow regime), indicated as *a* = 0.302 and *b* = 0.25.

For comparison purposes of the methodologies presented, the input data were also processed for the methods of Keller and Bliesner (1990) and Ju *et al.* (2015), covering six levels of emitter flow variation, namely, 0.08, 0.10, 0.12, 0.14, 0.16 and 0.18 for the extension of the total number of paired lateral emitters, estimated by equation (2) and corresponding to 141, 153, 164, 173, 182 and 190.

First, considering a constant diameter of the paired sides, to evaluate the studied methods encompassing six levels of emitter flow variation, the method of Keller and Bliesner (8 to 18%) is shown in Figure 1, which illustrates the relationship of the total number of emitters (*N*) with the ratio of the pressure difference along the uphill and downhill sections under a fixed uniform slope of 1% according to the method of Albuquerque Filho *et al.* (2025), the method of Keller and Bliesner (1990) and the method of Ju *et al.* (2015), considering a single commercial diameter of 13.6 mm for the uphill and downhill sections.

In this figure, a similar performance of the paired sides is observed for the new method mentioned, with the pressure difference ratio on the sides of the uphill and downhill slopes being closer to 1, followed by the methods of Keller and Bliesner (1990) and Ju *et al.* (2015).

Figure 1. Relationships between the total number of emitters and the ratio of pressure difference along the uphill and downhill sections under a fixed uniform slope of 1%, according to the methods of Albuquerque Filho *et al.* (2025), Keller and Bliesner (1990) and Ju *et al.* (2015), considering a constant diameter of 13.6 mm for the uphill and downhill sections.



Source: The authors (2025).

To characterize the variation in commercial diameters and the scope of the method by Albuquerque Filho *et al.* (2025), the validation of the studied methods is indicated in Table 1, which is based on the results of the dimensioning of a paired lateral line under the effect of two levels of mixed commercial diameter, corresponding to 13.6 and 12.0 mm and 13.0 and 10.0 mm, with the larger selected for the uphill lateral line and the smaller for the downhill lateral line, in addition to two levels of uniform slope (1 and 2%) based on the methodology presented in equations (1–19). To test the scope and accuracy of the new method for solving *the BSP*, Table 2 also presents the results of the iterative calculation procedure of equation (15), with a constant ($K_D = 1$) for the paired lateral line under the effect of two levels of single commercial diameter, 13.6 mm and 13 mm, and two levels of uniform slope (1 and 2%).

To evaluate the performance of the method by Albuquerque Filho *et al.* (2025) and the other two methods studied, Tables 1 and 2 present average values for the best position of the *BSP derivation line*, which are calculated for six levels of emitter flow variation, by hydraulic variation (8 to 18%) and the respective coefficients of variation of the ratio between the average pressure differences of the uphill and downhill sections. However, as expected, according to the new principle in the definition of the *BSP* and average values presented in Tables 1 and 2, the two alternative commercial diameters studied, i.e., single commercial diameter and mixed commercial diameter, were considered, and considering the sources of variation evaluated, the new method indicated results for the ratio between the pressure difference of the uphill and downhill sides much closer to 1, in relation to the other two methods, as well as less relative variability in the results of the coefficient of variation.

Table 1. Average values of the *BSP solution* estimated for paired lateral sections under the effect of two levels of mixed commercial diameter, corresponding to 13.6 and 12.0 mm and 13.0 and 10.0 mm, two slope levels (1 and 2%), and coefficients of variation between the average pressure differences of the uphill and downhill sections, according to the methods of Albuquerque Filho *et al.* (2025), Keller and Bliesner (1990) and Ju *et al.* (2015).

