

Hydraulic characterization of Moistube and SLECI irrigation systems compared to conventional drip irrigation

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Abstract: The water shortage associated with climate change necessitates the enhancement of conventional irrigation techniques in arid regions. In this study, a series of tests were conducted in a laboratory to define the discharge-pressure relationship and flow uniformity of the novel Moistube and SLECI irrigation systems in comparison with conventional drip irrigation. The objective of this study is to identify the characteristics of water flow under Moistube and SLECI irrigation at varying operating pressures by assessing the homogeneity of water distribution at different ramp lengths. The average discharge of Moistube varied from 0.3 L hr⁻¹ m⁻¹ at 1.47 m to 7.94 L hr⁻¹ m⁻¹ at 15 m, it increases with increasing pressure represented by a power function. The coefficient of variation is located within the acceptable range (< 20%) and decreases with increasing operating pressure. For SLECI, there is a positive correlation between discharge and pressure, characterized by a partially turbulent flow. Moistube and SLECI system are intolerant ($X > 0.2$) to pressure variations. The discharge of the self-regulating dripper varied between 3.50 L hr⁻¹ at 0.5 bar and 3.5 L hr⁻¹ at 3 bar. Ordinary self-regulating drippers are very tolerant of pressure variations ($0.05 < X < 0.1$). These results suggest that the ramp length of Moistube and SLECI should be taken into account in the design of these systems to ensure uniform irrigation, generally do not exceed 40 m. The high sensitivity of Moistube and SLECI to variations in operating pressure means that a suitable design must be chosen for crops during installation.

Keywords: Moistube, SLECI, conventional dripper, operating pressure, dripper uniformity.

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1 Introduction

Morocco is one of the countries most threatened by water scarcity (Zinkernagel et al., 2020). It is ranked 22nd among the countries most exposed to the risks of water insecurity. Water resources in Morocco

are under different pressures, namely the increase in water demand due to the demographic explosion, recurrent droughts, irregular rain-fall because of climate change, and finally the requirements of economic development (Mateos Matilla et al., 2022).

In the context of climate change, water management constitutes a pivotal aspect of Moroccan agricultural policy. A considerable portion of Morocco's territory is situated within arid and desert zones. The estimated potential water resources

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amount to 22 billion m³, equating to approximately 700 m³ per inhabitant per year. This places Morocco in a situation of structural water stress (Harbouze et al., 2019).

The adoption of technological advances in irrigation has allowed for the considerable intensification of agricultural production. However, because of the succession of drought years during 2010–2020, the hydraulic dams show a water deficit of nearly 45% compared to a year of normal precipitation. In view of this water stress, the State decided from 1 October 2023, to stop irrigation by the dams of the center (Provinces of Tadla and El Haouz) and the south (Province of Souss-Massa and Darâa-Tafilalt). In this context of scarcity, the development of technological keys to water control and management for efficient and sustainable irrigated agriculture is desirable (Pereira et al., 2023).

The use of subsurface irrigation helps to save water by minimizing unproductive water loss components such as surface runoff, soil evaporation and percolation. Despite minimal water losses in subsurface drip irrigation, there is still a problem of nutrients and water leaching, especially in light-textured soils (Kanda et al., 2018).

Moistube irrigation is a semi-permeable porous membrane, and a relatively new technology that simulates the clay pot irrigation (Kanda et al., 2020). Moistube is an irrigation band composed of a semi-permeable flexible membrane with pores in the nanometer scale, with approximately 100,000 nanopores per square centimeter and a pore size of 10 to 900 nm (Akbar et al., 2023), the nanopores are uniformly and densely distributed, facilitating the uniform, two-dimensional and continuous irrigation of the crop root zone (Lyu et al., 2016). The development of nano-irrigation by Moistube as an innovative and efficient subsurface irrigation system has gained extensive application, achieving significant savings and improvements in crop yields and water use efficiency compared to traditional irrigation methods (Dirwai et al., 2021).

Similarly, SLECI (Self-regulating, Low Energy, Clay based Irrigation) represents a transition from traditional clay pot irrigation to modern irrigation techniques. SLECI is part of micro-irrigation systems based on a natural physical principle, using clay as a porous and water-permeable material (Pereira et al., 2023).

As demonstrated by Malchev et al. (2022), the application of SLECI irrigation technology has demonstrated convincing results with moringas in Namibia, cucumbers in Ghana and cherries in Bulgaria.

