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Tapered drip laterals and manifolds in flat and rectangular irrigation units

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Summary and objective

Multiple-diameter laterals and manifolds reduce the material consumption and the total cost in microirrigation systems, however, the length of each sublateral should be determined carefully to assure appropriate performance and uniformity of emitter flow rates. The most accurate method is numerical trial and error, which is time-consuming. Many research efforts have been made to propose simple analytical design procedures. By using the power-law form of the Darcy-Weisbach formula, and equal emitters spacing for the sublaterals, Sadeghi et al. (2016) extended a previously introduced design solution for one-diameter laterals to tapered laterals. Recently, a simplified procedure to design dual-diameter drip laterals has been introduced (Baiamonte and Palermo, 2022), providing relative errors in pressure heads less than 0.5%, and allowing to set different materials, flow rates, and emitter interspaces for each sublateral. Moreover, this analytical procedure easily allows detecting the required commercial emitter characteristics, which is an issue poorly attempted in the past. **The objective of this work is to extend the aforementioned solution to rectangular irrigation units laid on flat fields.**

Dual-diameter drip laterals

Consider a dual-diameter drip lateral, where N_I and N_{II} (j = 1, 2, …, N) non-pressure compensating emitters (N-PCE), interspaced S (m), in each sublateral are installed (**Fig. 1**). D_I and D_{II} are the inside diameters, and the lateral length is $L = S\,(N_I + N_{II})$, counted from the right distal end, where the abscissa $X = 0$ and the pressure head is the minimum, h_{min} (m). At the inlet ($X = L$), where the drip lateral is fed by a water discharge, q_{in} (l/h), the pressure head equals h_{in} (m) that matches the maximum pressure head h_{max} (m).

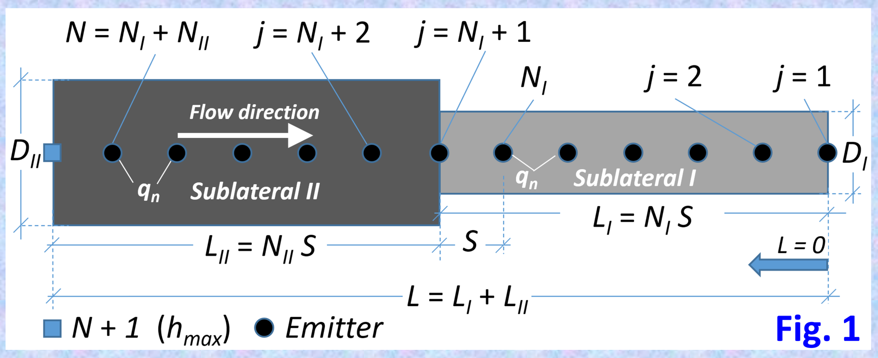


Fig. 1

Energy balance equations and design relationships

For the two sublaterals, **Fig. 2** shows the characteristic parameters and pressure head tolerances of the two sublaterals (δ_I and δ_{II}). By assuming a uniform emitters flow rate, the energy balance equation of each sublaterals, can be written:

For the Sublateral I

$$h_{*j} = h_{*min} + H(j-1,-r) \quad \text{with } h_{*min} = \frac{h_{min}}{K_{L,I}\,S}$$

For the Sublateral II

$$h_{*j} = h_{*n} + [H(j-1,-r) - H(N_I,-r)] \quad \text{with } h_{*n} = \frac{h_n}{K_{L,II}\,S}$$

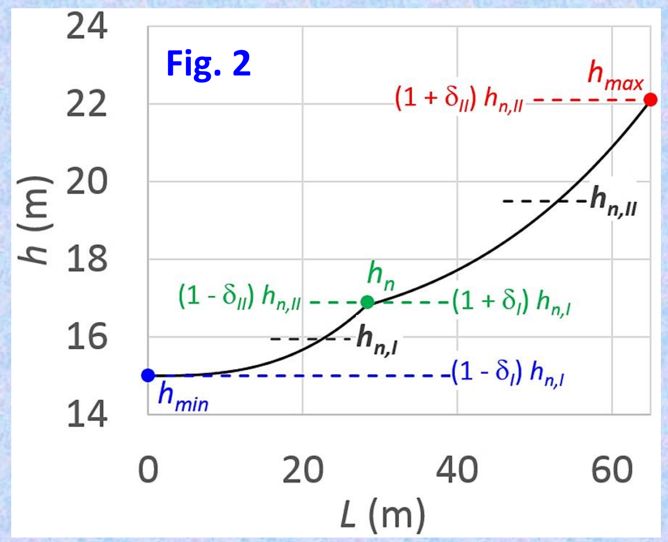
Where:

