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BULBOCALC PARA DETERMINAÇÃO DO NÚMERO E ESPAÇAMENTO ENTRE EMISSORES PARA IRRIGAÇÃO LOCALIZADA POR GOTEJAMENTO EM CULTURAS PERENES

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1 RESUMO

O dimensionamento de sistemas de irrigação localizada por gotejamento requer o conhecimento da geometria do bulbo molhado, o qual permite determinar a área molhada pelo emissor e atender o pressuposto da área mínima molhada e da sobreposição necessária. Este trabalho tem como objetivo determinar o número e o espaçamento entre emissores para irrigação localizada por gotejamento em culturas perenes por meio de uma planilha eletrônica simplificada. A planilha eletrônica BULBOCALC foi elaborada no software Microsoft Excel ® utilizando a linguagem de programação – *Visual Basic for Applications* (VBA). Para validação adotou-se dois estudos de caso, sendo um por meio de método empírico e outro pelo método de campo. De forma simples, a BULBOCALC se mostrou uma ferramenta eficaz para determinar o número e espaçamento entre emissores, sendo ainda, possível visualizar graficamente a geometria do bulbo molhado para testes de campo.

Palavras-chave: agricultura irrigada, sistemas de irrigação, microirrigação, emissores.

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BULBOCALC FOR DETERMINING THE NUMBER AND SPACING BETWEEN EMITTERS FOR LOCALIZED DRIP IRRIGATION IN PERENNIAL CROPS

2 ABSTRACT

The design of localized drip irrigation systems requires knowledge of the geometry of the wet bulb, which allows for determining the area wetted by the emitter and meeting the assumption of the minimum wetted area and the necessary overlap. This work aims to determine the number and spacing between emitters for localized drip irrigation in perennial crops via a simplified electronic spreadsheet. The BULBOCALC spreadsheet was created in Microsoft Excel® software via the following programming language: Visual Basic Applications (VBAs). For validation, two case studies were adopted, one using an empirical method and the other using the field method. Simply put, BULBOCALC proved to be an effective tool for determining the

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number and spacing between emitters, and it is also possible to graphically visualize the geometry of the wet bulb for field tests.

Keywords: irrigated agriculture, irrigation systems, micro-irrigation, emitters.

3 INTRODUCTION

Irrigation is a technique that consists of applying water through equipment or methods to meet the total or partial water demand of plants to achieve desirable levels of production and/or aesthetics required by the user. This technique, when used with discretion and respect to hydraulic and environmental principles, generates economic and social benefits and contributes significantly to increasing agricultural production and food security.

In irrigation, water is applied through four main methods, which are classified according to the form of water application: surface irrigation, underground irrigation, sprinkler irrigation and localized irrigation (Bernardo *et al.*, 2019). Among these methods, the most efficient method for the use of water is localized irrigation, which uses drip and microsprinkler irrigation systems (Frizzone, 2012; Hasan *et al.*, 2023; Liu *et al.*, 2024).

Localized irrigation has the following main characteristics: high frequency and low intensity of water application. In addition, this method applies water directly to the root system region, reduces losses due to evaporation and deep percolation, and presents high application uniformity (Guo; Li, 2024). Another important characteristic is the wet area formed by the emitter, called the wet bulb, which, depending on several factors, such as the flow rate and spacing between emitters, can form a wet strip (Bernardo *et al.*, 2019).

The wet bulb is formed because the emitters release a small flow in a certain location so that when the water flows from the emitter to the soil, it reaches a small of the soil, the radius of which increases as irrigation continues (Pizarro, 1996; Vishwakarma *et al.*, 2023). The formation of wet bulbs in the soil is influenced by the structure, texture and initial moisture of the soil, the flow rate of the emitter, the frequency and duration of irrigation, the capillary movement of the water and the water retention capacity of the soil (Levien *et al.*, 2010; Ortíz- Samprón *et al.*, 2024).

Determining wet bulb geometry is crucial for efficient planning and management of localized irrigation, especially with respect to estimating the volume of wetted soil (Martí *et al.*, 2024). Furthermore, knowledge of the maximum wet bulb diameter allows the determination of the number of emitters per plant required to achieve the percentage of area to be wetted per plant, which directly influences hydraulic sizing and irrigation management (Frizzone, 2012; Vishwakarma *et al.*, 2023).

