Journal of Applied Biological Sciences 9 (2): 50-57, 2015
ISSN: 1307-1130, E-ISSN: 2146-0108, www.nobel.gen.tr

# Modeling Drop Size Emitted from Irrigation Impact Sprinklers using Gene Expression Programing and Multiple Linear and Nonlinear Regression Methods

Vahdat AHMADIFAR[*1] Reza DELIRHASANNIA[1] Amir Hosein NAZEMI[1] Ali Ashraf SADRADDINI[1]
[1]Department of Water Engineering, Faculty of Agriculture, University of Tabriz, Tabriz, Iran

*Corresponding author:
Email: vahdatahmadifar@yahoo.com

Received: June 08, 2015
Accepted: July 14, 2015

**Abstract**

The characteristics of drops produced by sprinklers have important role in designing, evaluation of sprinkler irrigation, determining wind drift and evaporation losses and soil compaction. Predicting the size of emitted drops can improve the accuracy of above mentioned issues. In this research Gene Expression Programing (GEP) as one of artificial intelligent methods and multiple linear and nonlinear regression methods (MLR and MNLR) were applied for modeling the size of the drops produced by sprinklers. The input data were included nozzle diameter, operation pressure, and the distance from sprinkler and the outputs was the average size of landed drops in a given distances from sprinkler. The experiments were conducted in 22 combinations of nozzle diameters and operation pressure and in a windless condition. In each experiment 9 to 14 measurement stations were considered with 1.5 meters spacing intervals from sprinkler. Using digital photography method and analyzing the taken photos, hydro dynamical properties of drops in photos were determined. Obtained data were classified in the nozzles diameters, operation pressures, distances from sprinkler in one side and average size of landed drops in each station in the other side. Finally the GEP method and MLR and MNLR methods were applied to develop models for predicting landed drop size in certain distances. Comparisons between models outputs and experimental data were done to evaluate models performances. The results showed that in GEP method, F5 model with R=0.9599 and RMSE=0.4060 mm, and in MNLR method L1 model with R=0.9333 and RMSE=0.5442 mm, have good accuracy to be proposed as proper models for predicting emitted drop size from irrigation impact sprinklers.

**Key words:** Drop size, impact sprinkler, modeling, nozzle diameter, operation pressure

## INTRODUCTION

Sprinklers as devices for water application play a key role in the operation of sprinkler irrigation systems. The sizes of the drops produced by sprinklers have vast applications in designing, evaluating, and simulating of these systems. In order to define wind drift and evaporation losses, kinetic energy of drops, soil compaction, soil erosion, and damage on crops, drop size can be a determining parameter. Also, distribution pattern, distribution radius and application characteristics of a sprinkler depend on the produced drop size [4]. Each combination of nozzle size and operation pressure can result in population of drops with different ranges of size. Regarding the wide variety range of nozzle size and working pressure and measuring drop sizes through experiments under all conditions are impossible. Therefore, developing models and predicting size distribution or average size of drops can be very useful in this issue. Although there have been many studies done on drop size expectancy of sprinklers for example in fuel injector [14] and firefighting devices [5] and [7] but there have been limited studies reported for irrigation sprinklers.

Li et al. [9] proposed the following empirical model in order to fit the drop distribution curve of the agricultural sprinklers:

$$P_V = 100(1 - e^{-0.693(\frac{D}{D_{50}})^n}) \quad [1]$$

where D is the drop diameter, $P_v$ is the percentage of the total mass of distributed water belonging to drops smaller than D, $D_{50}$ is the average size of the drops and n is the dimensionless power. In order to determine the required parameters of this equation, Kincaid et al. [6] suggested the following equations:

$$D_{50} = a_d + b_d R \quad [2]$$

$$n = a_n + b_n R \quad [3]$$

in the above equations R is the ratio of the nozzle diameter (D, mm) to the sprinkler's pressure (P, kPa) and $a_d$, $b_d$, $a_n$, $b_n$ are the empirical coefficients. Kincaid et al. [6] proposed values of these coefficients for seven different types of sprinklers and Playán et al. [13] reported for two other types of sprinklers. As mentioned before, predicting the drop size produced by sprinklers has been done in other scientific fields. For instance Kim et al. [5] developed a predictive model for droplet size and velocity distribution in fuel jet emitted from motor fuel injectors and evaluated the model with experimental data. The provided model consisted of stochastic and deterministic parts. The stochastic part used the maximum entropy law and the deterministic part used the unstable wave motion. The comparisons between experimental data and predicted drops sizes performed for some types of injectors confirmed the model ability to predict drop size and velocity distribution for wide range of fuel injectors and sprays.