h_{*j}	Emitter pressure head normalized with respect to S and $K_{L,I}$
h_{*min}	Minimum value of h_*
h_{*n}	Normalized Emitter pressure head at the section change, $j = N_I + 1$: $h_{*n} = h_{*min} + H(N_I,-r)$

$K_{L,I} = \frac{10.675}{C^r}\frac{q_n{}^r}{D_{L,I}^s}$	Energy gradient for the sublateral I (Hazen-Williams)
$K_{L,II} = \frac{10.675}{C^r}\frac{q_n{}^r}{D_{L,II}^s}$	Energy gradient for the sublateral II
$H(j-1,-r) = \sum_{j=1}^{j}(j-1)^{-r}$	Generalized Harmonic Number

Denoting δ_L the lateral pressure head tolerance (**Fig. 2**), and imposing h_{in} at $j = N$, an explicit relationship of the parameter $h_{*min} = h_{min}/S\,K_{L,I}$ which is independent by $\delta_{L,I}$ and $\delta_{L,II}$, but by their sum, δ_L, was derived:

A) $$h_{*min} = \frac{h_{min}}{S\,K_{L,I}} = \frac{1-\delta_L}{2\,\delta_L} H(N_I,-r)\,(1 + D_{*L}^s\,\Psi_L) \quad \text{with } \Psi_L = \frac{H(N_I+N_{II},-r)}{H(N_I,-r)} - 1$$

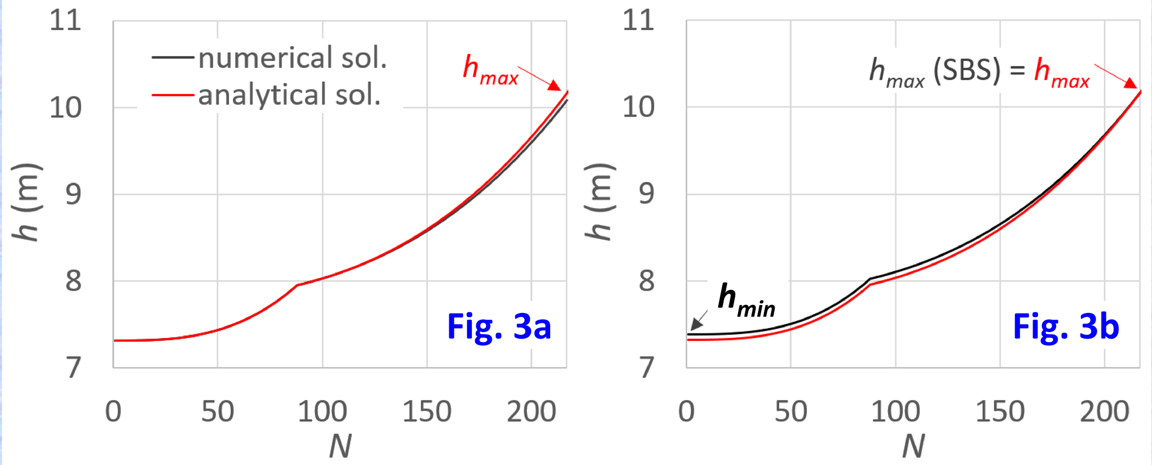


Where $D_{*L} = D_{L,I}/D_{L,II}$. For one diameter lateral, i.e. $D_{*L} = 1$ or $N_{II} = 0$, the Eq. A) matches Eq. (23) derived in Baiamonte (2018):

$$\frac{h_{min}}{S\,K_L} = \frac{H(N,-r)\,(1-\delta_L)}{2\,\delta_L}$$

For fixed δ and the other input variables (q_n, S, N_I, D_I, D_{II}), Eq. A) allows determining the required minimum pressure head, h_{min}.