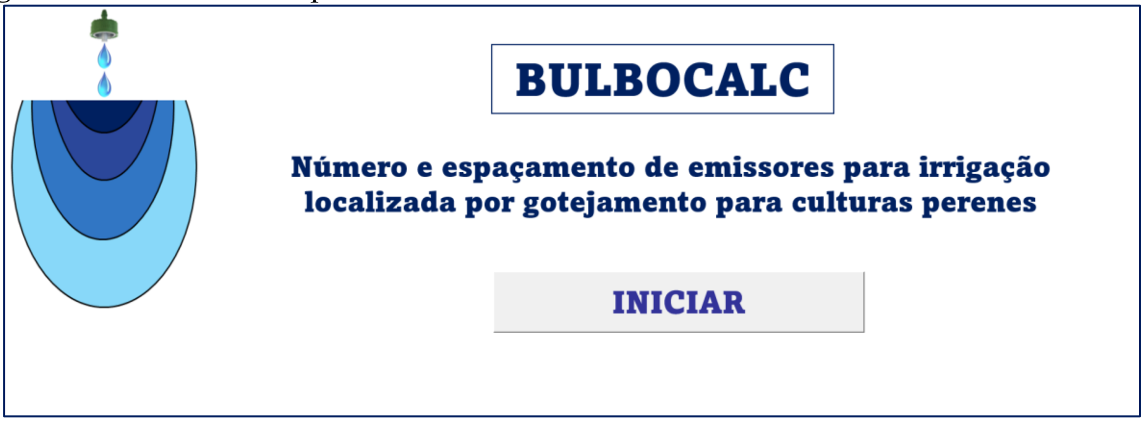
The wet bulb geometry can be determined or estimated via analytical, numerical or empirical methods, in addition to field tests. Empirical methods offer an approximate way to estimate wet bulb dimensions via information related to the irrigation system and soil data, such as the dripper flow rate and soil hydraulic conductivity (Maia; Levien, 2010). Keller (1984) developed a method to estimate the maximum wet bulb diameter as a function of texture, soil stratification degree and root depth, considering a dripper with a flow rate of 4.0 L h $^{-1}$.

Each method requires data collection and resolution with different levels of complexity (Vishwakarma *et al.*, 2023). In this context, the present work aims to determine the number and spacing between emitters for localized drip irrigation in perennial crops via a simplified electronic spreadsheet.

4 MATERIALS AND METHODS

To facilitate and automate the calculations for determining the number and spacing between emitters in localized drip irrigation, a Microsoft Excel macroenabled spreadsheet (.xlsm) was created. The spreadsheet called BULBOCALC (Figure 1) was developed via Microsoft Excel® software via the *visual basic for applications* (VBA) programming language.

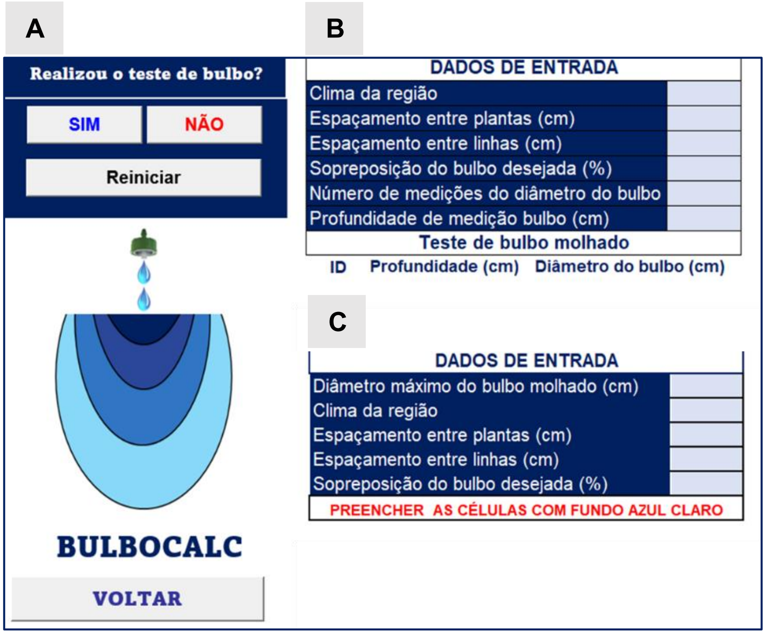
Figure 1. BULBOCALC spreadsheet interface



BULBOCALC allows the user to choose two ways to calculate the number of emitters per plant (NE) and the spacing between emitters (Se). To do this, simply click on the “YES” option if the bulb test is performed in the field or “NO” if the bulb diameter value (Dw) is obtained via some empirical method, such as that proposed by Keller (1984) (Figure 2A).