The commonality between Moistube and SLECI irrigation is that water flows from the nanopores according to the water potential of the surrounding soil and the operating pressure to moisten a limited subsoil horizon in the area around the roots (Lyu et al., 2016). This type of irrigation minimizes water losses due to runoff and direct evaporation from the soil surface (Zhang et al., 2015).

In Morocco, surface irrigation using micro-irrigation has been widely adopted by farmers, while subsurface irrigation using Moistube is still in the experimental phase. Furthermore, SLECI irrigation is being introduced for the first time in Morocco. In order to facilitate the generalization of these new irrigation systems by farmers, it is essential to conduct comprehensive studies in Morocco to confirm the results obtained in other countries.

The uniform distribution of water is a desirable property of an irrigation system. If the system does not distribute water evenly, the result is excessive or deficient irrigation (Aydin, 2019). Furthermore, uniformity of delivery is a crucial factor in determining the total amount of water applied. It is crucial to examine the correlation between the discharge and the operational pressure of an irrigation system in order to ascertain the flow regime and the uniformity with which water is distributed across an irrigation network (Kanda et al., 2020). The principal basic criteria for the conception of an efficient irrigation system are its hydraulic characteristics and

uniformity parameters (Elamin et al., 2017). Consequently, the manufacturing varieties and changes in the performance of an irrigation system must be taken into consideration as an important parameter causing variations in dripper discharge (Hassan et al., 2019). The same irrigation system may have different flow rates, even between two emitters manufactured using the same technology, the same machine and the same manufacturing conditions (Özekici and Sneed, 1995).

The objective of this study is to undertake a comparative analysis of the hydraulic characteristics of the novel nano-irrigation systems and conventional drip irrigation techniques. This will be achieved through the execution of laboratory tests, which will examine the variation in discharge under diverse operating pressures and hydraulic conditions. This will allow for the determination of the flow characteristics of each system and the uniformity of water distribution during irrigation.

2 Material and methods

2.1 Pressure-discharge relationship

To define the discharge-pressure and the uniformity of water distribution, a comparative protocol between Moistube and SLECI subsurface

nano-irrigation systems and drip irrigation of surface (self-regulating dripper) was set up in the laboratory (Figure 1).

One meter sections of Moistube were placed in collectors (H=45 cm, L=100 cm, W=40 cm) to measure discharge at seven water reservoir heights (1.45, 3.27, 5.27, 6.84, 10, 13 and 15 m). There is no guideline on the length required for testing the discharge characteristics of porous pipes, The length was kept small so that friction losses were minimized (Kirnak et al., 2004).

For SLECI technology, the discharge depends on the density of the clay pores (type M, type XL). For the two types, the flow rate of 24 SLECI elements was measured over a pressure range of 1 to 5 m at 0.5 m intervals. Moistube and SLECI discharge were obtained by measuring the volume of water collected in one hour using a 1,000 mL graduated cylinder.

24 drippers integrated into an 18 m length ramp were used to measure flow under six pressures (0.5, 1, 1.5, 2, 2.5 and 3 bar). The Discharge was measured by averaging the volume of 24 drippers collected in 10 min using a 1000 mL graduated cylinder. The characteristics of the self-regulating drippers tested are shown in Table 1.

Table 1 Identification of the characteristics of the auto-regulating drippers tested

Type	Auto-regulating dripper integrated into the ramp
Nominal flow rate	3.5 L h ⁻¹
Operating pressure	0.5-4 bar
Diameter	16 mm
Dripper spacing	0.75 m

Operating pressures depend on the resistance of the irrigation pipes. Moistube and SLECI operate at low pressures (from 0.2 bar), while high pressures can alter their structures. It is essential to maintain adequate pressure to preserve the integrity of these subsurface irrigation systems. The protocol used for these experiments is defined in ISO 9261 "Agricultural irrigation equipment - Emitters and Emitting-pipe systems - Specifications and tests methods".

The discharge-pressure curve was represented by a power function illustrated in Equation 1 (Kanda et al., 2018).

$$Q = k_p h^x \quad (1)$$

Where Q : flow rate (L hr⁻¹), k_p : emitter constant, h : operating pressure (bar) and x is emitter exponent.

