Journal of Scientific Research and Reports

Volume 30, Issue 8, Page 35-45, 2024; Article no.JSRR.120094
ISSN: 2320-0227

Approximation of the Pressure-discharge Curve in Inline Drip Irrigation System

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jsrr/2024/v30i82222

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/120094

Original Research Article

Received: 02/03/2024
Accepted: 12/07/2024
Published: 15/07/2024

ABSTRACT

The efficiency of drip irrigation systems depends directly on the uniformity of water discharge from emission devices. Ideally, all emitters should discharge equal amounts of water, but variations occur due to hydraulic and manufacturing factors. This study established the pressure-discharge relationship curve and determined emitter flow variation caused by the hydraulic and the manufacturer's coefficients of variation for 2 and 4 lph inline emitters. The power exponent and constant of the pressure-discharge curve were determined by measuring the emitter flow rates at operating pressures ranging from 0.2 to 3.0 kg/cm². The emitter flow rates of 100 emitters were measured at an operating pressure of 1.0 kg/cm² to determine the manufacturing coefficient (V_m) and emitter flow variation ($q_{var(m)}$). The discharge exponent was found to be 0.46 for both emitter flow rates, with proportionality constants of 0.692 for 2 lph and 1.387 for 4 lph emitters respectively. The results showed a strong correlation between pressure and flow rate, with RMSE values of 0.51 and 0.34 lph, and coefficients of determination of 0.988 and 0.991 for 2 and 4 lph emitters,

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Cite as: *A. N., Kunapara, Subbaiah R., and Patel G. R. 2024. "Approximation of the Pressure-Discharge Curve in Inline Drip Irrigation System". Journal of Scientific Research and Reports 30 (8):35-45. https://doi.org/10.9734/jsrr/2024/v30i82222.*

respectively. High manufacturing precision was indicated by low V_m values of 0.0491 for 2 lph and 0.055 for 4 lph emitters, while $q_{var(m)}$ values were 0.261 for 2 lph and 0.283 for 4 lph emitters. Total coefficient of variation (V_q) values were 0.1 for 2 lph and 0.14 for 4 lph emitters, with total emitter flow variations (q_{var}) of 0.29 for 2 lph and 0.39 for 4 lph emitters. The study established the pressure-discharge curve for inline drip irrigation systems, emphasizing the critical relationship between pressure and flow rate. The derived chart from pressure discharge relationship is a valuable tool for estimating emitter flow variation due to hydraulic variation within the same subunit. Precise manufacturing and effective management of hydraulic variations are essential for ensuring uniform water distribution, optimizing drip irrigation systems, and ultimately enhancing crop yield and resource utilization.

Keywords: Drip irrigation; hydraulic coefficient of variation; Inline emitter; uniformity; manufacturing coefficient of variation; pressure discharge relationship.

1. INTRODUCTION

The drip system is the best irrigation system because of its excellent distribution uniformity. Drip irrigation is the most effective way to irrigate vegetables and horticulture crops [1]. This approach is popular because it can effectively manage fertilizer and water [2,3]. By frequently applying small amounts of irrigation water to various surface and subsurface areas near plants, drip irrigation systems have been shown to save 27–42% of water when compared to other methods [4,5,6]. Plants are irrigated by a drip irrigation system through a network of emitters and pipes. An attempt has been made to address some of the issues through automation. With temperature differential values as its foundation, the microcontroller-based system-maintained soil moisture content closer to the field capacity (30.02%). The developed system uses 8.6% less water and 49.6% less water than manually operated drip irrigation and check basin irrigation systems, respectively [7]. While the theory behind the drip irrigation system's ability to conserve water and fertilizer is sound, it's not always easy to implement. The method's high irrigation efficiency potential can be lost through improper design, management, and maintenance, which can result in ineffective operations and uneven field emitter discharge. In an attempt to get around these problems, irrigations frequently overirrigate their fields. Over-irrigation can result in the waste of water and nutrients.