For the “YES” option, the user must fill in some information, such as the climate of the region, spacing between plants and between rows, desired overlap, number of measurements of the bulb diameter and depth of measurement of the bulb (Figure 2B). For the “NO” option, the user must inform the maximum diameter of the wet bulb (Dw), the climate of the region, the spacing between plants and between rows and the desired overlap (Figure 2C).

Figure 2. Selection of the method and filling in the information to perform the calculations



The wet bulb (Dw) and its geometry can be determined via empirical and direct methods. The empirical method developed by Keller (1984) to determine the wet bulb (Dw) considers the soil texture, depth of the root system and degree of soil stratification for a dripper with a flow rate of 4.0 L h $^{-1}$ (Table 1).

Table 1. Indirect method for estimating wet bulb diameter (Dw) for different soil textures, root system depths (Z) and degrees of soil stratification.

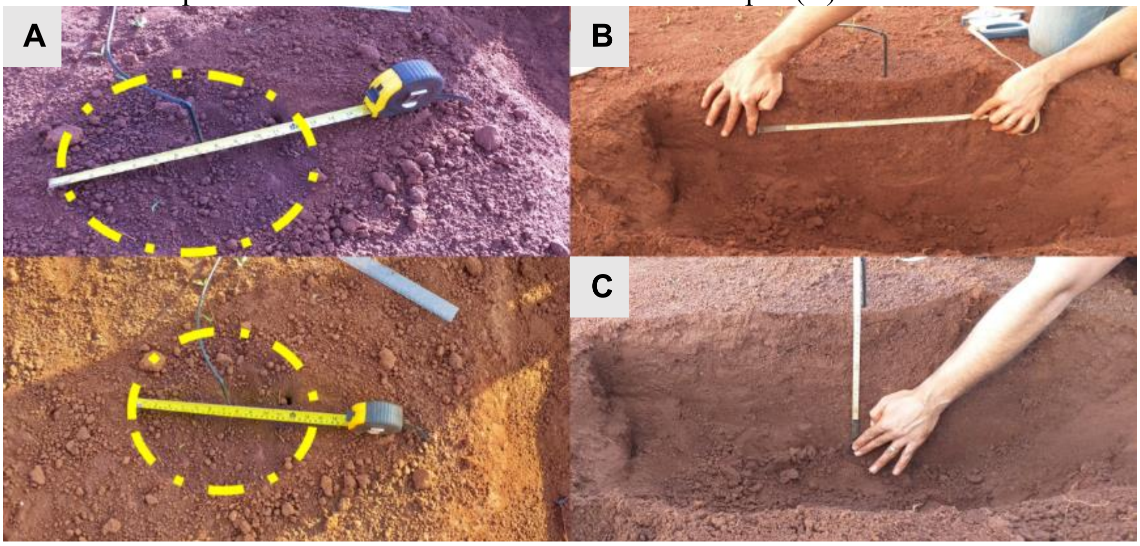
z (m)	Texture	Degree of soil stratification		
		1	2	3
0.75	Thick	0.50	0.80	1.10
	Average	0.90	1.20	1.50
	Fine	1.10	1.50	1.80
1.50	Thick	0.80	1.40	1.80
	Average	1.20	2.10	2.70
	Fine	1.50	2.00	2.40

where Z is the depth of the root system in m, 1 is homogeneous, 2 is slightly stratified and 3 is highly stratified.
Source: Keller (1984).

Direct methods, such as the trench method (Battam; Sutton; Boughton, 2003; Maia *et al.*, 2010), can be used to determine the wet bulb geometry. The respective method consists of opening a trench in the center of the wet bulb below the dripper after the cessation of irrigation. The depth of the trench can vary depending on the type of soil.

Among the parameters used to quantify the geometry of the wet bulb, the following stand out: surface diameter (Figure 3A), diameter at different depths, maximum diameter (Figure 3B), and depth of maximum diameter and maximum depth (Figure 3C), which are measured after opening the trench.

Figure 3. Surface diameter (A), wetted diameter at different depths and maximum diameter (B) and depth of maximum diameter and maximum depth (C).



To validate the BULBOCALC electronic spreadsheet, two case studies were applied, which are presented below.