Kollar and Farzaneh [7] proposed a model to simulate drop motions and formations in a two-phase environment of air and water along the moving path. Some effective parameters of modeling included droplet collision and coalescence, evaporation and cooling, gravitational settling, and turbulent dispersion of dispersed phase were considered. The experiments of this study were conducted in an icing wind tunnel for the distributed fluid in air. The Comparisons between the results of the model simulations and experimental measurements clarified satisfactory performance of the proposed model. Ren et al. [14] assessed a model for water distribution from firefighting sprays based on nozzle geometry, jet forming and emitted drops and considering the physical circumstances. The developed model was named Sprinkler Atomization Model (SAM). In order to study pressure effect on the produced drops characteristics experiments were done for one type of sprinkler and four working pressures. Using laser and photography techniques the size and velocity of drops were measured in 12 stations with 0.5 m radial spacing. The authors mentioned that Webber number (We) plays an important role in producing drops from sprays deflector pad.

In the recent years, application of the intelligent methods for an instance the Gene Expression Programming (GEP) method in the areas in which the relations of the input and output parameters are nonlinear, have been vastly developed. GEP has been implemented in different fields of water engineering such as Estimating soil wetting patterns for drip irrigation [16] and estimating outlet dissolved oxygen in micro-irrigation sand filters fed with effluents [11]. Multiple linear and nonlinear regression (MLR, MNLR) is a popular technique which can be applied to predict a dependent variable using a set of independent variables. The use of regression methods (MLR, MNLR) in water engineering can be mentioned prediction of soil water retention and saturated hydraulic conductivity [12] and modeling urban runoff, pollutant load and event mean concentration considering rainfall variables [10]. These methods are such a proper black box that rarely got limited to physical issues and are able to simulate nonlinear and unsteady phenomena such as discharging water jet from sprinkler's nozzle and forming drops regardless to environmental circumstances and to effective geometrical parameters on fluid movement on air. In the present study the following aims was considered:

1- Defining drop sizes in different combinations of nozzle, applied pressure and in different distances from the sprinkler.

2- Providing models in order to predict average size of the drops produced by impact sprinklers of irrigation system using GEP, MLR and MNLR methods.

Evaluating the presented models and introducing the proper one in order to predict the drop size of the sprinklers.

## MATERIALS AND METHODS

### Experiments

The experiments of determining application radius and measuring the produced drops characteristics in different combinations of pressures and nozzle diameters were conducted in indoor condition in hydraulics laboratory of Tabriz University, Tabriz, Iran. Figure 1 shows the schematic experimental setup.

In general 5 types of impact sprinklers with six different nozzles were used and for each sprinkler 4 different working pressure of 15 to 29 meters were applied which totaled 22 combinations of pressures and nozzles. By starting the pump, measurements of distribution radius and drop size got started. The characteristics of the used sprinklers, nozzle diameters, and working pressure are mentioned in Table 1.

**Table 1.** Nozzle diameters, working pressures, and sprinklers type used in the experiments

| sprinkler type | Nozzle diameter (mm) | working pressure |
|---|---|---|
| VYR 35 | 4.4 | 19, 23, 26, 29 |
| AQ-20 | 5.1 | 19, 23, 26, 29 |
| LANCER 30 30 625 | 6.3 | 15, 19, 23, 25 |
| ZM 6088 | 7 | 15, 19, 23, 25 |
| ZM 6088 | 8 | 15,17.5, 19, 23 |
| Zhaleh 5 | 9 | 17, 20 |

### Determining drop characteristics using photography method

Salvador et al. [15] introduced and validated a useful method based on digital photographic method which has ability to measure velocity, diameter, and angle of drops with good accuracy. After introducing this method, other researchers used the method in order to measure drop characteristics (Bautista-Capetillo et al. [2], Sanchez Burillo et al. [18], and Sayyadi et al. [19]). In this study digital photography method is also used to measure the drop characteristics. For this purpose, photography stations within distance of 1.5 meter were defined in the sprinkler application radius and a SONY-DSC-F828 digital camera and a black screen within dimensions of 60×40 cm placed like Figure 2 as background. This background helps drop to appear in the photos with enough resolution. As it is clear in Figure 2 the black background screen was placed 1.5 meter away from the camera lens and camera was focused on a ruler mounted to screen. This ruler was used as a reference for measurements of drops characteristics in the photos. The camera was set on minimum photo depth, maximum exposure value and 1/100 second for shutter speed.

Using this method the emerged drops are shown like a transparent cylinder in the photos as it is visible in Figure 3 which makes it possible to extract required characteristics. In order to measure drop characteristics the Digimizer Ver. 4.1.1.0. (Medcalc softwares) was used. Applied pressure, nozzle diameters, and distances of measurement stations from sprinklers were recorded from the experiments and drop sizes of each experiment were extracted from photos analysis. Consequently, by classification of the data and using GEP, MLR and MNLR methods, models were provided to predict average drop size based on nozzle diameter, working pressure, and distance from sprinkler. As consequent using these models in sprinklers within specific diameter and working pressure the sizes of drops in each point of sprinkler's distribution range could be predicted. Afterward considering relative population of drops and weighted average of extracted sizes, the average sizes of produced drops could be calculated.

