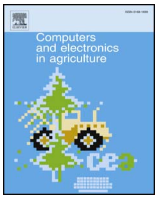
Computers and Electronics in Agriculture 142 (2017) 450–460

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag



Original papers

# Gene expression programming approach for modeling the hydraulic performance of labyrinth-channel emitters

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## ARTICLE INFO

*Keywords:*
Artificial intelligence
Drip irrigation
Emitter flow variation
Manufacturer's coefficient of variation

## ABSTRACT

The different hydraulic measures of emitter flow variation ($q_{var}$) and manufacturer's coefficient of variation ($CV_m$) at different operating pressure (P) and water temperature (T) were determined by measuring the discharge of different labyrinth-channel emitters. Gene expression programming (GEP) was used to model and predict $q_{var}$ and $CV_m$ of the labyrinth emitters. The structural parameters of each labyrinth emitter [namely, trapezoidal unit number (N), height (H), and spacing (S), and path width (W) and length (L)] as well as P and T were considered as independent variables. The accuracy of GEP models was evaluated by their coefficient of determination ($R^2$), root-mean-square error (RMSE), overall index of model performance (OI), and mean absolute error (MAE). Results of GEP applications established that L and S were the least important variables affecting $q_{var}$ and $CV_m$, respectively, while N and H were the most important variables. For $q_{var}$, the $GEP_{without\ L}$ model gave higher $R^2$ and OI and lower RMSE and MAE than those of the $GEP_{without\ S}$ model. Conversely, for $CV_m$, $R^2$ and OI of the $GEP_{without\ L}$ model were lower and its RMSE and MAE were higher than the corresponding parameters of the $GEP_{without\ S}$ model. Overall, our results indicated that the performance of the developed GEP models were better at predicting $q_{var}$ and $CV_m$ for non-pressure-compensating emitters than pressure-compensating ones. The GEP approach can be a good tool to predict the hydraulic performance of labyrinth emitters.

## 1. Introduction

Drip irrigation is considered the most efficient irrigation method because it can distribute water uniformly, precisely control the amount of water applied, and minimize evaporation, deep percolation, and salinity effects. Because of these advantages, drip irrigation has become a popular irrigation method. However, drip irrigation has some disadvantages; for example, decreased water distribution because of emitter clogging (Batchelor et al., 1996; Ayars et al., 1999). Emitters are either buried or placed on the soil surface, where they discharge water at a controlled rate. Water is supplied frequently to prevent moisture stress in the plants by maintaining favorable soil moisture conditions (Cook et al., 2003). Therefore, emitters play an important role in drip irrigation systems. Emitters are designed to discharge pressurized water from the pipes into the soil slowly and uniformly via energy dissipation in its internal structure. The internal structure of emitters greatly influences their hydraulic performance (Nakayama and Bucks, 1986).

Temperature variations influence water properties, especially viscosity, and this may affect emitter flow (Rodriguez-Sinobas et al., 1999). Emitters with labyrinth channels are used because of their simple structure and low cost. The labyrinth structure is the most important factor determining an emitter's performance (Alamoud et al., 2014; Zhang et al., 2011). Different dimensions within the labyrinth emitter can regulate discharge rate depending on the water pressure (Wei et al., 2007; Evans et al., 2007; Zhang et al., 2011). The transitional flow characteristics of labyrinth-channel emitters indicate that the internal flow is turbulent in practical pressure ranges (Evans et al., 2007; Zhao et al., 2009). Emitters with a square labyrinth cross section perform better than those with rectangular cross sections (Zhiqin and Lin, 2011).

Two uniformity criteria used in drip irrigation design are the emitter flow variation ($q_{var}$) and manufacturer's coefficient of variation ($CV_m$). Some researchers reported values of coefficient of variation (CV) for emitter after being used some time. Tripathi et al. (2011) reported CVs of 4.0% with wastewater and 6.46% with groundwater for subsurface (15 cm deep) lateral pipes after filtration through gravel and disk filters. Singh et al. (2006) found that the $q_{var}$ and CV of labyrinth-channel emitters ranged from acceptable to excellent across all lateral pipes, and this performance did not change markedly over two years. Zapata et al.

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http://dx.doi.org/10.1016/j.compag.2017.09.029
Received 21 May 2017; Received in revised form 17 September 2017; Accepted 21 September 2017