Case study 1: A hypothetical crop with a root system depth (z) of 0.75 m, spacing between plants of 1.00 m and between rows of 1.50 m, arid climate and a soil with medium and homogeneous texture was considered. Therefore, the diameter of the wet bulb (Dw) obtained empirically via the Keller method (1984) was 0.90.

Case study 2: The wet bulb test was carried out via the trench method (directly) in an experimental area of the Department of Rural Engineering and Socioeconomics (DERS) of the School of Agricultural Sciences (FCA/UNESP), Botucatu campus, São Paulo, Brazil, in 2021, whose soil was a Dystrophic Red Latosol with a clayey texture. The spacing between plants was 1.75 m, and that between rows was 1.20 m. The emitter used was a button type, model ClickTif HD, self-compensating and antidrainage, with a flow rate of 2 L h $^{-1}$ and a service pressure of 10--40 mca. The established irrigation time was 45 minutes, and one hour after the cessation of irrigation, three trenches were opened with the aid of a hoe at three points in the experimental area. Each trench was 1.20 m long and 1.0 m deep.

To quantify the wet bulb geometry, the following parameters were analyzed: surface diameter (DS), diameter at every 0.05 m depth (DM) and maximum diameter (Dw_{max}).), depth of maximum diameter (ZD_{max}.) and maximum depth ($Z_{max.}$) of the wet bulb. The respective parameters were measured with the aid of a metal tape measure and a tape measure, both of which were graduated in centimeters (cm). For the purpose of calculating the AM_{min}, P 20% was adopted since the Botucatu region has a hot and humid summer and a cold and dry winter (Franco *et al.*, 2023).

The number of emitters per plant (NEP) was determined from the calculation of the minimum wetted area (AM_{min}) and the wetted area determined in the field (AM) via the bulb test. This means that AM must be greater than or equal to AM_{min} for the NEP to be chosen correctly.

The minimum wetted area (AM_{min}) estimated via Equation (1) considers the area occupied by the plant (Sp × Sf) and the percentage of wetted area (P). According to Bernardo *et al.* (2019), P should be greater than 33% in arid climate regions and 20% in humid climate regions.

$$AM_{mín} = Sp \times Sl \times P \qquad (1)$$

where AM_{min} is the minimum wetted area (m²), Sp is the spacing between plants (m), Sl is the spacing between planting rows (m) and P is the percentage of wetted area (decimal).

The wetted area determined in the field (AM) was given by Equation 2, and the number of emitters per plant (NEP) was given by Equation 3.

$$AM = \frac{\pi \times D_{máx.}^{2}}{4} \quad (2)$$

where AM is the wetted area determined in the field (m²), $D_{max.}$ is the average maximum horizontal diameter of the wet bulb (m) obtained in the geometry test.

$$NEP = AM \times NE \quad (3)$$

where NEP is the number of emitters per plant, AM is the wetted area determined in the field (m²) and NE is the number of emitters used in the bulb geometry test.

To determine the spacing between emitters (Se), Equation (4) was used, which considers the wetted radius ($\frac{D_{máx.}}{2}$) that can be obtained via the empirical method proposed by Keller (1984) or the trench method (Battam; Sutton; Boughton, 2003; Maia *et al.*, 2010) and the desired overlap of the bulbs (a). The overlap should be between 15% and 30%, as values below 15% can form dry soil barriers and cause salt accumulation.

$$Se = r \times (2 - a) \quad (4)$$

where If is the emitter spacing (m), r is the wetted radius (m) and a is the desired overlap (decimal).

5 RESULTS AND DISCUSSION

For case study 1, according to the results obtained through BULBOCALC (Figure 4), two emitters per plant spaced 81 cm (0.81 m) apart are required for the defined overlap to be met via the empirical method.

Figure 4. Results for case study 1 – empirical method

RESULTADOS	
Área molhada por um emissor (m²)	0,64
Número de emissores por planta	2,00
Área molhada com 2 emissores (m²)	1,27
Espaçamento entre emissores (cm)	81,00

An analysis of case study 2, in which the field method (trench) was used, revealed that the average surface diameter (DS) was 0.33 m, the maximum wet bulb diameter (D_{max}) was 0.39 m, the maximum depth was 0.31 m, and the maximum diameter depth was 0.10 m (Table 2).