An error analysis, showed that the suggested procedure slightly overestimates h_{in}. However, slightly overestimating h_{in} (RE > 0), and imposing it in practice, determines a slight h_{min} overestimation, as displayed in **Fig. 3b**, which would favor the plants' wellbeing because a bit greater pressure head supplies a bit greater water volumes.



Dual-diameter drip laterals and manifold

If considering that $N_{rows} = N_{rows,I} + N_{rows,II}$, laterals, S_{rows} spaced, connected to the manifold, operate as $N = N_I + N_{II}$ emitters, S spaced, installed in the laterals, with $q = N\,q_n$, Eq. A) derived for dual-diameter drip laterals, can be extended to the manifold, making possible to design rectangular irrigation units.

Variables need to be changed according to the table:

Laterals →	Manifold	Laterals →	Manifold	Laterals →	Manifold	Laterals →	Manifold
S	S_{rows}	N_I	$N_{rows,I}$	Ψ_L	Ψ_M	$K_{L,I}$	$K_{M,I}$
h_{min}	$h_{M,min} = \Delta\,h_{min}$	N_{II}	$N_{rows,II}$	δ_L	δ_M	$D_{*L} = D_{L,I}/D_{L,II}$	$D_{*M} = D_{M,I}/D_{M,II}$

Thus, for the manifold, Eq. A) can be rewritten as:

B) $$h_{*M,min} = \frac{h_{M,min}}{S_{rows}\,K_{M,I}} = \frac{1-\delta_M}{2\,\delta_M} H(N_{rows,I},-r)\,(1 + D_{*M}^s\,\Psi_M) \quad \text{with } \Psi_M = \frac{H(N_{rows,I}+N_{rows,II},-r)}{H(N_{rows,I},-r)} - 1$$

Where $h_{M,min} = \Delta\,h_{min}$, with $\Delta = 1 + \delta_L$. This because for the manifold, for fixed δ_M, laterals' inlet pressure heads must vary around $\Delta\,h_n$.

Once, F_{*L} (Eq. A) and F_{*M} (Eq. B) are derived, the q_n and q_{in} relationships can be written:

$$q_n = \left(\frac{C_L^r D_{L,I}^s\,h_{min}}{10.675\,\boxed{\boldsymbol{h_{*min}}}\,S}\right)^{1/r} \qquad q_{in} = N\,N_{rows}\,q_n = N_{rows}\left(\frac{C_M^r\,D_{M,I}^s\,h_{M,min}}{10.675\,\boxed{\boldsymbol{h_{*M,min}}}\,S_{rows}}\right)^{1/r}$$

Finally, for fixed δ_L and D_{*M}, the manifold inside diameters, $D_{M,I}$ and $D_{M,II}$, can be calculated by (Baiamonte, 2018):

$$D_{M,I} = D_{L,I}\left(\frac{N^r\,\boldsymbol{h_{*M,min}}\,S_{rows}}{\Delta\,\boldsymbol{h_{*min}}\,S}\right)^{1/s} \qquad D_{M,II} = \frac{D_{M,I}}{D_{*M}}$$