This function helps characterize the flow regime by using the exponent value, where a value of 1 indicates laminar flow and a value of 0.5 indicates fully turbulent flow. The intermediate values

represent partially turbulent flow, and values below 0.5 indicate pressure-compensating properties (Clark et al., 2007).

2.2 Emission uniformity along the lateral

Porous irrigation pipes have pores where the size and distribution vary randomly and thus the emission along the pipe will vary (Kanda et al., 2018). The uniformity of emission from the Moistube was determined by measuring the flow on 1m segments of the pipe over a length of 20 m, this operation was repeated five times. As for the drip and SLECI are localized drippers, emission uniformity was calculated by measuring the flow of 50 drippers spaced 0.75 cm over a 38 m ramp length. The spacing differences reflect the structural and functional characteristics of each system. Moistube relies on

consistent measurement due to variability in pore distribution, while drip and SLECI can have more flexible spacing based on controlled, localized dripper design and the specific irrigation strategy.

Flow uniformity was evaluated by calculating the coefficient of variation (CV) for Equation 2 (Liang et al., 2009), an important parameter for irrigation system design to ensure homogeneous water distribution in the field.

$$CV = \frac{S}{q} \times 100 \tag{2}$$

Where,

CV: coefficient of variation (%);

S: standard deviation of discharge (L hr⁻¹ m⁻¹)/ (L hr⁻¹);

q: average discharge (L hr⁻¹ m⁻¹)/ (L hr⁻¹).

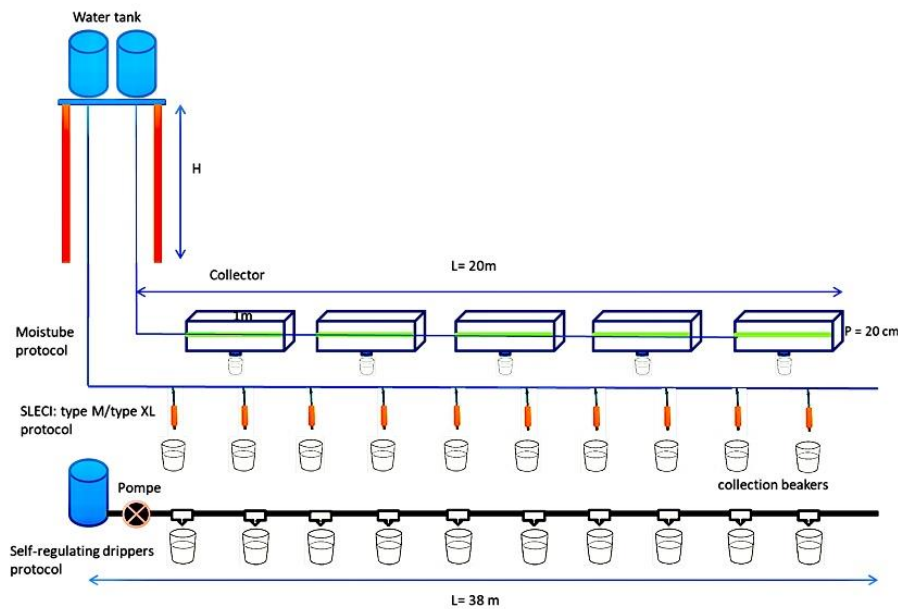
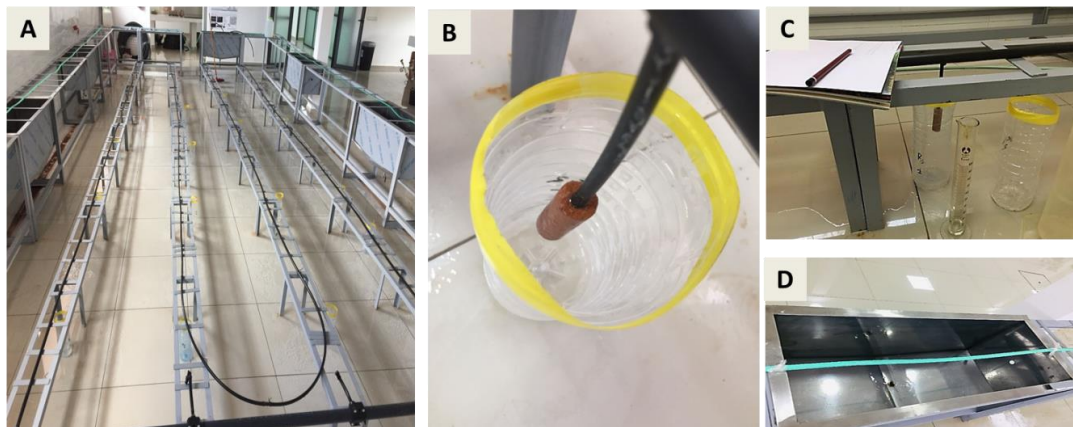


