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Prediction of wind drift and evaporation losses from sprinkler irrigation using neural network and multiple regression techniques

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ABSTRACT

Wind drift and evaporation losses (WDEL) play a significant role in the development of water conservation strategies in sprinkler irrigation. In this study, artificial neural network (ANN) and multiple linear regression (MLR) models were developed by taking data collected from published studies on predicted WDEL for several design, operational, and meteorological conditions of variables in sprinkler irrigation. Five combinations of input variables, including riser height, operating pressure, main nozzle diameter, auxiliary nozzle diameter (d_a), water discharge by main nozzle, water discharge by auxiliary nozzles, wind speed (WS), air temperature, and relative humidity were used to create prediction models for WDEL. The ANN and MLR models were trained and tested on 70% and 30% of the data points, respectively. The accuracy of the models was assessed by the coefficients of correlation (r), overall indices of model performance (OI), root mean square errors (RMSE), and mean absolute errors (MAE). Statistical results showed that the ANN and MLR models with all input variables had the best predicting capabilities. When comparing the results of different ANN and MLR models, it was seen that the ANN models had more success in predicting WDEL. The ANN models gave higher r (0.843–0.956) and OI (0.794–0.909) values, and lower RMSE (2.662%–4.886%) and MAE (2.197%–3.729%) values compared to the MLR models in the training stage. The MLR models' r values ranged from 0.794 to 0.864, OI values ranged from 0.747 to 0.816, RMSE values ranged from 4.562% to 5.514%, and MAE values ranged from 3.513% to 4.414%. Furthermore, a contribution analysis found that the design parameter d_a and the climatic parameter WS were considered to obtain the most robust estimation model. It can be stated that the ANN model is a more suitable tool than the MLR model for the prediction of WDEL from sprinkler-irrigation.

1. Introduction

Sprinkler irrigation is a preferred method of irrigation as the water available around the world becomes increasingly scarce, especially in arid and semi-arid regions. However, little is known about its performance under field conditions (Smith et al., 2002). The phenomenon of evaporation during sprinkler irrigation, including its relationships to other soil-plant-atmospheric processes, has not yet been completely understood (De Wrachien and Lorenzini, 2006), although it is important for the optimal design of irrigation and appropriate irrigation scheduling. The performance of sprinkler irrigation depends on design and operational factors. The most important design factors are the sprinkler type, nozzle diameter, and sprinkler spacing. Operational factors include operating pressure (P), the time of irrigation, and meteorological conditions during irrigation, especially wind speed (WS) (Keller and Bliesner, 1990; Carrión et al., 2001; Playán et al., 2006).

A significant percentage of the water discharged by a sprinkler irrigation system does not reach the crop canopy. This "lost" water is referred to as wind drift and evaporation losses (WDEL), and is expressed as a percentage of the gross volume of irrigation water. In the literature, values of WDEL have been reported ranging from 2%–50%) Playán et al., 2005). This variability is due to design, operational, and meteorological conditions at the experimental sites. The WDEL effect has been reported on in many research papers (e.g., laboratory, field tests, and analytical studies). Among the design factors, a large nozzle diameter produces large drop