Planning a drip irrigation system requires careful consideration of the emitters' hydraulic performance. The pressure drop's uneven distribution is the primary problem. Testing the hydraulic performance of a drip irrigation system is essential after installation. The topography of the field and the drip system's hydraulic performance both affect the field's water distribution disparities by varying the pressure heads that are available at various emitters. Thus, it is imperative to conduct research on the relationship between operating pressure and emitter discharge. As pressure variation increases, there is an increase in water loss because of a decrease in system uniformity and application efficiency [8]. However, plants can receive the water and fertilizer they require by applying it directly to their root zones through carefully designed drip irrigation systems. This technique maintains the soil's optimal moisture content while reducing water loss. Tough terrain can also be accommodated by customizing drip irrigation systems [9]. Using an online dripper that delivered 4 litres per hour, Manisha et al. [10] conducted a field experiment to investigate the hydraulic performance of a drip irrigation system. According to their research, 1.2 to 1.5 $kgcm^{-2}$ is the ideal pressure range for drip irrigation. The average emission uniformity coefficient was 95.04 percent, 95.95 percent, 94.44 percent, and 87.63 percent at 1.5, 0.9, and 0.7 $kgcm^{-2}$ pressure, respectively. Deshmukh et al. [11] tested a levelled field with inline emitters discharging 1.3 lph and 2.4 lph, respectively, for pressures of 0.7, 0.9, 1.2, and 1.5 $kgcm^{-2}$. 1.5 $kgcm^{-2}$ was found to be the optimal pressure for running the 1.3 and 2.4 l lph emitters. Popale et al. [12] evaluated the hydraulic performance of a drip irrigation system at various pressures (0.75, 1, and 1.25 $kgcm^{-2}$) using two emission devices: an online dripper (8 lph) and a drip-in dripper (1.3 lph). The findings demonstrated that while the coefficient of variation decreased, emission uniformity and uniformity of the uniformity coefficient both increased as operating pressure increased. Watering every plant in a field with the same amount of water would be very difficult, if not impossible, even with an irrigation system. Bhatnagar and Srivastava [13] state that inconsistent irrigation practices are a major factor in many cases of lower crop yields. Thus, the purpose of this study was to evaluate the drip irrigation system's hydraulic and manufacturing variation and to establish a pressure discharge relationship.

2. MATERIALS AND METHODS

2.1 Experimental Details

In order to assess the hydraulic performance of 2 and 4 lph inline emitters, an experiment was conducted in 2022 at the Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Anand Agricultural University, Godhra, which is located at Latitude 22°46'53.8"N Longitude 73°39'26.2".

The drip irrigation system used for the experimentation was composed of several key components designed to optimize water distribution efficiency. The system featured a water tank with a capacity of 2000 litres, ensuring a sufficient water supply for irrigation needs. At the control head, the system was equipped with a 1.0 horse power pump and two types of filters: a hydro cyclone filter and a disc filter, which together ensured the water was adequately filtered before distribution as shown in Fig. 1.

The distribution network of the system was thoughtfully designed with durable materials and precise specifications. The main line was selected of PVC with a diameter of 75 mm, while the sub-main line was constructed from HDPE and measured 63 mm in diameter. For the lateral lines, LDPE was used, and these lines had a diameter of 16 mm. The emitters used were of the inline type, with two different discharge rates available: 2 lph and 4 lph. The emitters were spaced at 60 cm intervals along the lateral length 60 m. This setup allowed for precise water delivery evaluation of different hydraulic parameters.

2.2 Emitter Flow Variations Caused by Hydraulics

Solomon and Keller [14] computed the distribution of emission rates within drip irrigation systems under various circumstances. Assuming a Hat field, they first developed a general expression for the pressure available at any point within the system's pipe network. This allowed the calculation of the emitter flow rate to be expected at any point, based on the assumed emitter flow rate equation: The equation for drip irrigation emitter flow, as demonstrated by Wu and Giltin [15], is as follows:

$$q = kh^x \quad (1)$$

Where q, k, h, and x represent the flow of the emitter, the constant of proportionality, the pressure head, and the discharge exponent of the emitter, respectively. Assuming that all emitters in the system respond to pressure as indicated by above equation, these calculations determine the expected distribution of average emission rates corresponding to the various pressures throughout the system.

Fig. 1. Experimental set up of drip irrigation system

The emitter flow variation along a lateral line caused by hydraulics was determined by emitter flow profiles. Since the emitter profiles are smooth curves for uniform slope situations, the emitter flow variation [15] can also be shown by comparing maximum and minimum emitter flows and can be expressed as

$$q_{var(H)} = \frac{q_{max(H)} - q_{\min(H)}}{q_{\max(H)}} \quad (2)$$

Where, $q_{var(H)}$ is the emitter flow variation by hydraulics and $q_{max(H)}$ and $q_{min(H)}$ are maximum and minimum emitter flow, respectively. A definite relationship between the UCC and $q_{var(H)}$ was developed by Wu et al. [14] and showed that a 10 percent emitter flow variation, $q_{var(H)}$ is equivalent to a Christiansen uniformity coefficient, UCC, 97.5 percent and a 20 percent $q_{var(H)}$ is equivalent to a UCC of 95 percent. The Hydraulic variation of emitter flow usually is expressed statistically by hydraulics coefficient of variation which is:

$$V_H = \frac{S_H}{\bar{q}_H} \quad (3)$$

Where, the V_H is hydraulics coefficient of variation of emitter flow, $\bar{q}_H$ is the mean emitter flow and S_H is the standard deviation of emitter flow. In this study, the variations in emitter flow caused by hydraulic factors were investigated. Specifically, emitter flow rates of 2 and 4 litres per hour (lph) were measured under different pressure conditions. The relationship between pressure and discharge was established for all three emitter flow rates.