Figure 1 Experimental design of Moistube, SLECI and drip irrigation



(a) self-regulating drippers; (b) SLECI system; (c) SLECI Flow Measurement; (d) Moistube irrigation

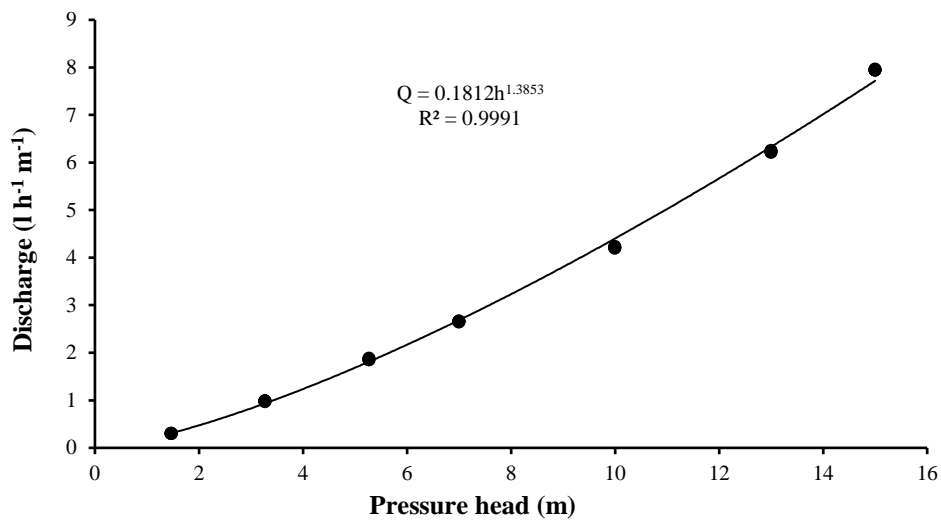
Figure 2 Experimental protocol used in the laboratory

2.3 Statistical analysis

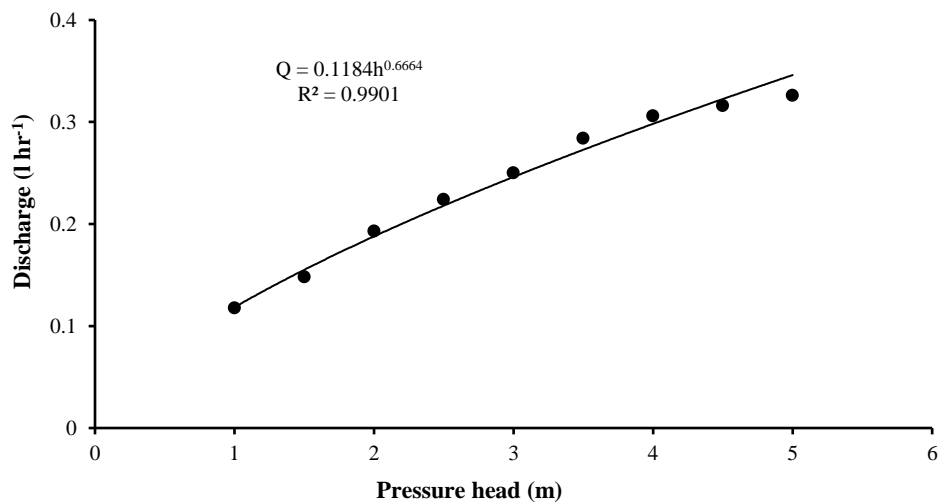
Data was analysed with SPSS version 26 using Pearson correlation. The analysis was conducted at a 1% significance level.