### Gene Expression Programming

The Genetic Programming (GP) was introduced as a generalization of Genetic Algorithms (GA) [8]. This method was initially presented by Koza in 1992 [8] based on the Darwin theory. Making combinations of different populations and selecting the best generation and modifying the further generations in order to get the best consequence is the base of this method. The GP does the mentioned process automatically and it can be presented as a computer program. In this method initially no functional relation is considered and the method is able to optimize the model structure and its parameters. The GEP method was presented by Ferreira in 1999, this method is somehow similar to GP method. Unlike the GP method there are some genetic operators for the modified reproduction of people which the base of all these innovations is in the simple and variable structure of genes in the GEP method. This structure not only permits coding of each considered program but also permits an effective perfection process too. Also this complex by and adaptive structure uses a powerful collection of genetic operators which properly search for a solution environment. As it is in nature, finder operators of GEP, always produce a correct and validated structure, so remarkably matches the genetic variation [3].

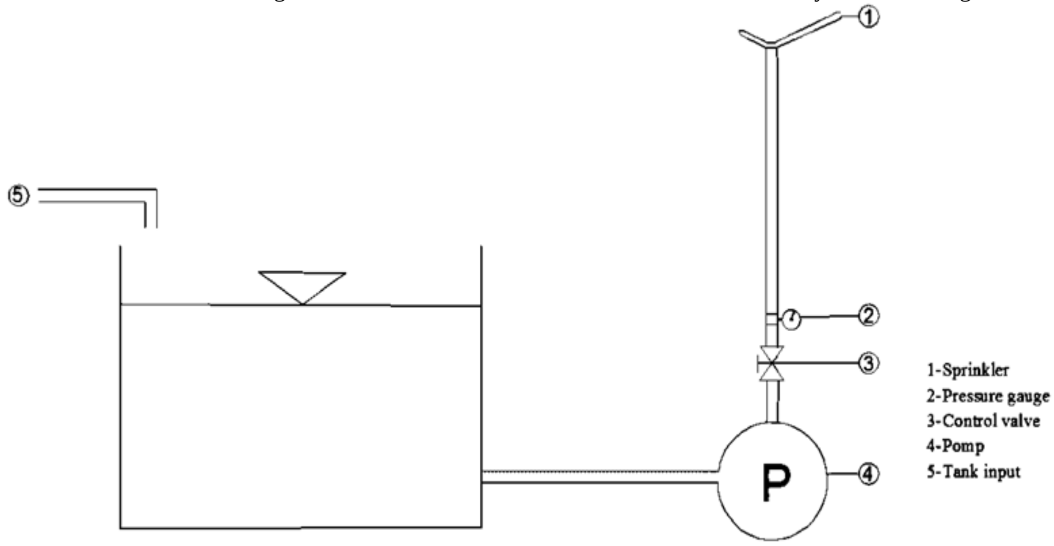



**Figure 1.** Experimental setup

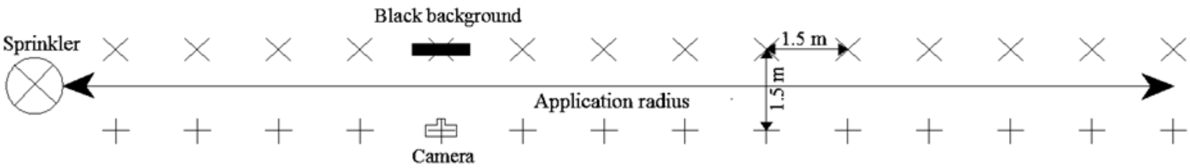



**Figure 2.** Schematic position of photography tools in the experiments


**Figure 3.** Representing the drops in the photos with measurable geometries

The process of the modeling the distributed drops using the GEP method consists of five steps:

1- The first step includes regression function. For a prefect regression, value of $f_i$ resulting from an individual program of i equals $f_i = f_{max} = nR$. The benefit of using this regression function is that the system using it can find the optimized solution. The Root of Mean Squared Errors (RMSE) is considered as a criterion for regression error.

2- The second step includes choosing collections of function in order to create chromosomes. In general estimating the drop diameter from input parameters using the GEP method will be as Eq. 4.

$$D_d = f\{P, D_n, L\} \quad [4]$$

where $D_d$ is drop size (mm), L is the distance from the sprinklers (m), $D_n$ is the nozzle diameter (mm) and P is the sprinkler working pressure (m).

3- Selecting the chromosome's structure which includes the head length and number of genes.

4- Selecting the linking function which defines the relations among branches.