2.3 Emitter Flow Variations Caused by Manufacturer

The manufacturing variation of emitter flow usually is expressed statistically by manufacturer's coefficient of variation given by the Wu and Gitlin [15]:

$$V_m = \frac{S_m}{\bar{q}_m} \quad (4)$$

Where, the V_m is manufacturer's coefficient of variation of emitter flow, $\bar{q}_m$ is the mean emitter flow and S_m is the standard deviation of emitter flow. The ASAE interpretation of manufacturing coefficient of variation is shown in Table 1.

The manufacturing variation of emitter flow exists in any emitter at any section of the lateral line based on a normal distribution. The emitter flow variation caused by the manufacturer and expressed by $q_{\min(m)}$ and $q_{\max(m)}$ can be defined by the Wu and Gitlin [15]:

$$q_{var(m)} = 1 - \frac{q_{\min(m)}}{q_{\max(m)}} \quad (5)$$

Where, $q_{var(m)}$ is the emitter flow variation by manufacturing. The sample included 100 emitters for each discharge rate of 2 and 4 lph. The measurements were conducted under the recommended operating pressure of 1 kg/cm² for each emitter sperately as depicted in Fig. 2.

2.4 The Total Variation of Emitter Flow

Previous sections show the effect of emitter flow variations caused by hydraulics and manufacturer's variation separately [16]. However, the emitter flow variation for a drip irrigation system in the field was affected by both hydraulics and manufacturer's variation. The total variance can be determined considering that the variation caused by hydraulics and manufacturer can be linearly combined as shown by Bralts et al. [17]:

$$V_q^2 = V_H^2 + V_m^2 \quad (6)$$

Where, V_q is the total coefficient of variation caused by hydraulics V_h and manufacturing V_m. The total coefficient of variation can be determined as

$$V_q = \sqrt{V_H^2 + V_m^2} \quad (7)$$

The total emitter flow variation can also be shown by maximum and minimum emitter flow as shown in equation above and proposed by Bralts [17].

2.5 Root Mean Squared Error (RMSE)

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{n}\left|(O)_i - (P)_i\right|^2}, \quad (0 \le \text{RMSE} \le +\infty) \quad (8)$$

Above Equation is commonly used to calculate the root mean squared error (RMSE), which is a metric that quantifies the overall agreement between observed and modelled datasets in real units. Unlike the mean absolute error (MAE), the RMSE considers the weighted measure of the error, giving more importance to larger deviations between observed and modelled values. It is computed by taking the square root of the average of the squared differences between observed and modelled values.

Table 1. Recommended classification of manufacture's coefficient of variation

Emitter type	V_m range	Classification
Point Source	<0.05	Good
	0.05 to 0.10	Average
	0.10 to 0.15	Marginal
	>0.15	Unaccepted
Line Source	<0.10	Good
	0.10 to 0.20	Average
	>0.20	Marginal

Source: Design, installation, and performance of drip irrigation system, ASAE, Engineering Practice, 1985, ASAE EP 405

Fig. 2. Measurement flow of distinct emitter for calculation of manufacturer's coefficient of variation

The Advances in Water Resource and Protection has several characteristics and considerations. First, it is a non-negative metric that has no upper limit, with a perfect model resulting in an RMSE value of zero, indicating a perfect match between observed and modelled data. Second, the RMSE is more sensitive to high magnitude events and peaks, as the squaring process amplifies the impact of larger errors. It tends to be less sensitive to low magnitude events.

When comparing RMSE values across different datasets or events, it is important to consider the scale of the data being analysed. The evaluation metric is dependent on the dataset's scale, which can lead to variations in the assessment of different catchments.

It is worth mentioning that RMSE is comparable to other metrics such as sum squared error (SSE) and mean squared error (MSE), but it is generally preferred due to its representation in the original units of the data, making it more interpretable. SSE and MSE are expressed in squared units, which can make interpretation more challenging.

While RMSE provides valuable information about the overall agreement between observed and modelled data, it should not be considered in isolation. It is recommended to assess model performance using multiple evaluation criteria, such as MAE, R-squared (coefficient of determination) and visual inspection of the observed versus modelled data. This comprehensive approach ensures a more thorough understanding of the model's accuracy and predictive capabilities.