Methods	**Diameter (mm)**	**Slope (%)**	ΔH_a	ΔH_d	R_H	*CV*	*BSP*
Albuquerque Filho *et al.* (2025)	13, 6 and 12	1	3.64	3.74	0.97	0.003	0.496
		2	3.87	3.80	1.02	0.016	0.442
	13 and 10	1	4.99	5.02	0.99	0.019	0.573
		2	5.37	5.45	0.98	0.025	0.537
Keller and Bliesner (1990)	13, 6 and 12	1	3.77	3.55	1.08	0.073	0.503
		2	4.10	3.44	1.22	0.092	0.460
	13 and 10	1	5.04	4.94	1.03	0.043	0.577
		2	5.60	5.02	1.15	0.127	0.548
Ju *et al.* (2015)	13, 6 and 12	1	3.97	3.28	1.24	0.121	0.514
		2	4.41	3.01	1.52	0.199	0.476
	13 and 10	1	5.25	4.58	1.15	0.013	0.585
		2	5.81	4.65	1.28	0.105	0.559

ΔH_a = pressure difference on the side of the slope (m); ΔH_d = pressure difference on the side of the downhill slope (m); R_H = ratio between the pressure difference on the side of the slope and downhill slope; *CV* = coefficient of variation of R_H; *BSP* = best position of the derivation line.

Source: The authors (2025).

Table 2. Average values of the *BSP* solution estimated for paired lateral sections under the effects of two sizes of single commercial diameter, 13.6 mm and 13 mm, two slope levels (1 and 2%), and the respective coefficients of variation between the average pressure differences of the uphill and downhill sections, according to the methods of Albuquerque Filho *et al.* (2025), Keller and Bliesner (1990) and Ju *et al.* (2015).

Methods	**Diameter (mm)**	**Slope (%)**	ΔH_a	ΔH_d	R_H	*CV*	*BSP*
Albuquerque Filho *et al.* (2025)	13.6	1	2.59	2.62	0.99	0.009	0.421
		2	2.53	2.53	1.01	0.029	0.345
	13	1	2.62	2.61	1.00	0.009	0.427
		2	2.55	2.57	1.01	0.047	0.357
Keller and Bliesner (1990)	13.6	1	2.69	2.49	1.11	0.093	0.430
		2	2.80	2.14	1.43	0.341	0.370
	13	1	2.74	2.48	1.13	0.079	0.435
		2	2.82	2.20	1.37	0.260	0.379
Ju *et al.* (2015)	13.6	1	2.90	2.25	1.32	0.100	0.466
		2	3.09	1.80	1.92	0.547	0.393
	13	1	2.91	2.29	1.32	0.140	0.450
		2	3.08	1.90	1.81	0.499	0.401

ΔH_a = pressure difference on the side of the slope (m); ΔH_d = pressure difference on the side of the downhill slope (m); R_H = ratio between the pressure difference on the side of the slope and downhill slope; *CV* = coefficient of variation of R_H; *BSP* = best position of the derivation line.
Source: The authors (2025).

Thus, the estimates of the best position of the derivation line (BSP) indicated better accuracy and possibly greater reliability when the method of Albuquerque Filho *et al.* (2025) was used, followed by the methods of Keller and Bliesner (1990) and Ju *et al.* (2015).

6 CONCLUSION

The method by Albuquerque Filho *et al.* (2025) is comprehensive and very precise compared with the other methods cited in this study, being considered the one that best dimensioned the paired lateral lines, with the least difference in performance between the uphill and downhill sections, and can be applied for practical purposes without excessive calculation effort, followed by the methods of Keller and Bliesner (1990) and Ju *et al.* (2015).

7 REFERENCES

ALBUQUERQUE FILHO, JAC; ALMEIDA, CDGC; SILVA, MM; FRIZZONE, JA; SANTOS JÚNIOR, JA; SILVA, AO An alternative analytical approach to designing paired lateral lines for microirrigation on Slopes **Journal of Irrigation and Drainage Engineering** , Reston, v. 151, n. 4, p. 04025013-1-04025013-13, 2025. DOI: https://doi.org/10.1061/JIDEDH.IRENG-10483. Available at: https://ascelibrary.org/doi/10.1061/JIDEDH.IRENG-10483. Accessed on: Oct. 15, 2025.

BAIAMONTE, G.; PROVENZANO, G.; RALLO, G. Analytical approach determining the optimal length of paired drip laterals in uniform sloped fields . **Journal of Irrigation and Drainage Engineering** , Reston, v. 141, n. 1, p. 04014042-1-04014042-8, 2015. DOI: https://doi.org/10.1061/(ASCE)IR.1943-4774.0000768. Available at: https://ascelibrary.org/doi/10.1061/%28ASCE%29IR.1943-4774.0000768. Accessed on: October 11, 2025.