5- Selecting the genetic operators and rates of them. In this case the synthetic items of all optimization operators such as mutation, inversion, three types of transposition, and three types of compounds are used.

Considered parameters and their values in developing the model for estimating the drop size produced by impact sprinklers using the GEP method are summarized in Table 2.

**Table 2.** Applied parameters in GEP modeling and considered values

| parameter | value |
|---|---|
| Head size | 8 |
| Chromosomes | 30 |
| Genes | 3 |
| Mutation rate | 0.044 |
| Inversion rate | 0.1 |
| One –point recombination rate | 0.3 |
| Two –point recombination rate | 0.3 |
| Gene recombination rate | 0.1 |
| IS transposition rate | 0.1 |
| RIS transposition rate | 0.1 |
| Gene transposition rate | 0.1 |
| Fitness function error type | RMSE |
| Linking function | + |

**Regression - based methods**

The general forms of the linear and nonlinear regression methods can be respectively written as:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + ... + \beta_p X_{ip} + \varepsilon_i \quad [5]$$

$$Y_i = f(x_i + \theta) + \varepsilon_i \quad [6]$$

where, for a set of i observations, $Y_i$ is the predicted variable, $\beta_0$ is a coefficient, $\beta_1$, $\beta_2$,…, $\beta_p$ are the coefficients of the $X_{i1}$, $X_{i2}$, …, $X_{ip}$ independent variables (predictors), Θ is the nonlinear parameter in case of use and εi is the residual error (differences between observations and predicted values) [1]. The hypotheses required to apply regression methods are: (i) the predictor variables must be independent, and (ii) the residual errors εi must be independent and they must be normally distributed, with 0 mean and σ2 constant variance. The goal of the regression analysis is to determine the values of the parameters of the regression equation and then to quantify the goodness of the fit in respect of the dependent variable Y [17].

**Evaluation Parameters**

After modeling, running the models and extracting the results, in order to analyze the performance of models, statistical indexes of Root Mean Squared Errors (RMSE) and correlation coefficient (R) were used as below.

$$R = \left( \frac{\sum_{i=1}^{N} (X_i - \overline{X})(Y_i - \overline{Y})}{\sum_{i=1}^{N} (X_i - \overline{X})^2 \times \sum_{i=1}^{N} (Y_i - \overline{Y})^2} \right) \quad [7]$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (Y_i - X_i)^2}{N}} \quad [8]$$

where $x_i$ are the observed drop size, $y_i$ are the predicted drop size, N is the number of observations, $\overline{X}$ is the average of observed drop size and $\overline{Y}$ is the average of observed drop size.

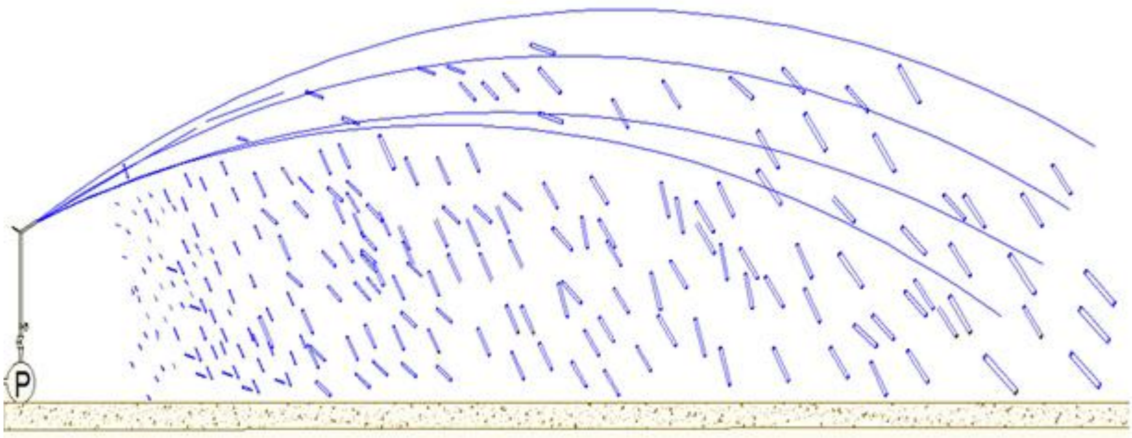



**Figure 4**. Schematic drop size distribution along application radius

## RESULTS AND DISCUSSION

### Analysis of the drop size produced by sprinklers

In the present study the size of landed drops were measured along the precipitation profile with spatial intervals of 1.5 meters from sprinkler. Different nozzle diameters and working pressures were considered in the experiments. Digital photography method was applied for taking photos from drops in each station. Drops with high contrast and resolution were selected in photos and drops geometrical measurements and analysis were conducted on drops. As a consequence, the average value of recorded size in each station was considered as the representative size in that station. In all experiments it was observed that drop sizes increased by increasing distance from sprinkler. Drop size distribution along application radius is schematically shown in Figure 4.