3. RESULTS AND DISCUSSION

3.1 Hydraulic Performance of Emitter

The hydraulic performance of the inline emitters, specifically the variations in emitter flow rates due to changes in pressure, was evaluated using the relationship of *q, k, h,* and *x* mentioned in equation. The experimental data for both 2 lph and 4 lph emitters were analyzed to derive specific equations representing their flow characteristics as shown in equation 9 and 10 for 2 and 4 lph emitter flow rate respectively.

$$Q = 0.692H^{0.46}, \quad R^2 = 0.988 \qquad (9)$$

$$Q = 1.387H^{0.46}, \quad R^2 = 0.991 \qquad (10)$$

Where, Q emitter flow in litre per hour and H is inlet pressure (m). For the 2 and 4 lph emitter, the flow rate equations were determined with a RSME (0.51 and 0.34 respectively), indicating a strong correlation between the pressure head and the emitter flow rate. The observed and predicted value of emitter flow rate are shown in Figs. 5 and 6 for 2 and 4 lph emitter respectively. Using the derived relationship of pressure discharge from equation 9 and 10, the charts were prepared to predict for 2 and 4 lph emitter flow variation caused by hydraulics ($q_{var(H)}$) as depicted in Tables 2 and 3 respectively. The predicted chart is important tool for estimation of emitter flow variation due to hydraulic variation within same subunit. However, achieving the highest uniformity of water application requires careful consideration of both hydraulic and manufacturing variations.

The graphical representations of these relationships for 2 and 4 lph emitter showed that as the pressure head increased, the flow rate of the emitters also increased in accordance with the derived equations as depicted in Figs. 3 and 4 respectively. The consistency of the discharge exponent (0.46) across both emitter types suggests a similar hydraulic behaviour in response to pressure changes. These results highlight the reliability and predictability of the emitters under varying pressure conditions, which is crucial for ensuring uniform water distribution in the drip irrigation system. The strong correlation coefficient values underscore the accuracy of the modelled equations, reinforcing their applicability in practical irrigation scenarios to optimize water usage and enhance crop growth efficiency. The results are in conformity with the findings of Deshmukh et al. [11], Myres and Bucks [18], and Shashi kant [19].