**Nomenclature**

| | |
|---|---|
| c1–c4 | constants |
| $C_{sx}$ | skewness coefficient |
| CV | coefficient of variation |
| $CV_m$ | manufacturer's coefficient of variation |
| $E_i$ | experimental value |
| $E_n$ | minimum experimental value |
| $E_x$ | maximum experimental value |
| ET | expression tree |
| $\overline{E}$ | average experimental value |
| GAs | genetic algorithms |
| GEP | gene expression programming |
| GP | genetic programming |
| H | trapezoidal unit height (mm) |
| $k_x$ | kurtosis coefficient |
| L | path length (mm) |
| MAE | mean absolute error |
| N | trapezoidal unit number |
| n | total number of emitters along the lateral line<br>number of observations |
| OI | overall index of model performance |
| P | operating pressure (kPa) |
| $P_i$ | predicted value |
| $q_i$ | discharge rate of emitter $i$ (L h$^{-1}$) |
| $q_{max}$ | maximum emitter discharge rate (L h$^{-1}$) |
| $q_{min}$ | minimum emitter discharge rate (L h$^{-1}$) |
| $q_{var}$ | emitter flow variation (%) |
| $\bar{q}$ | average emitter discharge rate (L h$^{-1}$) |
| $R^2$ | coefficient of determination |
| RMSE | root-mean-square error |
| S | trapezoidal unit spacing (mm) |
| $S_d$ | standard deviation of emitter discharge rate |
| $S_x$ | standard deviation |
| T | water temperature (°C) |
| W | path width (mm) |
| $x_{max}$ | maximum value |
| $x_{mean}$ | mean value |
| $x_{min}$ | minimum value |
| $\alpha_1$ | intercept of the fitting line equation |
| $\alpha_o$ | slope of the fitting line equation |

(2013) reported that the CV of discharge within irrigation events was 12%, while that between different irrigation events was 10%. Under field conditions, any variation in flow channel area or shape away from a standard size will cause $q_{var}$ to fluctuate. Other factors affecting $q_{var}$ include field topography, water temperature (T), soil hydraulic characteristics, emitter spacing, and emitter clogging (Nakayama and Bucks, 1986; Mizyed and Kruse, 1989). Alamoud et al. (2014) showed that the structural parameters of labyrinth emitters are correlated with their hydraulic performance, particularly the trapezoidal unit (dentation) number and height.

Ferreira (2001a) invented gene expression programming (GEP), which is the natural development of genetic algorithms (GAs) and genetic programming (GP). GP was first proposed by Koza (1992), and is a generalization of genetic algorithms (GAs) (Goldberg, 1989). GEP has been applied in fields as diverse as artificial intelligence; artificial life; engineering and science; financial markets; industrial, chemical, and biological processes; and mechanical models. GEP has been used to solve problems including symbolic regression, multi-agent strategies, time series prediction, circuit design, and evolutionary neural networks (Samadianfard, 2012).

In engineering sciences, many researchers from different fields have employed GEP. Whigham and Crapper (2001) used GEP for rainfall-runoff modeling. Martí et al. (2013) used GEP to model dissolved oxygen at a sand filter outlet. Ebtehaja et al. (2015) used GEP to estimate a side weir discharge coefficient. Alazba et al. (2016) and Yassin et al. (2016a, 2016c) estimated reference evapotranspiration in an arid climate with GEP. Yassin et al. (2016b) investigated the suitability of GEP to model the infiltrated water volume in furrow irrigation.

A poorly designed and managed drip irrigation system results in non-uniform water distribution, and non-uniform irrigation results in poor crop development and lower yields. The structural design of the emitters used in drip irrigation systems is thus worthy of further investigation. However, the capability of GEP to estimate the hydraulic performance of labyrinth emitters has not previously been examined. Therefore, the objectives of our study are to (1) investigate the applicability of the GEP approach to estimate the hydraulic performance (namely, $q_{var}$ and $CV_m$) of labyrinth emitters; (2) evaluate the performance of the developed GEP models through statistical comparison of the hydraulic performance obtained from the models and experimental results; and (3) study the influence of structural parameters of labyrinth-channel emitters on the performance of developed models.

## 2. Materials and methods

### 2.1. Experimental procedure

The hydraulic performance experiments were carried out using five types of drip emitters, all of which contained a long-path labyrinth channel emitter consisting of trapezoidal-shaped units fitted inside a drip line system. The experimental layout was fitted to support the drip lines, as shown in Fig. 1. One drip line was positioned along the framework, and a 50 × 50 × 50 cm water tank placed on a stand supplied

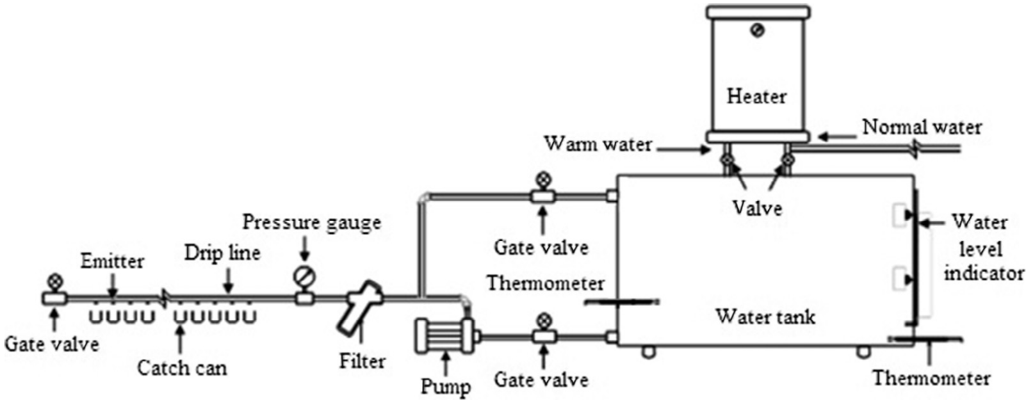

**Fig. 1.** Experiment layout of the setup used to measure emitter discharge rate.