Figure 5 shows the Average values of measured drop sizes emitted from different nozzle-pressure combinations in each station.

The variations of drop diameter with pressure variation are presented in Table 3 for each nozzle. Increasing nozzle diameter with pressure decreasing showed that within nozzle diameter increment, pressure differences had tangible effect on drop diameter increment. As in 4.4 millimeter nozzle by 10 meter pressure decrement, drop diameter increased 26%, nevertheless in 8 millimeter nozzle 8 meter decrement in pressure resulted in 40% of drop diameter increment.

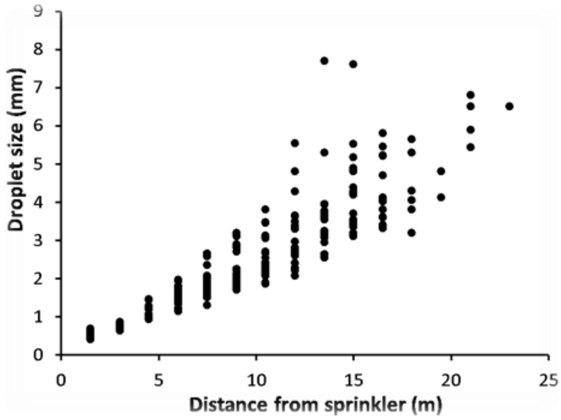



**Figure 5.** Average measured drop sizes emitted from different nozzle-pressure combinations in each station

**Table 3**. Percentage of difference in drop size due to pressure decrement in different nozzles

| Nozzle diameter (mm) | Pressure variation (m) | Resize drops (%) |
|---|---|---|
| 4.4 | -10 | 26 |
| 6.1 | -10 | 24 |
| 6.3 | -10 | 30 |
| 7 | -10 | 33 |
| 8 | -8 | 40 |
| 9 | -3 | 16 |

### Modeling the drops produced by sprinkler

After classification the experimental data including nozzle diameter, sprinkler operation pressure, measurement distances from sprinklers and drops sizes; the GEP, linear and nonlinear regression methods were applied and predictive models were developed. Then, drop size predictions were performed based on nozzle diameter and sprinkler operation pressure.

### GEP model results

In this method in order to estimate diameter of the emitted drops from sprinkler, measured size of the drops entered as dependent variable and nozzles diameter, sprinklers working pressure, and distance from sprinkler entered as independent variables into the GEP model. 70 % of total data were randomly considered for training process and the remaining 30 % were used for model testing and validation. Considering the effect of different mathematical operators on estimating the drops size, 5 scenarios with different combinations of mathematical operators were defined. It is clear that the scenario with high accuracy, minimum operators and also simple formula structure will be the most applicable scenario. Table 4 shows the scenarios made by combining different mathematical operators and the results of modeling the drop size by corresponding scenarios. In the mentioned table, the F5 model uses simple formula structure and minimum mathematical operators (+,-,×,/). Also, R and RMSE values for training data calculated 0.9599 and 0.4060 mm for testing process were 0.9292 and 0.5574 mm, respectively. Thus, this model was selected as the best model. The equation for F5 model is written as:

$$D_d = \left[\frac{-9.6}{(P^2/(8.46L)+L}\right] + \left[\left(\frac{5.95L}{P}\right) + \left(\frac{P+D_n}{(8.47)^2}\right)\right] + \left[\frac{L}{(-9.81-D_n)\times(D_n-4.52\times(-9.81+P))}\right] \quad [9]$$

where $D_d$ is drop size (mm), L is the distance from the sprinklers (m), $D_n$ is the nozzle diameter (mm), and P is the sprinkler working pressure (m).

As it is seen in Table 4 some scenarios has bigger values for RMSE and R rather that the F5 model but considering their lower values for testing data and using more mathematical operators in the model, the F5 scenario will lead to better estimations.

### Results of regression methods

In this study linear and nonlinear regression methods were used in order to provide predicting models for drop size distributed by impact sprinklers. In these methods measured diameters were entered as dependent variable and nozzle diameters, sprinklers operation pressure and distance from sprinkler were considered as independent variables. 70% of data were randomly used as train data and 30% of resting data were used as test data for developed model. The resulted models were evaluated by comparing models results and measured data.