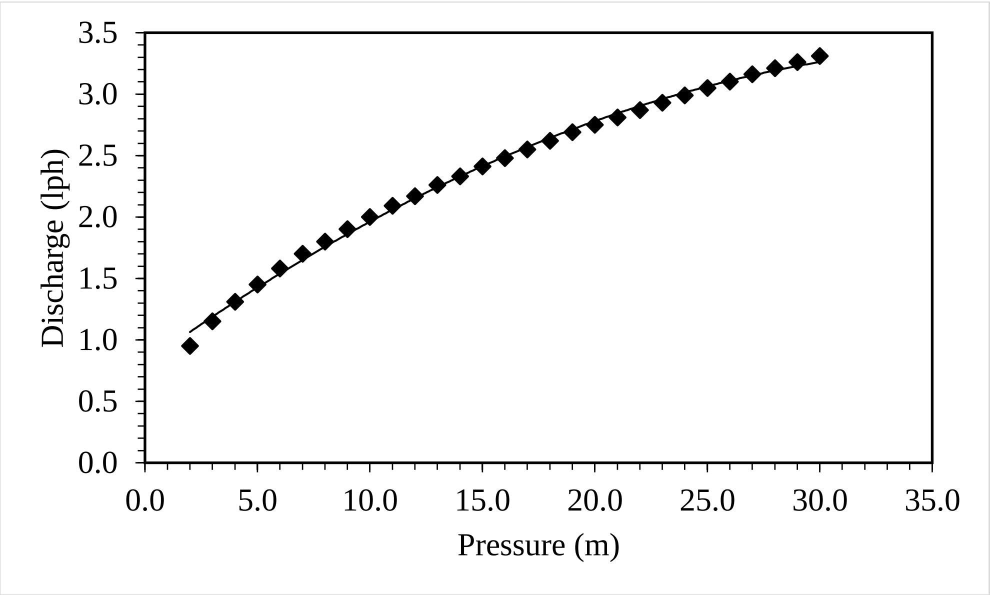

Fig. 3. Pressure discharge relationship of 2 lph emitter

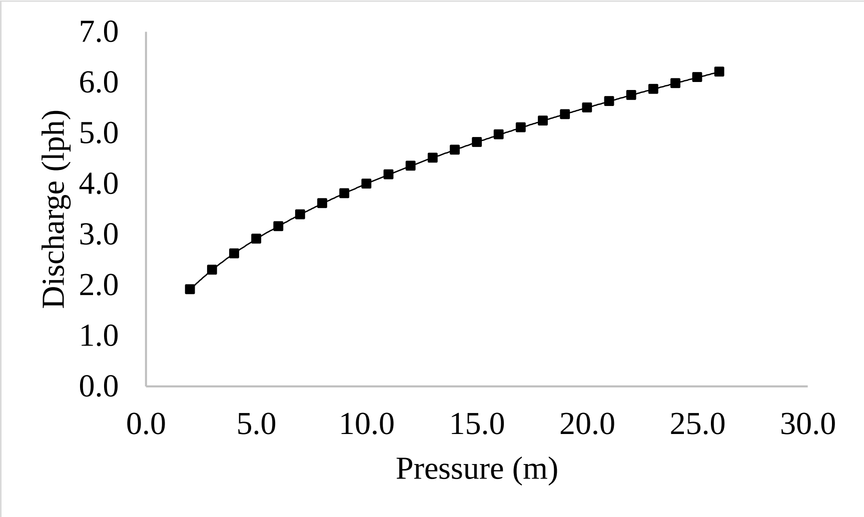

Fig. 4. Pressure discharge relationship of 4 lph emitter

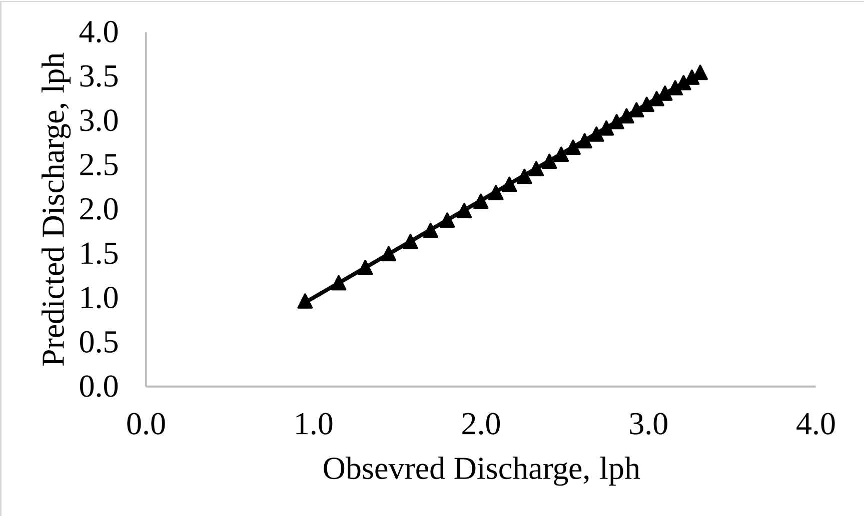

Fig. 5. Observed and predicted discharge for 2 lph emitter

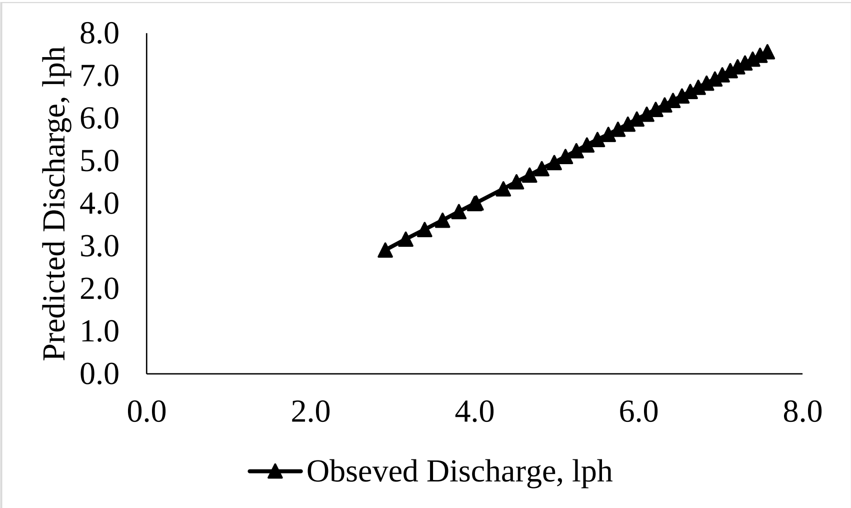

Fig. 6. Observed and predicted discharge for 2 lph emitter

Table 2. Prediction hydraulic variation of emitter flow ($q_{var(H)}$) at different inlet and outlet pressures for 4 lph emitter discharges