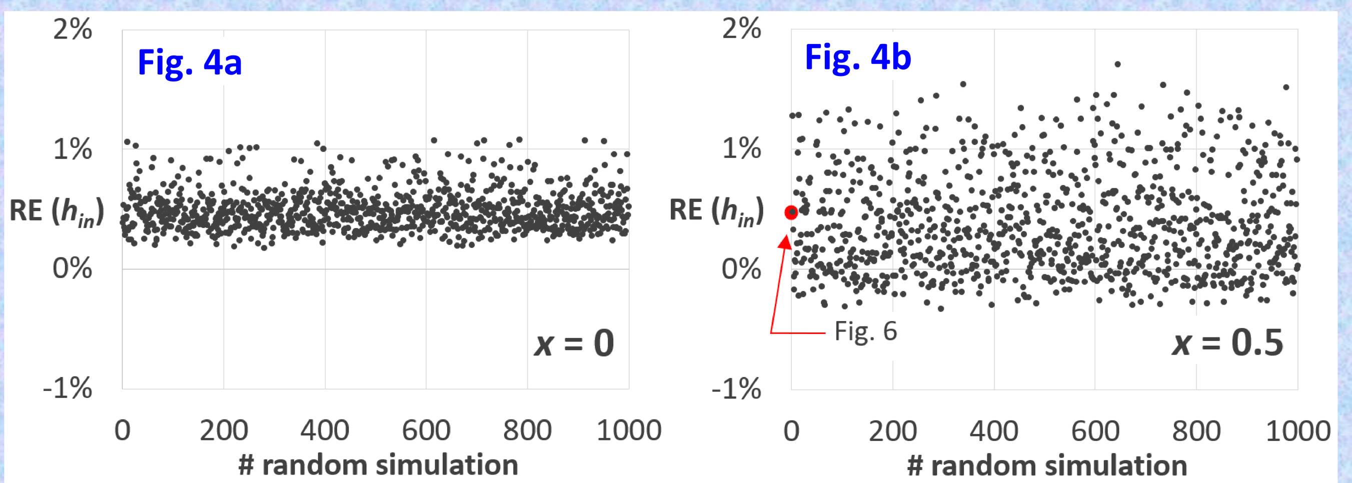
Error Analysis

For # 1000 random simulation, and for fixed emitter exponent, $x = 0$ and $x = 0.5$, relative errors, RE, with respect to the exact SBS, have been calculated:

$$RE = \frac{h_{in,analytical} - h_{in,SBS}}{h_{in,SBS}}$$

Range of variability of the design parameter considered in the error analysis.

	S (m)	N_I	N_L	δ_L	D_{*L}	$D_{L,1}$ (mm)	q_n (l/h)	S_{rows} (m)	$N_{rows,I}$	N_{rows}	D_{*M}
min	0.5	20	50	0.01	0.65	13.8	2	1	20	50	0.65
max	1.5	N_L	300	0.05	0.80	17.7	8	4	N_{rows}	150	0.80



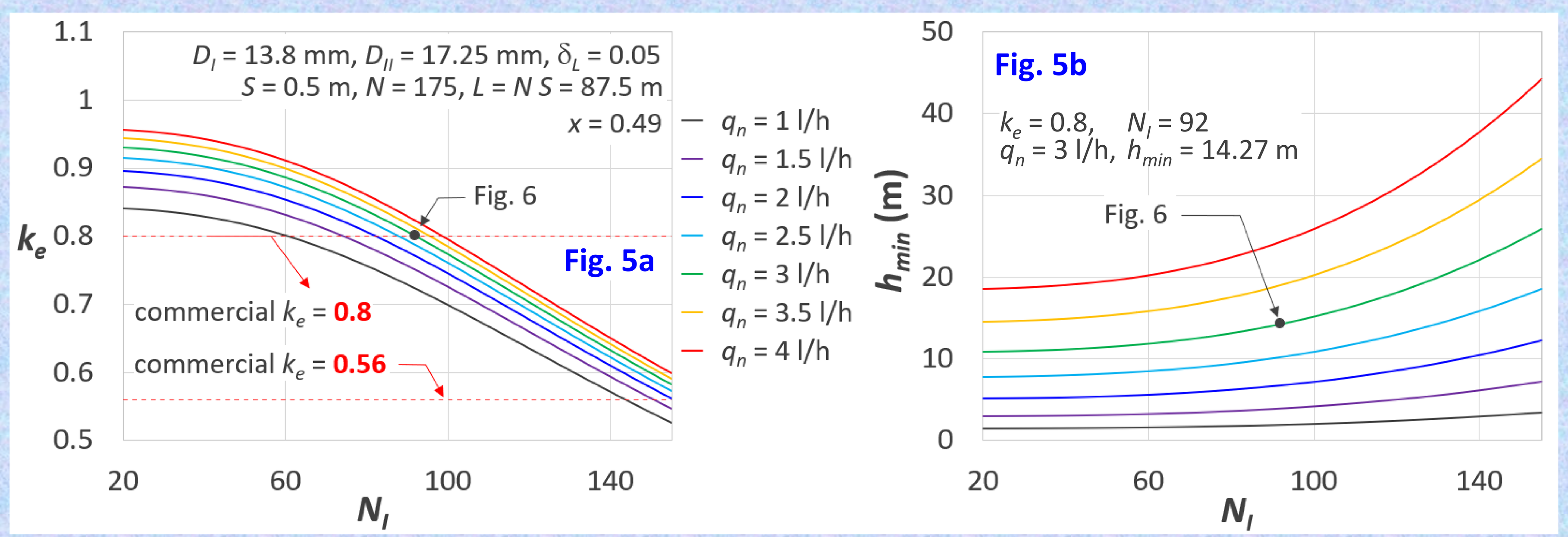
REs are displayed in **Fig. 4a** and **Fig. 4b**. For $x = 0$ (PCE emitters), RE is less than 1.1 % (**Fig. 4a**), whereas a bit higher REs occur for $x = 0.5$ (**Fig. 4b**), because of the uniform emitter flow rate assumption. **Fig. 4b** also shows RE corresponding to the application illustrated in **Fig. 6**.