3 Results and discussion

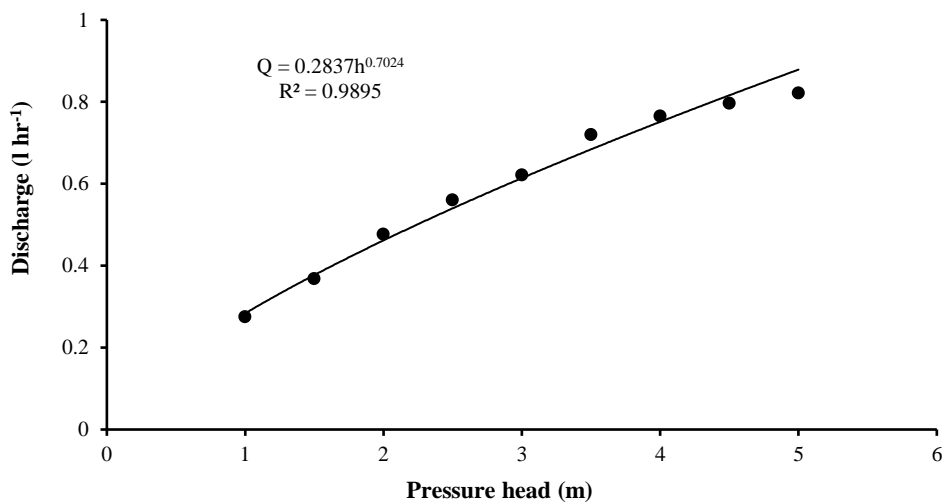
3.1 Pressure-discharge relationship



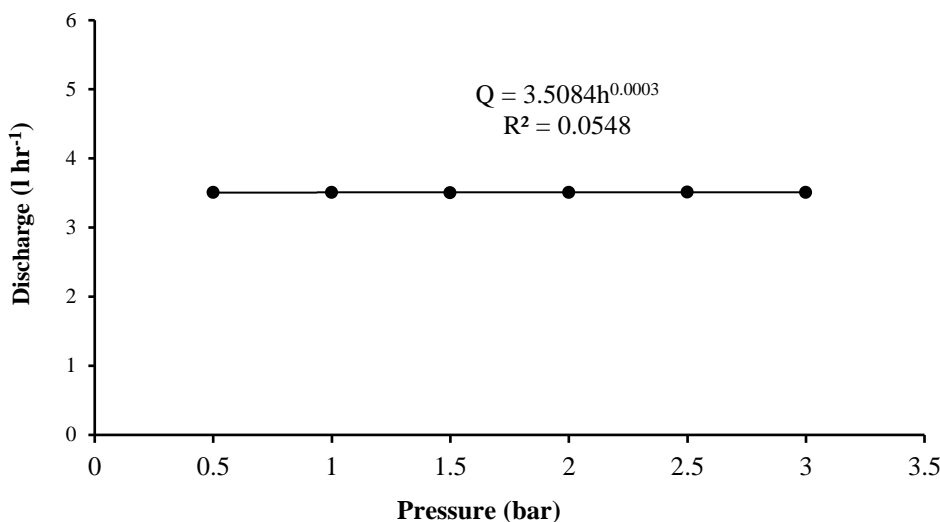
(a) Moistube



(b) SLECI type M



(c) SLECI type XL



(d) Self-regulating drippers

Figure 3 Discharge- pressure relationship

Moistube discharge under increasing pressure variation can be represented by a power function ($R^2=0.99$) as illustrated in Figure 3a. Average discharge varies from $0.3 \text{ L hr}^{-1} \text{ m}^{-1}$ at 1.47 m to $7.94 \text{ L hr}^{-1} \text{ m}^{-1}$ at 15 m. Pearson test indicates a high positive correlation between discharge and operating pressure $r=0.992^{**}$ ($p < 0.01$). The relationship between discharge and pressure can be expressed by the equation $Q = 0.1812h^{1.3853}$, an exponent value greater than 1 indicates that the Moistube is sensitive to changes in pressure and has intolerant, similar to drippers without pressure compensation, which means that the length maintained during installation must be short (Kirnak et al., 2004).

The value of the exponent shows that the flow regime is laminar (Clark et al., 2007), this suggests the need to maintain an adequate Moistube length during installation in the field, or to adopt a high-performance design to ensure uniform water flow velocity through the system. The high sensitivity of the Moistube discharge to pressure variation, as indicated by the exponent value greater than 1, is coherent with studies carried out for porous irrigation pipes (Pinto et al., 2014; Kanda et al., 2018; Hallam and Lahlali, 2021). According to the equation, there will be no discharge from the Moistube at zero pressure. As explained by Zhang (2013), Moistube discharge varies with soil water potential and system pressure. Therefore, in the absence of pressure, flow

will only be obtained if there is suction from the surrounding soil.