		Inlet Pressure (meter)																											
	Pressure	**30**	**29**	**28**	**27**	**26**	**25**	**24**	**23**	**22**	**21**	**20**	**19**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**
Outlet Pressure (meter)	**2**	0.71	0.71	0.70	0.70	0.69	0.69	0.68	0.67	0.67	0.66	0.65	0.64	0.64	0.63	0.62	0.60	0.59	0.58	0.56	0.54	0.52	0.50	0.47	0.44	0.40	0.34	0.27	0.17
	3	0.65	0.65	0.64	0.64	0.63	0.62	0.62	0.61	0.60	0.59	0.58	0.57	0.56	0.55	0.54	0.52	0.51	0.49	0.47	0.45	0.43	0.40	0.36	0.32	0.27	0.21	0.12	
	4	0.60	0.60	0.59	0.58	0.58	0.57	0.56	0.55	0.54	0.53	0.52	0.51	0.50	0.49	0.47	0.46	0.44	0.42	0.40	0.37	0.34	0.31	0.27	0.23	0.17	0.10		
	5	0.56	0.55	0.55	0.54	0.53	0.52	0.51	0.50	0.49	0.48	0.47	0.46	0.45	0.43	0.41	0.40	0.38	0.36	0.33	0.30	0.27	0.24	0.19	0.14	0.08			
	6	0.52	0.52	0.51	0.50	0.49	0.48	0.47	0.46	0.45	0.44	0.43	0.41	0.40	0.38	0.36	0.34	0.32	0.30	0.27	0.24	0.21	0.17	0.12	0.07				
	7	0.49	0.48	0.47	0.46	0.45	0.44	0.43	0.42	0.41	0.40	0.38	0.37	0.35	0.34	0.32	0.30	0.27	0.25	0.22	0.19	0.15	0.11	0.06					
	8	0.46	0.45	0.44	0.43	0.42	0.41	0.40	0.38	0.37	0.36	0.34	0.33	0.31	0.29	0.27	0.25	0.23	0.20	0.17	0.14	0.10	0.05						
	9	0.43	0.42	0.41	0.40	0.39	0.37	0.36	0.35	0.34	0.32	0.31	0.29	0.27	0.25	0.23	0.21	0.18	0.16	0.12	0.09	0.05							
	10	0.40	0.39	0.38	0.37	0.36	0.34	0.33	0.32	0.30	0.29	0.27	0.26	0.24	0.22	0.19	0.17	0.14	0.11	0.08	0.04								
	11	0.37	0.36	0.35	0.34	0.33	0.31	0.30	0.29	0.27	0.26	0.24	0.22	0.20	0.18	0.16	0.13	0.11	0.07	0.04									
	12	0.34	0.33	0.32	0.31	0.30	0.29	0.27	0.26	0.24	0.23	0.21	0.19	0.17	0.15	0.12	0.10	0.07	0.04										
	13	0.32	0.31	0.30	0.29	0.27	0.26	0.25	0.23	0.21	0.20	0.18	0.16	0.14	0.12	0.09	0.06	0.03											
	14	0.30	0.28	0.27	0.26	0.25	0.23	0.22	0.20	0.19	0.17	0.15	0.13	0.11	0.09	0.06	0.03												
	15	0.27	0.26	0.25	0.24	0.22	0.21	0.19	0.18	0.16	0.14	0.12	0.10	0.08	0.06	0.03													
	16	0.25	0.24	0.23	0.21	0.20	0.19	0.17	0.15	0.14	0.12	0.10	0.08	0.05	0.03														
	17	0.23	0.22	0.21	0.19	0.18	0.16	0.15	0.13	0.11	0.09	0.07	0.05	0.03															
	18	0.21	0.20	0.18	0.17	0.16	0.14	0.12	0.11	0.09	0.07	0.05	0.02																
	19	0.19	0.18	0.16	0.15	0.13	0.12	0.10	0.08	0.07	0.04	0.02																	
	20	0.17	0.16	0.14	0.13	0.11	0.10	0.08	0.06	0.04	0.02																		
	21	0.15	0.14	0.12	0.11	0.09	0.08	0.06	0.04	0.02																			
	22	0.13	0.12	0.11	0.09	0.07	0.06	0.04	0.02																				
	23	0.12	0.10	0.09	0.07	0.05	0.04	0.02																					
	24	0.10	0.08	0.07	0.05	0.04	0.02																						
	25	0.08	0.07	0.05	0.03	0.02																							
	26	0.06	0.05	0.03	0.02																								
	27	0.05	0.03	0.02																									
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	29	0.02																											

Table 3. Prediction hydraulic variation of emitter flow ($q_{var(H)}$) at different inlet and outlet pressures for 4 lph emitter discharges