### MLR model results

The comparisons between observed data from experiments and predicted data from the MLR model showed that the model estimates negative values in drop diameter for small drops (with diameters smaller than 0.6

**Table 4**. Results extracted by the GEP method in different scenarios

| Scenario | Applied mathematical operators | Train data | | Test data | |
|---|---|---|---|---|---|
| | | R | RMSE(mm) | R | RMSE(mm) |
| F1 | {+, -, ×, /, √x, Exp, Ln, $X^2$, $X^3$, $X^{(1/3)}$,Sin(X), Cos(X), Arctan(X)} | 0.9621 | 0.3927 | 0.9228 | 0.6296 |
| F2 | {+, -, ×, /, √x, $X^2$, $X^3$, $X^{(1/3)}$,Sin(X), Cos(X), Arctan(X)} | 0.9575 | 0.4151 | 0.9238 | 0.5785 |
| F3 | {×, /, √x, Exp, Ln, $X^2$, $X^3$, $X^{(1/3)}$} | 0.9625 | 0.3903 | 0.9088 | 0.9106 |
| F4 | {+, -, ×, /, Exp, Ln} | 0.9631 | 0.3890 | 0.8814 | 0.7425 |
| **F5** | **{+, -, ×, /}** | **0.9599** | **0.4060** | **0.9292** | **0.5574** |

**Table 5**. MNLR method scenarios in order to predict drops sizes

| Scenario | Function | Train data | | Test data | |
|---|---|---|---|---|---|
| | | R | RMSE (mm) | R | RMSE (mm) |
| **L1** | $D_d = aL^b P^c D_n^e$ | **0.9333** | **0.5442** | **0.9029** | **0.5279** |
| L2 | $D_d = aL^b + cP^e + fD_n^h$ | 0.8356 | 0.8081 | 0.8608 | 0.6320 |
| L3 | $D_d = aL^b P^c + eD_n^f$ | 0.8360 | 0.8080 | 0.8628 | 0.6336 |
| L4 | $D_d = aL^b + P^c eD_n^f$ | 0.9196 | 0.5741 | 0.9231 | 0.5428 |
| L5 | $D_d = (aL^b D_n^f) + eP^c$ | 0.8358 | 08082 | 0.8620 | 0.6352 |

mm) in the some cases. Additionally, R and RMSE values for train data calculated 0.9004 and 0.5239 mm and for test data obtained 0.9055 and 0.6413 mm respectively. These values indicated lowest accuracy among developed models. The provided equation can be written as:

$$D_d = 1.079 + 0.282L - 0.07P + 0.033D_n \quad [10]$$

the equation parameters have been previously introduced in Equations 9.

**MNLR model results**

Several functional structures in the base MNLR models were applied in order to provide predictive models. 5 scenarios with satisfied accuracy were selected among considered functions. Table 5 shows the provided scenarios by different mathematical functions and the corresponding results of modeling drop size. L1 model within value of 0.9333 for correlation coefficient (R) and 0.5442 mm for RMSE for train data and R =0.9029 and RMSE = 0.5279 mm for test data, showed the highest accuracy between MNLR functions.

The proposed equation for MNLR model (L1) is written as Equation 11.

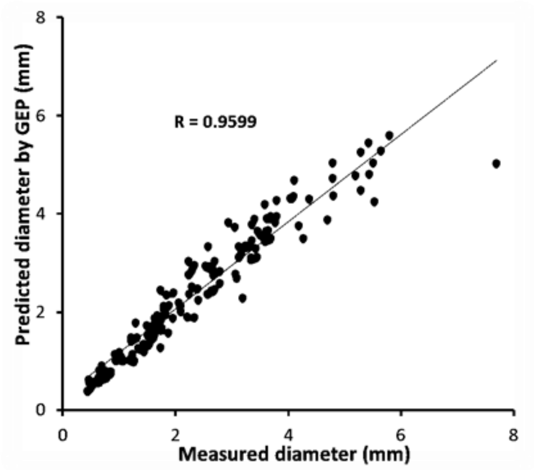
$$D_d = 1.9L^{1.18} P^{-0.86} D_n^{0.093} \quad [11]$$

the equation parameters have been previously introduced in Equations 9.

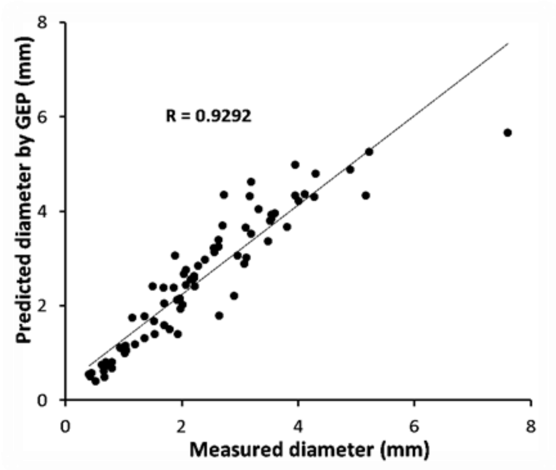
Figure 6 shows the scatter plot of the train and test data for experiments and predicted by GEP, MLR and MNLR models.