The capacity of soil to suction depends on a number of factors, including soil texture, moisture content and the presence of organic matter. In a laboratory the conditions can be controlled to simulate different suction pressures. In order to make comparisons with field conditions it is important to be aware that the maximum suction pressure exerted by the surrounding soil is typically around 80 kPa for natural water.

The Figures 3b and 3c show that the discharge of SLECI type M and XL elements increases with increasing pressure. The Pearson test showed a high positive correlation between flow rate and operating pressure $r=0.978^{**}$ ($p < 0, 01$) type M and $r=0.981^{**}$ ($p < 0.01$) type XL. The relationship between discharge and operating pressure is expressed by $Q = 0.1184h^{0.6664}$ for the type M and $Q = 0.2837h^{0.7024}$ for the type XL, According to the two equations, the values of X indicate that the SLECI system is tolerant to pressure variations.

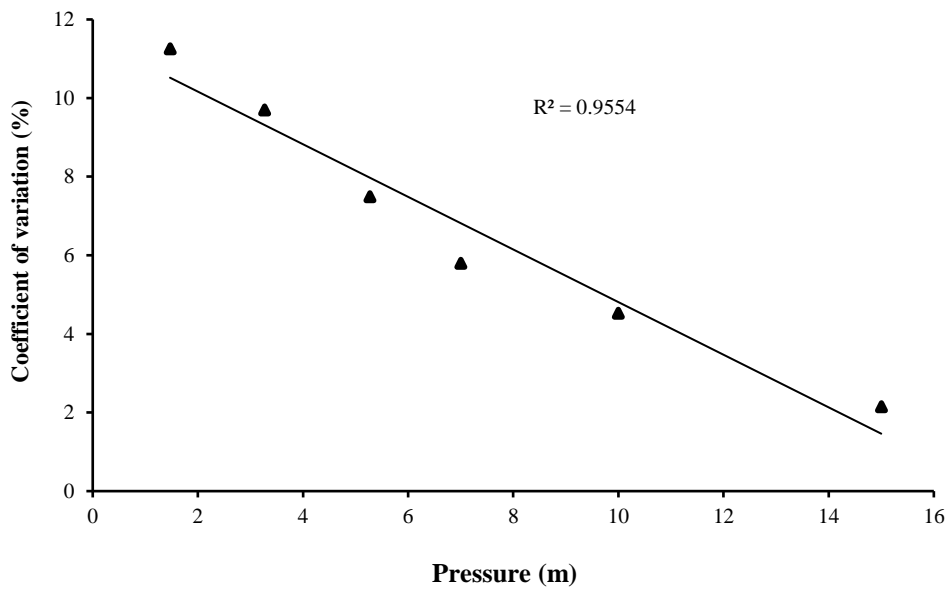
Exponent values for the SLECI system intermediate between 0.5 and 1 represent partially turbulent flow. The curves show that from a pressure of 4.5 the discharge variation is almost stationary, indicating that all the micropores in this system are active over a pressure of 5m, contrary to the Moistube system. Our results indicate that operating pressure is

the main factor controlling the two systems, as suction from the surrounding soil would be negligible at very low operating pressures. Depending on the pore density of the SLECI elements, the flow rate of type M is lower than that of type XL at all operating pressures. Increasing pressure variation helps to produce more water through inactive pores at low pressures. However, increasing pressure increases the volume of moistened soil and the infiltration capacity.