		Inlet Pressure (meter)																											
	Pressure	**30**	**29**	**28**	**27**	**26**	**25**	**24**	**23**	**22**	**21**	**20**	**19**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**
Outlet Pressure (meter)	**2**	0.71	0.71	0.70	0.70	0.69	0.69	0.68	0.67	0.67	0.66	0.65	0.64	0.64	0.63	0.62	0.60	0.59	0.58	0.56	0.54	0.52	0.50	0.47	0.44	0.40	0.34	0.27	0.17
	3	0.65	0.65	0.64	0.64	0.63	0.62	0.62	0.61	0.60	0.59	0.58	0.57	0.56	0.55	0.54	0.52	0.51	0.49	0.47	0.45	0.43	0.40	0.36	0.32	0.27	0.21	0.12	
	4	0.60	0.60	0.59	0.58	0.58	0.57	0.56	0.55	0.54	0.53	0.52	0.51	0.50	0.49	0.47	0.46	0.44	0.42	0.40	0.37	0.34	0.31	0.27	0.23	0.17	0.10		
	5	0.56	0.55	0.55	0.54	0.53	0.52	0.51	0.50	0.49	0.48	0.47	0.46	0.45	0.43	0.41	0.40	0.38	0.36	0.33	0.30	0.27	0.24	0.19	0.14	0.08			
	6	0.52	0.52	0.51	0.50	0.49	0.48	0.47	0.46	0.45	0.44	0.43	0.41	0.40	0.38	0.36	0.34	0.32	0.30	0.27	0.24	0.21	0.17	0.12	0.07				
	7	0.49	0.48	0.47	0.46	0.45	0.44	0.43	0.42	0.41	0.40	0.38	0.37	0.35	0.34	0.32	0.30	0.27	0.25	0.22	0.19	0.15	0.11	0.06					
	8	0.46	0.45	0.44	0.43	0.42	0.41	0.40	0.38	0.37	0.36	0.34	0.33	0.31	0.29	0.27	0.25	0.23	0.20	0.17	0.14	0.10	0.05						
	9	0.43	0.42	0.41	0.40	0.39	0.37	0.36	0.35	0.34	0.32	0.31	0.29	0.27	0.25	0.23	0.21	0.18	0.16	0.12	0.09	0.05							
	10	0.40	0.39	0.38	0.37	0.36	0.34	0.33	0.32	0.30	0.29	0.27	0.26	0.24	0.22	0.19	0.17	0.14	0.11	0.08	0.04								
	11	0.37	0.36	0.35	0.34	0.33	0.31	0.30	0.29	0.27	0.26	0.24	0.22	0.20	0.18	0.16	0.13	0.11	0.07	0.04									
	12	0.34	0.33	0.32	0.31	0.30	0.29	0.27	0.26	0.24	0.23	0.21	0.19	0.17	0.15	0.12	0.10	0.07	0.04										
	13	0.32	0.31	0.30	0.29	0.27	0.26	0.25	0.23	0.21	0.20	0.18	0.16	0.14	0.12	0.09	0.06	0.03											
	14	0.30	0.28	0.27	0.26	0.25	0.23	0.22	0.20	0.19	0.17	0.15	0.13	0.11	0.09	0.06	0.03												
	15	0.27	0.26	0.25	0.24	0.22	0.21	0.19	0.18	0.16	0.14	0.12	0.10	0.08	0.06	0.03													
	16	0.25	0.24	0.23	0.21	0.20	0.19	0.17	0.15	0.14	0.12	0.10	0.08	0.05	0.03														
	17	0.23	0.22	0.21	0.19	0.18	0.16	0.15	0.13	0.11	0.09	0.07	0.05	0.03															
	18	0.21	0.20	0.18	0.17	0.16	0.14	0.12	0.11	0.09	0.07	0.05	0.02																
	19	0.19	0.18	0.16	0.15	0.13	0.12	0.10	0.08	0.07	0.04	0.02																	
	20	0.17	0.16	0.14	0.13	0.11	0.10	0.08	0.06	0.04	0.02																		
	21	0.15	0.14	0.12	0.11	0.09	0.08	0.06	0.04	0.02																			
	22	0.13	0.12	0.11	0.09	0.07	0.06	0.04	0.02																				
	23	0.12	0.10	0.09	0.07	0.05	0.04	0.02																					
	24	0.10	0.08	0.07	0.05	0.04	0.02																						
	25	0.08	0.07	0.05	0.03	0.02																							
	26	0.06	0.05	0.03	0.02																								
	27	0.05	0.03	0.02																									
	28	0.03	0.02																										
	29	0.02																											

3.2 Manufacturer's Coefficient of Variation

The assessment of manufacturing variation for the inline emitters was conducted by evaluating the manufacturer's coefficient of variation (V_m) and the emitter flow variation (q_{var}) for both 2 lph and 4 lph emitters. The measurement of emitter discharge rate for 100 emitters of 2 and 4 lph was undertaken at 1 kg/cm². After careful collection of measurements, the manufacturer's coefficient of variation was determined as 0.0491 and 0.055 for 2 and 4 lph emitters, respectively. Similarly, experimental tests conducted by Bralts [17] and Solomon [20] have indicated that the manufacturer's coefficient of variation for different emitters or lateral lines ranges from 0.05 to 0.20. The emitter flow variation (q_{var}) caused by the manufacturer was found to be 0.261 for the 2 lph emitters and 0.283 for the 4 lph emitters [21].