# CONCLUSION

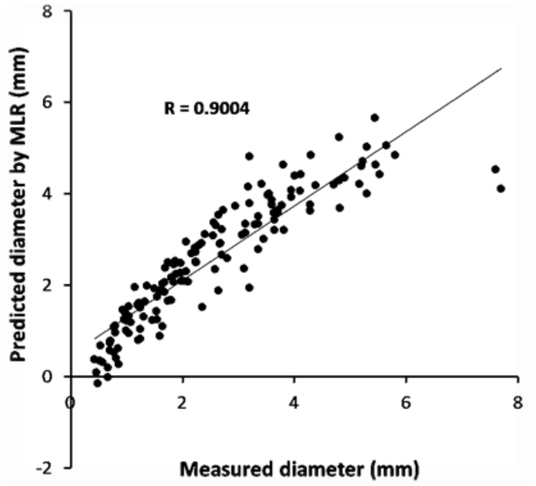
In the present study multiple regression (MLR and MNLR) and GEP models were applied in order to predict the drop sizes based on nozzle diameter and working pressure of agricultural sprinklers. The results showed that in general the intelligent GEP model had more accurate results in comparison with regression models. The model provided using MLR method due to lower accuracy and estimating negative values for smaller drops could not be proposed as a proper model. Results showed that in GEP method F5 model due to using simple mathematical operators and more accuracy with R=0.9599 and RMSE=0.4060 mm and among different provided models in MNLR methods L1 model due to high accuracy and using simple formula structure with R=0.9333 and RMSE=0.5442 mm were the most proper models. The investigation of nozzle diameter and working pressure effects on produced drop size clarified that the most variation in the average drop size occurs in bigger nozzles where 8 meters decrement of pressure for 8 millimeter nozzle resulted in 40% of drop size increment. While 10 meters of pressure decrement of 4.4 millimeter nozzle only resulted in 26% of drop size increment. Also, in all experiments drop size increased by increasing distance from the sprinklers. Regarding to the importance of drops size made by sprinkler on many affecting parameters of sprinkler irrigation, provided models could have effective role on predicting, evaluation of irrigation systems, modelling the water distribution, and selecting suitable sprinkler.



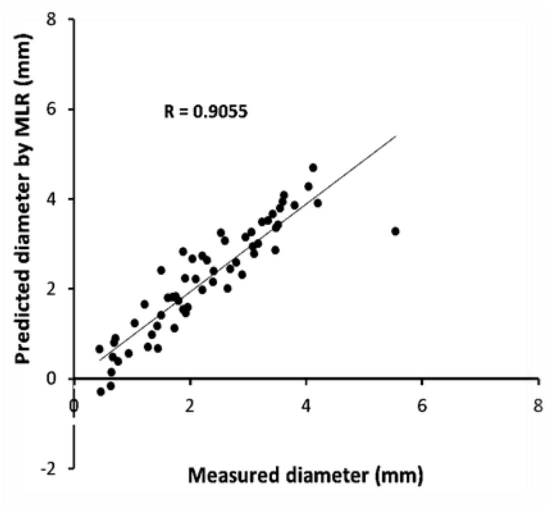

(A)



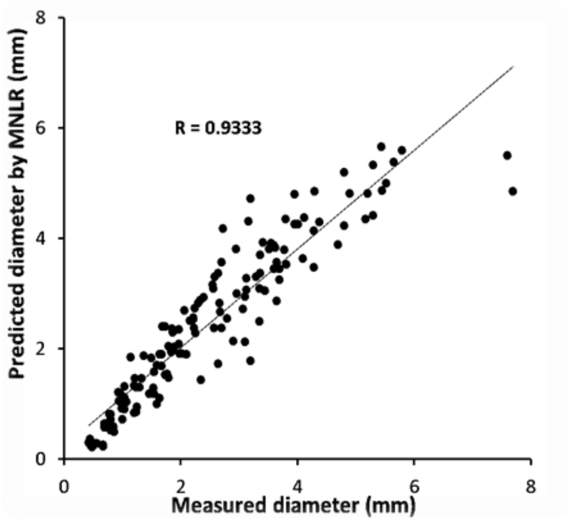

(B)



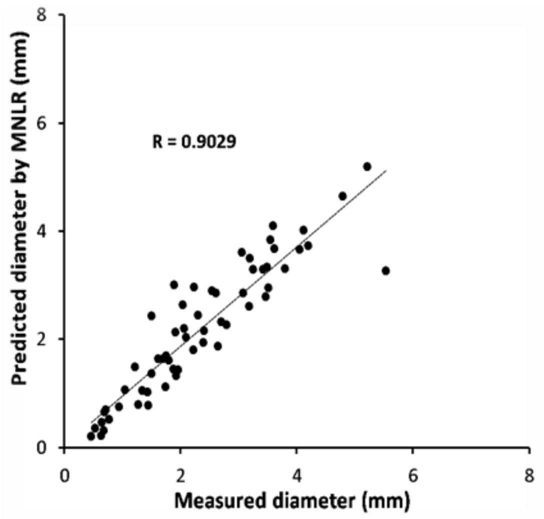

(A)




(B)




(A)




(B)

**Figure 6.** Scatter plot between measured average drop size and estimated by GEP, MLR and MNLR models, Train data (A) and Test data (B)

## REFERENCES

[1] Bates, D. M. and Watts, D. G. 1988. Nonlinear Regression Analysis and Its Applications. Wiley, New York, USA. pp. 90.