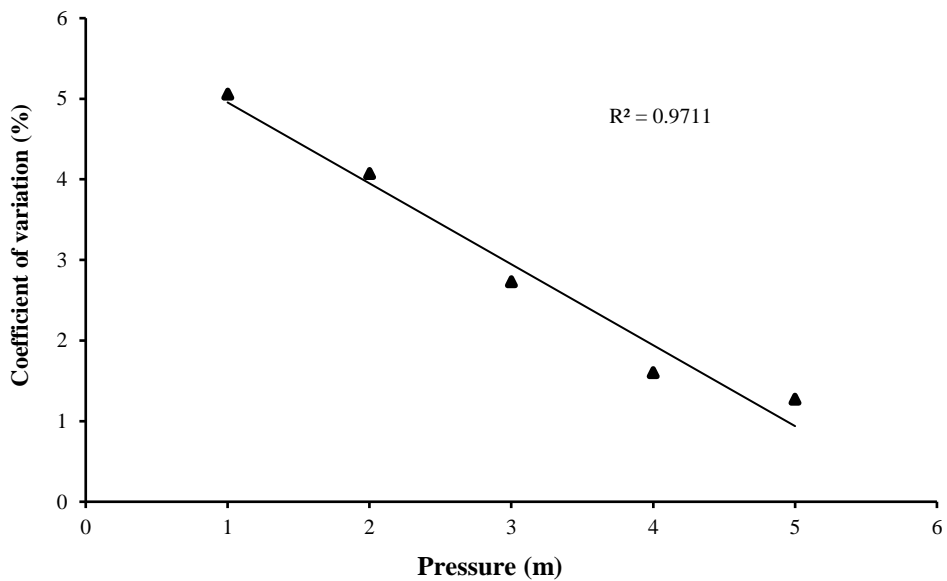
According to the results obtained, the discharge of the self-regulating dripper is less affected by pressure variation, varying between 3.50 L h⁻¹ and 3.51 L h⁻¹ as shown in Figure 3d. The discharge-pressure

relationship is expressed as a power function $Q = 3.5084h^{0.0003}$, whose exponent value x indicates that the dripper is highly tolerant to pressure variation. The results are in accordance with the findings of the tests conducted on self-regulating drippers (3.5 L h⁻¹) at the Hydraulics and Standardization Laboratory of the Directorate of Irrigation and Agricultural Spatial Planning. These drippers are essential for efficient irrigation, especially where the terrain is subject to pressure variations (slopes). They deliver a uniform quantity of water to the plants, precisely and evenly over long installations.

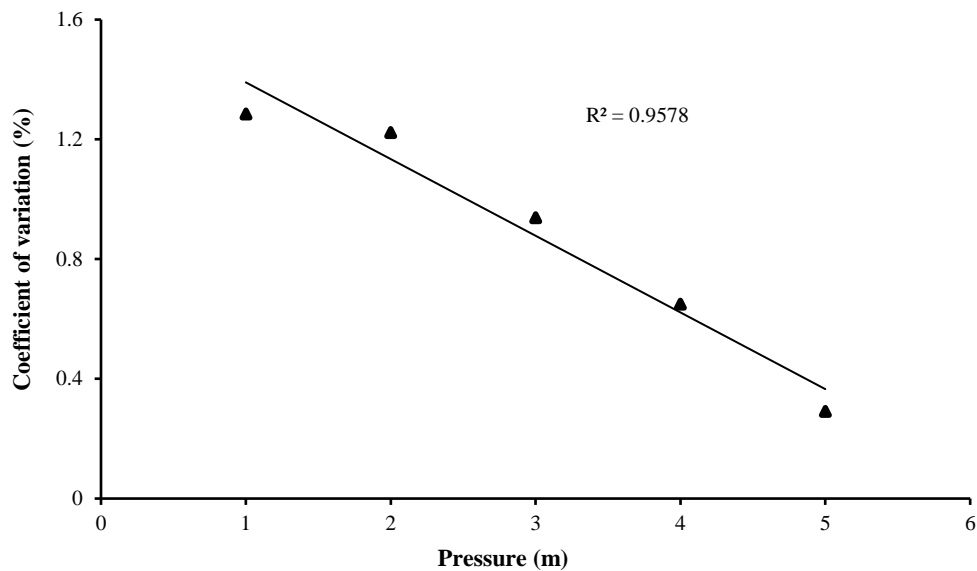
3.2 Emission uniformity along the lateral