Selecting the characteristics of commercial emitters

The design procedure also makes it possible to easily select the characteristics of the commercial emitters (k_e and x):

$$k_e = \left(\frac{q_n}{(1+\delta_L)h_{min}}\right)^x$$

For fixed input variables, and **x = 0.49**, **Fig. 5a** shows the calculated k_e, by varying the number of emitters of the sublateral I, N_I, with q_n as a parameter. In **Fig. 5b**, the corresponding, h_{min}, versus N_I, with q_n as a parameter, is also shown.



Characteristics of commercial emitters.

s (m)	ϕ (mm)	D (mm)	k_e (l h⁻¹ m⁻ˣ)	x	color
0.2	16	13.8	0.43	0.55	yellow
0.3			0.69	0.50	blue
0.4			1.32	0.49	black
0.5			2.48	0.51	red
0.6	20	17.25	0.56	0.52	yellow
0.75			**0.80**	0.49	blue
1.00			1.2	0.48	black
1.25			2.35	0.49	red
1.50			4.94	0.47	green

Assuming available in commerce, the above reported emitters of the drip laterals, an application of the suggested procedure was performed (see **Figs. 5** and **6**, k_e **= 0.8 l h⁻¹ m⁻ˣ**).

Application

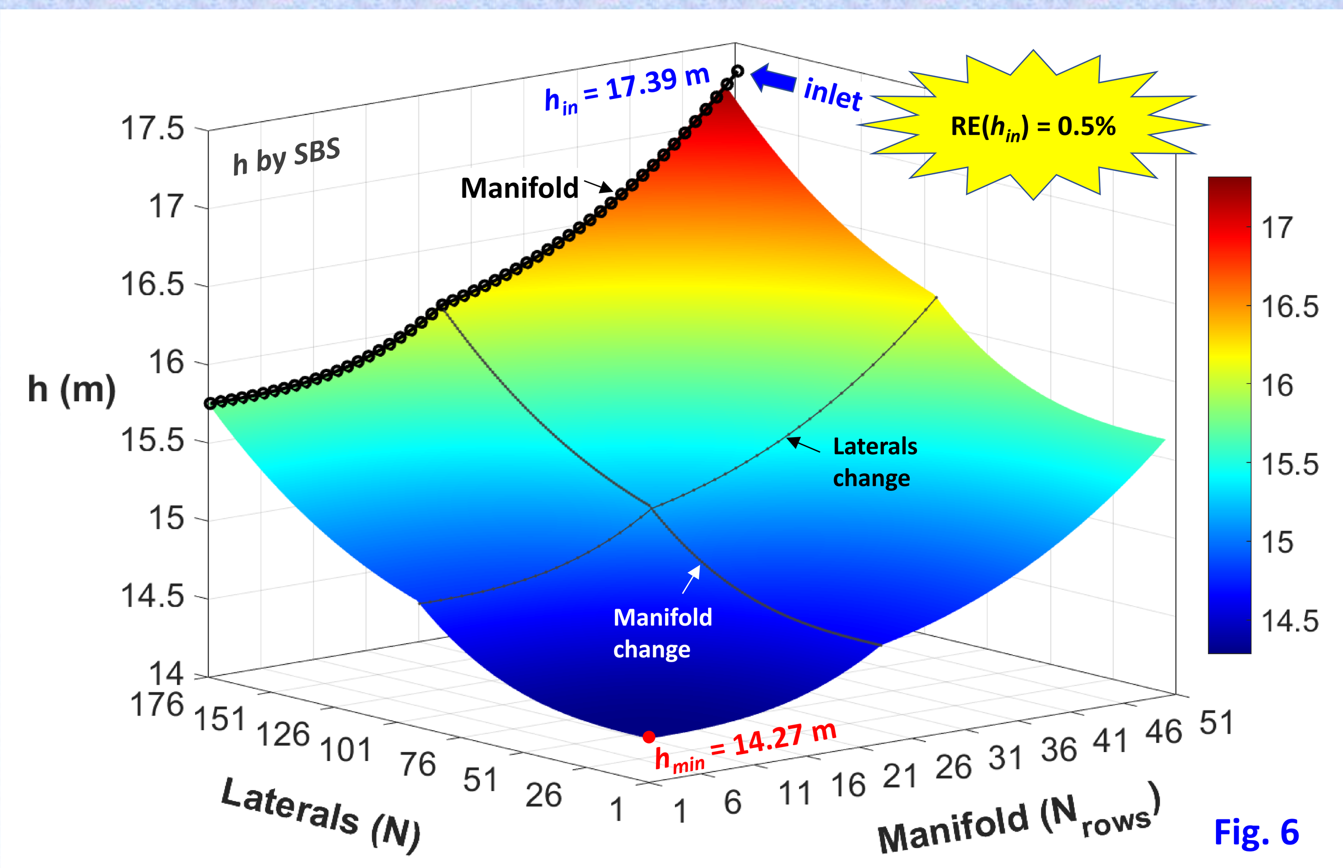


Fig. 6

TAPERED DRIP LATERALS

- S = 0.5 m
- $D_{L,I}$ = 13.8 mm