CARRIÓN, F.; TARJUELO, JM; HERNÁNDEZ, D.; MORENO, MA Design of microirrigation subunit of minimum cost with proper Operation . **Irrigation Science** , Heidelberg, v. 31, p. 1199-1211, 2013. DOI: https://doi.org/10.1007/s00271-013-0399-8. Available at: https://link.springer.com/article/10.1007/s00271-013-0399-8. Accessed on: October 11, 2025.

JIANG, S.; KANG, Y. Simple method for the design of microirrigation paired laterals . **Journal of Irrigation and Drainage Engineering** , Reston, v. 136, n. 4, p. 271-275, 2010. DOI: https://doi.org/10.1061/(ASCE)IR.1943-4774.0000178. Available at: https://ascelibrary.org/doi/10.1061/%28ASCE%29IR.1943-4774.0000178. Accessed on: October 22, 2025.

JUANA, L.; LOSADA, A.; RODRIGUEZ-SINOBAS, L.; SANCHEZ, R. Analytical relationships for designing rectangular drip irrigation units . **Journal of Irrigation and Drainage Engineering** , Reston, v. 130, n. 1, p. 47-59, 2004. DOI: https://doi.org/10.1061/(ASCE)0733-9437(2004)130:1(47). Available at: https://ascelibrary.org/doi/10.1061/%28ASCE%290733-9437%282004%29130%3A1%2847%29. Accessed on: Oct. 15, 2025.

JU, XL; WECKLER, PR; WU, PT; ZHU, DL; WANG, XK; LI, Z. New simplified approach for hydraulics design of microirrigation paired Laterals . **Transactions of the ASABE** , St. Joseph, v. 50, n. 6, p. 1521-1534, 2015. DOI: https://doi.org/10.13031/trans.58.11092. Available at: https://elibrary.asabe.org/abstract.asp?aid=46554. Accessed on: October 9, 2025.

MONSERRAT, J.; BARRAGAN, J.; COTS, L. Design of paired sides on uniformly sloping fields . **Journal of Irrigation and Drainage Engineering** , Reston, v. 144, n. 6, p. 04018008-1-04018008-6, 2018. DOI: https://doi.org/10.1061/(ASCE)IR.1943-4774.0001308. Available at: https://ascelibrary.org/doi/10.1061/%28ASCE%29IR.1943-4774.0001308. Accessed on: October 15, 2025.

RODRÍGUEZ-SINOBAS, L.; JUANA, L.; LOSADA, A. Effects of temperature changes on emitter Discharge **Journal of Irrigation and Drainage Engineering** , Reston, v. 125, n. 2, p. 64-73, 1999. DOI: https://doi.org/10.1061/(ASCE)0733-9437(1999)125:2(64). Available at: https://ascelibrary.org/doi/10.1061/%28ASCE%290733-9437%281999%29125%3A2%2864%29. Accessed on: October 22, 2025.

WU, IP; GITLIN, HM Energy gradient line for drip irrigation laterals . **Journal of**

Irrigation and Drainage Engineering , Reston, v. 101, n. 4, p. 323-326 , 1975. DOI: https://doi.org/10.1061/JRCEA4.0001075. Available at: https://ascelebrary.org/doi/10.1061/JRCEA4.0001075. Accessed on: October 15, 2025.

KELLER, J.; BLIESNER, RD **Sprinkler and trickle irrigation** . New York: Van Nostrand Reinhold, 1990.

KELLER, J.; KARMELI, D. Trickle irrigation design parameters . **Transactions of the ASAE** , St. Joseph, v. 17, n. 4, p. 678-684, 1974. DOI: https://doi.org/10.13031/2013.36936. Available at: https://elibrary.asabe.org/abstract.asp??JID=3&AID=36936&CID=t1974&v=17&i=4&T=1. Accessed on: October 17, 2025.

MELO, LL de; MELO, VGML de; FRIZZONE, JA; CAMARGO, AP de. Method for designing paired drip irrigation lateral lines on uniformly sloping terrain. *In* : INOVAGRI INTERNATIONAL MEETING, 5th, 2019, Fortaleza. **Proceedings** [...]. Fortaleza: INOVAGRI, 2019. p. 1-11.