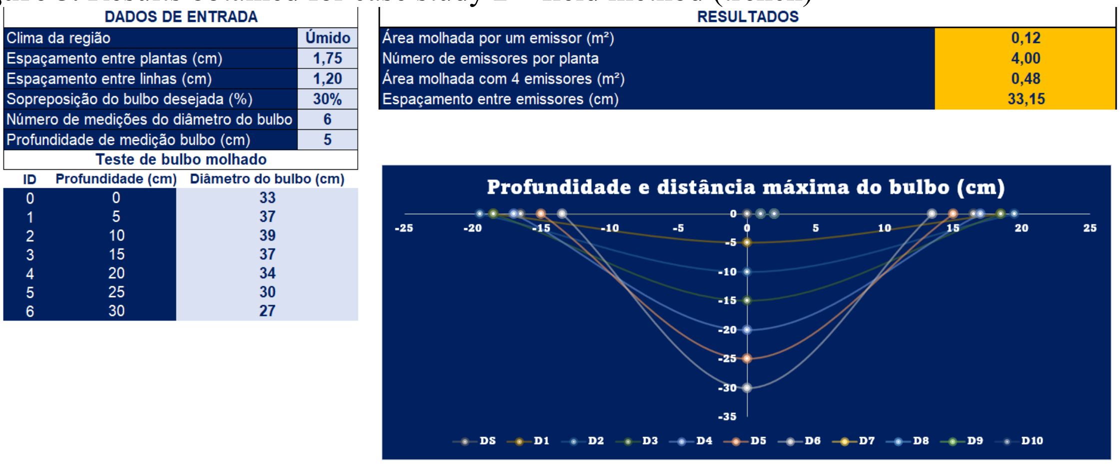
Table 2. Results of wet bulb geometry in clayey-textured Dystrophic Red Latosol using the trench method

Trench 1		Trench 2		Trench 3		Average	
Z (m)	**DM (m)**	**Z (m)**	**DM (m)**	**Z (m)**	**DM (m)**	**Z (m)**	**DM (m)**
5	0.34	5	0.40	5	0.37	5	0.37
10	0.40	10	0.36	10	0,42	10	0,39
15	0,39	15	0,33	15	0,39	15	0,37
20	0,37	20	0,30	20	0,35	20	0,34
25	0,34	25	0,25	25	0,33	25	0,30
30	0,32	30	0,22	30	0,29	30	0,27
DS	0,33	DS	0,33	DS	0,34	DS	0,33
$Dw_{máx.}$	0,40	$Dw_{máx.}$	0,40	$Dw_{máx.}$	0,42	$Dw_{máx.}$	0,41
$Z_{máx.}$	0,30	$Z_{máx.}$	0,29	$Z_{máx.}$	0,33	$Z_{max.}$	0.31
$ZD_{max.}$	0.10	$ZD_{max.}$	0.10	$ZD_{max.}$	0.10	$ZD_{max.}$	0.10

where Z is the depth; DM is the wet bulb diameter at every 0.05 m depth; DS is the surface diameter of the bulb; and $Dw_{Max.}$ Maximum bulb diameter; $Z_{Max.}$ – maximum depth; $ZD_{Max.}$ – maximum diameter depth.

Figure 5 presents the results, as well as the graph of the maximum depth and distance of the wet bulb. Four emitters per plant (NEP) are necessary, and these must be spaced (if) at 33.15 cm (0.33 m) to meet the 30% overlap. Furthermore, the $_{\text{maximum Dw}}$ for the soil studied is at a depth of 10 cm (0.10 m).

Figure 5. Results obtained for case study 2 – field method (trench)



Soil texture is one of the factors that influences the geometry of wet bulbs. Soils with a clayey texture have many micropores and a lower basic infiltration rate (BIR); therefore, the formation of wet bulbs occurs mainly horizontally, corroborating the results obtained in the field test. Furthermore, when the emitter flow rate is constant, the variation in the bulb is not significant over time, but when the irrigation time is very long, the bulb tends to develop in depth, resulting in water percolation, i.e., water and/or nutrient losses (Pizarro, 1996).

Knowledge of the wet bulb geometry through BULBOCALC allows us to determine the dimensions and volume of wet soil. In addition, it has become a tool for optimizing water use (reducing deep water percolation), determining the number of emitters per plant, the hydraulic design of the system and the management of irrigation water.

6 CONCLUSIONS

The BULBOCALC spreadsheet is a practical tool that allows the user to perform fundamental calculations for sizing localized drip irrigation systems for perennial crops. In addition, it graphically presents the parameters of wet bulb geometry, making it possible to determine the number and spacing between emitters for localized drip irrigation.

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