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Nomenclature

ANN	Artificial neural network
b_i	Estimated regression coefficients
b_o	Value of $\hat{Y}$ when all of the independent variables are equal to zero
B_1	Biases in the hidden layer
B_2	Biases in the output layer
C_{sx}	Kurtosis coefficient
d_a	Auxiliary nozzle diameter
d_m	Main nozzle diameter
E_i	Experimental value
E_m	Maximum experimental value
E_n	Minimum experimental value
$\overline{E}$	Average experimental value
f	Activation (transfer) function
H_r	Riser height
ID_C	Recorded irrigation depth
$\overline{ID_C}$	Average ID_C
ID_D	Irrigation depth applied by the sprinkler system
K_x	Skewness coefficient
m	Number of independent or predictor variables
MAE	Mean absolute error
MLR	Multiple linear regression
n'	Number of observations
n_j	Hidden layer neuron's value
n_k	Output layer neuron's value
N_i	Number of input neurons
N_j	Number of output neurons
OI	Overall index of model performance
P	Operating pressure
P_i	Predicted value
$\overline{P}$	Average predicted value
p-values	Probability of independent variables
Q	Sprinkler discharge rate
q_a	Water discharge by auxiliary nozzle
q_m	Water discharge by main nozzle
r	Coefficient of correlation
R^2	Determination coefficient
RH	Relative humidity
RMSE	Root mean square error
SE	Regression standard error
S_S and S_L	Spacing between laterals and between sprinklers along the lateral, respectively
S_x	Standard deviation
t	Operating time
T	Air temperature
t-stat	T statistic
VIF	Variance inflation factor
W_1	Weights from the input layer to the hidden layer
W_2	Weights from the hidden layer to the output layer
WDEL	Wind drift and evaporation losses
WS	Wind speed
X_a	Mean value
x_i	Independent or predictor variables
X_i	Normalized input parameters
X_m	Maximum value
X_n	Minimum value
$\hat{Y}$	Predicted or expected value of the dependent variable
T	Normalized input/output parameters
Z_{max}	Maximum value of the input/output parameters
Z_{min}	Minimum value of the input/output parameters
Z_o	Original experimental data
α_1	Intercept of the fitting line equation
α_o	Slope of the fitting line equation

Subscripts

i	Number of input neuron
j	Number of hidden neuron
k	Number of output neuron

diameters, which are more resistant to drift and present less area per unit of mass (Keller and Bliesner, 1990). Therefore, they are less affected by WDEL. Increasing nozzle elevation over the soil surface (riser height, H_r) has been reported to increase WDEL, owing to longer drop trajectories and increased wind exposure. However, in operational factors, an increase in P results in a decrease in the resulting drop diameters (Montero et al., 2003), with an increase in WDEL. WS is a serious limiting meteorological factor disrupting the trajectory of droplets and induces droplet evaporation, thereby increasing WDEL in sprinkler irrigation (Faci and Bercero, 1991; Seginer et al., 1991; Kincaid et al., 1996; Burt et al., 1997; Tarjuelo et al., 1994, 1999; Dechmi et al., 2003; Playán et al., 2005, 2006; Sanchez et al., 2010a,b; Zapata et al., 2007).

An experimental estimation of WDEL is costly as well as time-consuming, but alternatively, WDEL can be estimated using soft computing techniques such as artificial neural networks (ANNs). ANNs are computational models inspired in the neural structures of intelligent organisms, neurons, and synapses, which acquire knowledge through experience. Without any assumptions or knowledge about the underlying principles, ANN is an effective tool for modeling nonlinear processes, as it requires few inputs and is able to precisely extract the generalized relationship between input and output data without any understanding of the physical process involved (Haykin, 1999; Sudheer et al., 2003). The accuracy increases with increasing available data (Basheer and Hajmeer, 2000; Jain et al., 2004).

ANNs have attracted considerable interest recently in a wide number of applications in various engineering fields: rainfall-runoff (Hsu et al., 1995; Fernando and Jayawardena, 1998; Shrestha et al., 2005), evapotranspiration (Kişi, 2007; Khoob, 2008; Ozkan et al., 2011; Yassin et al., 2016a,b), suspended sediments (Ciğizoğlu, 2002), water quality parameters (Schleiter et al., 1999; Karul et al., 2000; Maier and Dandy, 2000), water distributions under drip irrigation (Lazarovitch et al., 2009; Hinnell et al., 2010), wind effects on sprinkler distribution patterns (Sayyadi et al., 2012), soil penetration resistance (Santos et al., 2012), furrow irrigation infiltration (Mattar et al., 2015), and the hydraulic performance of labyrinth-channel emitters (Mattar and Alamoud, 2015). However, the knowledge of ANN in modeling WDEL in sprinkler irrigation is limited. Therefore, the objectives of study are to (1) explore the applicability of an ANN approach for the estimation of WDEL with various input combinations, (2) develop multiple linear regression (MLR) models to predict WDEL using ANN training data, (3) compare the predictive capabilities of ANN with MLR models using statistical criteria, and (4) perform a contribution analysis of the developed ANN models to identify important factors affecting WDEL.

2. Material and methods

2.1. Experimental database

The ANN and MLR models were developed using experimental data from four published studies (Abo-Ghobar, 1993; Dechmi