- $D_{L,II}$ = 17.25 mm
- k_e **= 0.8 l h⁻¹ m⁻ˣ**
- N_I = 92
- N_{II} = 83
- N = 175
- $L = N\,S$ = 87.5 m
- $\delta_{L,I}$ = 0.019
- $\delta_{L,II}$ = 0.031
- δ_L = 0.05

TAPERED MANIFOLD

- S_{rows} = 2 m
- $D_{M,I}$ = 61.5 mm
- $D_{M,II}$ = 76.8 mm
- $N_{rows,I}$ = 23
- $N_{rows,II}$ = 27
- N_{rows} = 50
- $L_M = N_{rows}\,S_{rows}$ = 100 m
- $\delta_{M,I}$ = 0.014
- $\delta_{M,II}$ = 0.036
- δ_M = 0.05

$\delta = \delta_L + \delta_M = 10\,\%$

$$h_{in} = h_{min}\,\Delta^2\left(\frac{1+\delta_{M,I}}{1-\delta_{M,I}}\right)\left(\frac{1+\delta_M-\delta_{M,I}}{1-\delta_M+\delta_{M,I}}\right) = 17.4 \text{ m}$$

Conclusions

In this work, a recently introduced procedure to design dual-diameter drip laterals under the uniform emitters' flow rate assumption, was extended to design rectangular irrigation units. An error analysis showed that the RE in inlet pressure head, is in the ranges, **(RE < 1.1 %)** and **(-0.31 % < RE < 1.71%)**, for pressure compensating (PCE) and non-pressure compensating emitters (N-PCE), respectively.

References

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