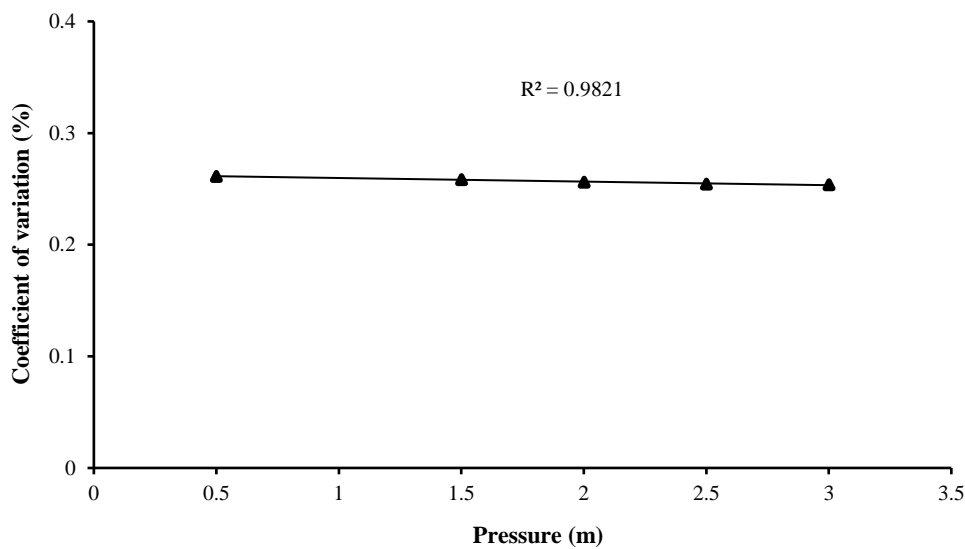
(a) Moistube



(b) SLECI type M



(c) SLECI type XL



(d) Self-regulating drippers

Figure 4 Emission variation along lateral length varying pressure

CV ranged from 2.14% to 11.24%, with an average of 6.81% (Figure 4a), which is within the acceptable range (<20%) for line-source emitters (Teeluck and Sutton, 1998). CV decreased linearly ($R^2= 0.95$) with increasing pressure. This can be attributed to pore enlargement and an increase in the number of active pores that did not emit at low pressures. Consequently, the Moistube can be designed and operated at pressures between 3 m and 15 m where CV values are below 10% to ensure good uniformity of water distribution during irrigation. The lower the CV, the higher the emission uniformity, and the greater the assurance that the crop receives the required amount of water. The results of this study

show that acceptable uniformity can be achieved with a Moistube length in excess of 20 m. CV values were better than those for porous plastic pipes found by Teeluck and Sutton (1998) (23.9%-58%) and Liang et al. (2009) (14.3%- 48.7%). The results obtained are consistent with those of Kanda et al. (2018) (4.4%-16.1%) and Hallam and Lahlali (2021) (4.32%-18.86%) .

Figures 4b and 4c show that CV ranged from 1.27% to 5.05% with an average of 2.94% for SLECI type M and from 0.29% to 1.28% with an average of 0.87% for SLECI type XL, indicating good homogeneity for type M and very good homogeneity for type XL. CV decreased linearly for the two types M ($R^2= 0.97$) and

XL ($R^2= 0.97$) and XL ($R^2= 0.95$) with increasing pressure. What Moistube and SLECI irrigation have in common is that increasing pressure activates more pores to diffuse water during irrigation. The quantity of water delivered by these systems to the crops depends essentially on the operating pressures, the higher the needs for water of the crops, the greater the need to work with high pressures.

CV values range from 0.25% to 0.26%, indicating very good homogeneity of water distribution for self-regulating drippers. As opposed to Moistube and SLECI, the coefficient of variation remains stable with increasing pressure.

4 Conclusion

The comparative study between the new nano-irrigation systems and conventional drip irrigation focused principally on defining the discharge-pressure characteristics of each system and determining the coefficient of variation under different ramp lengths and operating pressures. The results of this study show that Moistube and SLECI flow rate increases with pressure. The best operating pressure range for Moistube irrigation is between 3m and 15m, where CV values are below 10%. The high sensitivity of these systems to smaller changes in pressure would be a problem in successfully obtaining a homogeneous flow rate in the field. The optimum length of the ramp must not exceed 40 m. Self-regulating dripper flow is less affected by pressure variation. Compared to the Moistube and SLECI, self-regulating drippers are recommended for efficient irrigation, especially where the terrain is subject to pressure variations (slopes). They deliver a uniform quantity of water to the plants, precisely and evenly over long installations.

As Moistube and SLECI irrigation technologies are still experimental, it is essential to conduct field-limited and laboratory tests to refine their design. Key areas of study include installation costs, energy efficiency, and resistance to clogging under various pressures, especially due to suspended solids in water. Since these systems are suited for arid zones, it's

crucial to assess their durability in high temperatures and examine efficient fertilizer application using this nanotechnology. This research will help determine the most appropriate irrigation system for specific conditions.

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