[2] Bautista-Capetillo, C. F., Salvador, R., Burguete, J., Montero, J., Tarjuelo, J. M., Zapata, N., González, J. and Playán, E. 2009. Comparing mythologies for the characterization of water drops emitted by an irrigation sprinkler. Transactions of ASABE, 52(5): 1493-1504.

[3] Ferreira, C. 2001. Gene expression programming: a new adaptive algorithm for solving problems. Complex Systems, 13(2): 87-129.

[4] Keller, J. and Bliesner, R. D. 1990. Sprinkler and trickle irrigation. Van Nostrand Reinhold, New York, USA. pp. 652.

[5] Kim, W.T., Mitra, S. K., Li, X., Prociw, L. A. and Hu, T.C. J. 2003. A predictive model for the initial droplet size and velocity distributions in sprays and comparison with experiments. Particle and Particle Systems Characterization, 20: 135-149.

[6] Kincaid, D. C., Solomon, K. H. and Oliphant, J. C. 1996. Drop size distribution for irrigation sprinklers. Transactions of ASAE, 39(3): 839-845.

[7] Kollár, L. E. and Farzaneh, M. 2007. Modeling the evolution of droplet size distribution in two – phase flows. International Journal of Multiphase Flow, 33: 1255–1270.

[8] Koza, J. R. 1992. Genetic Programming: On the Programming of Computers by Means of Natural Selection. MIT Press, Cambridge, USA. pp. 813.

[9] Li, J., Kawano, H. and Yu, K. 1994. Droplet size distributions from different shaped sprinkler nozzles. Transactions of ASAE, 37(6): 1871-1878.

[10] Maniquiz, M., Lee, S. and Kim, L. H. 2010. Multiple linear regression models of urban runoff pollutant load and event mean concentration considering rainfall variables. Journal of Environmental Sciences, 22(6): 946–952.

[11] Martí, P., Shiri, j., Duran-Ros, M. and Arbat, G. 2013. Artificial neural networks vs. Gene Expression Programming for estimating outlet dissolved oxygen in micro-irrigation sand filters fed with effluents. Computers and Electronics in Agriculture, 99:176-185.

[12] Merdun, H., Cınar, Ö., Meral, R. and Apan. M. 2006. Comparison of artificial neural network and regression pedotransfer functions for prediction of soil water retention and saturated hydraulic conductivity. Soil & Tillage Research, 90: 108–116.

[13] Playán, E., Zapata, N., Faci, J. M., Tolosa, D., Lacueva, J. L., Pelegrín, J., Salvador, R., Sánchez, I. and Lafita, A. 2006. Assessing sprinkler irrigation uniformity using a ballistic simulation model. Agricultural Water Management, 84: 89-100.

[14] Ren, N., Blum, A., Zheng, Y., Do, C. and Marshall, A., 2009. Quantifying the initial spray from fire sprinklers. Fire Safety Science, 9: 503-514.

[15] Salvador, R., Bautista-Capetillo, C., Burguete, J., Zapata, N. and Playán, E. 2009. A photographic methodology for drop characterization in agricultural sprinklers. Irrigation Science, 27: 307–317.

[16] Samadianfard, S., Sadraddini, A. A., Nazemi, A. H., Provenzano, G. and Kisi, Ö. 2012. Estimating soil wetting patterns for drip irrigation using genetic programming. Spanish Journal of Agricultural Research, 10(4): 1155-1166.

[17] Samadianfard, S., Delirhasannia, R.,Torabi Azad, M., Samadianfard, S. M. and Jeihouni, M. 2015. Intelligent Analysis of Global Warming Effects on Sea Surface Temperature in Hormuzgan Coast, Persian Gulf. International Journal of Global Warming, In Press.

[18] Sanchez Burillo, G., Delirhasannia, R., Playán, E., Paniagua, P., Latorre, B. and Burguete, J. 2013. Initial drop velocity in a fixed spray plate sprinkler. Journal of Irrigation and Drainage Engineering, 139(7): 521–531.

[19] Sayyadi, H., Nazemi, A. H., Sadraddini, A. A. and Delirhasannia, R. 2014. Characterising droplets and precipitation profiles of a fixed spray-plate sprinkler. Biosystems Enginering, 119: 13-24.