These values indicate that the 4 lph emitters exhibited slightly more variation in manufacturing consistency compared to the 2 lph emitters. The relatively low V_m values for both emitters suggest a high level of manufacturing precision, ensuring that the emitters perform consistently under identical pressure conditions. However, the slightly higher q_{var} values point to a greater degree of flow rate variability, which could impact the uniformity of water distribution in the irrigation system.

Understanding and minimizing manufacturing variations is critical for achieving optimal performance in drip irrigation systems, as even small discrepancies can lead to significant differences in water delivery to crops. The findings from this assessment highlight the importance of stringent quality control measures in the production of emitters to maintain uniform flow rates and enhance the overall efficiency of the irrigation system.

3.3 The Total Variation of Emitter Flow

Previous sections have shown the effect of emitter flow variations caused by hydraulics and manufacturer's variation separately. However, in a real-world drip irrigation system laid in the field, emitter flow variation is influenced by both hydraulics and manufacturer's variation simultaneously. To measure the total variation of emitter flow for a 2 lph emitter, a lateral line with 100 emitters spaced at 0.6 meters and with a diameter of 16 mm was laid in the field. The discharge of each emitter was recorded at an operating pressure of 1.5 kg/cm². Based on the obtained results, the total variation of emitter flow was determined for both 2 and 4 lph emitters.

The total coefficient of variation (q_{cv}) and emitter flow variation (q_{var}) were analyzed as system parameters. These values are constant for any soil type but will change if there are alterations in system parameters such as emitter discharge, lateral spacing, or diameter. In this study, the emitter discharge was varied as the system parameter. For the 2 lph emitter, the total coefficient of variation (q_{cv}) was found to be 0.10, and the emitter flow variation (q_{var}) was 0.29. For the 4 lph emitter, the q_{cv} increased to 0.14, and the q_{var} to 0.39.

The higher variation in the coefficient of variation and emitter flow rate for the 4 lph emitters compared to the 2 lph emitters may be attributed to the same lateral and emitter spacings. However, the total discharge becomes double for the 4 lph emitters for the same lateral length and emitter spacing as the 2 lph emitters. This increase in discharge can exacerbate the effects of both hydraulic and manufacturing variations, leading to greater inconsistency in water delivery. Understanding and managing these variations is essential for optimizing the efficiency and uniformity of water distribution in drip irrigation systems, ultimately leading to better crop yields and resource utilization.

4. CONCLUSIONS

Through this study, an in-depth investigation of the complex dynamics of how pressure influences the water flow from emitter devices in drip irrigation systems was carried out. An investigation was conducted to investigate the dynamic relationship between hydraulic parameters, such as fluctuations in pressure, and manufacturing quality, which together have an effect on the uniformity of water distribution. The research underlined the crucial significance that precise manufacturing procedures have in guaranteeing consistent performance among emitters. This was accomplished by identifying distinct patterns in how emitters react to varied operating pressures.

Additionally, the study highlighted the necessity of efficient hydraulic management in the context of agricultural settings in order to ensure appropriate water distribution. It was underlined that these parameters are not only vital for optimizing agricultural yields but also essential for the exploitation of water resources in a sustainable manner. Through the elucidation of these linkages, the research offers significant insights that can be used to influence the design and management of drip irrigation systems. The ultimate goal of the study is to improve efficiency and reduce water waste. The data, taken as a whole, highlight the fact that attaining uniform water distribution requires a delicate but important balance between hydraulic dynamics and manufacturing accuracy. It is essential to have this information in order to advance agricultural methods in the direction of increased production and environmental sustainability.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

HIGHLIGHTS OF RESEARCH

- Established pressure-discharge relationship curve for 2 and 4 lph emitters in drip irrigation systems.
- Determined consistent discharge exponent of 0.46 and proportionality constants for different emitter flow rates.
- Demonstrated strong correlation between pressure and flow rate, supported by high coefficients of determination.
- Highlighted high manufacturing precision with low coefficients of variation and emitter flow variations.
- - Emphasized the critical role of precise manufacturing and hydraulic management in achieving uniform water distribution and enhancing agricultural productivity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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