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Estimation model of pH and electrical conductivity in nutrient solutions for crops using artificial networks design

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ABSTRACT This paper presents a design of an Artificial Neural Network (ANN) to modelling pH and electrical conductivity (EC) in a nutrient solution designed for crops. In the ANN design, a combination of the nutrient solution was made by adding sodium carbonate and water to raise the pH and lower the EC, respectively. In the model simulation, an error of 1.18 mL of sodium carbonate and 0.92 mL of water was obtained for the 47 combinations of the experiment. An average mean error of 0.23 for pH. 0.304 mS/cm for the EC was obtained. In this work, an alternative to the conventional methodology was presented. As a result, the error is reduced, and the calibration of nutrient solutions is facilitated.

KEYWORDS— Neural networks, model, hydroponic, nutrient solutions, pH, and electrical conductivity.

I. INTRODUCTION

During the last few years, the world has been working on developing modern agriculture due to the demand for food caused by the increase in population. As a result, the technology in this area has grown and improved in yield and quality of the primary product [1]. Today, the technology application is essential because around the world, different problems exist, for example, water scarcity, soil erosion, and abrupt changes in weather conditions. For this, protected agriculture offers a possible solution [2].

The irrigation system is one of the most important parts of crop development because this process hydrates the plant [3]. Fertigation, in addition to water, also provides nutrients through fertilizers [4]. Nutrient solutions are applied in different types of agriculture; however, it becomes more important in soilless agricultural techniques like hydroponics, where it is necessary to provide the essential nutrients for the crop [5].

Nutrient solutions in this process become more important as it requires proper pH and Electrical Conductivity (EC) conditions [6]. Currently, the adjustments of these variables are worked manually through human intervention and consist of adding solutions to modify these variables in the nutrient solution. Furthermore, the precision of the pH is necessary because not having good values has negative consequences for the crop, such as root damage, conditions for the appearance of some pathogens, and difficulty in nutrient absorption [7].

The EC is a measure of nutrient salts available in the nutritive solution. Not having adequate values could negatively affect the plant's health and growth. For these reasons, it is important to maintain the proper conditions of these variables [8]. Artificial intelligence is an alternative to solve this challenge by adjusting pH and EC variables.

The irrigation system is one of the most important parts of agriculture, an Artificial Intelligence (AI) estimation approach to model nitrate distribution patterns under subsurface and surface drip irrigation is shown in [9]. The estimation was done using a Whale Optimization Algorithm (WOA) and applied to an ANN; this model was optimized using Boruta-Random Forest (BRF) feature selection (BRF-FS). The WOA-ANN was compared with conventional ANN and Support Vector Regression (SVR) models.

Another research compares neural network algorithms for estimating tomato crop yields using data from different cities in Iran [10], including mean annual temperature, relative humidity, adequate rainfall, wind speed, and evapotranspiration over 50 years. The results obtained showed that Bayesian optimization showed lower uncertainty.

Researchers have confirmed that Artificial Neural Networks (ANN) work in implementing hydroponic cultivation systems. For this work, an ANN was simulated using MATLAB to estimate the pH and EC of a nutrient solution in a hydroponic system, where the volume of solutions was determined to obtain the desired pH and EC value. In addition, the ANN was validated by made laboratory experiments.

II. DEVELOPMENT

The nutrient solution is mainly used in hydroponic systems; it is generally composed of an acid solution, an alkaline solution, and a buffer, whose composition depends on the growth phase of the plant and the climatic conditions [11]. However, this process is generally worked manually, subject to human error (measurement). It is also more time-consuming because the user must add solutions and approach the desired value, resulting in higher solution consumption and poor accuracy of the required values.

Fig. 1 shows the general diagram of the calibration of the nutrient solution. Due to the characteristics of the nutrient solution, only two combinations were used: an acid pH of 3.74 and a high electrical conductivity of 6.46 mS/cm. Sodium carbonate (Na_2CO_3) and water (H_2O) were used to increase the pH and reduce the EC, respectively. Both solutions were added manually by a user.

A. NUTRITIVE SOLUTION DESIGN

For each crop, specific proportions of macronutrients and micronutrients are required; Table I shows the ppm of each element added to the nutrient solution [12].

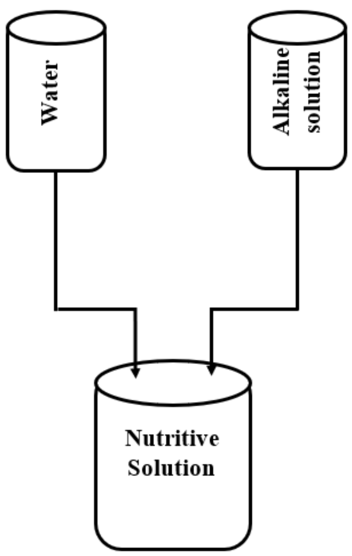

Fig. 1. Nutrient solution calibration.

TABLE I. CONCENTRATIONS OF ELEMENTS IN THE NUTRIENT SOLUTION.

Element	ppm
N	300
P	80
K	250
Ca	300
Mg	75
S	100
Fe	4
Mn	1
B	0.5
Cu	0.5
Zn	0.5

In addition to the essential elements, sodium selenite and salicylic acid at 0.5% were added to the nutrient solution to stress the cilantro crop and obtain an improvement in antioxidants.

B. ARTIFICIAL NEURAL NETWORK

Artificial neural networks can resolve multiple parameters yielding accurate solutions based on inputs. ANNs have been shown to solve nonlinear relationships in biological systems. One of the main advantages of using ANNs is that they do not require dynamic equations or mathematical models to control one or more system variables. In addition, the training of these only requires experimental data and does not require mastery of the subject or process being modeled [13].

1. ANN training

a) Data acquisition

Table II was established to obtain the ANN training data, and combinations of different volumes of solutions were made with a fixed pH value and modifying the EC in a range of values. The crop requirements of the region are similar, for pH are 5.5 to 6.5, and for EC are 1.5 to 3 mS/cm.

TABLE II. CONCENTRATIONS OF ELEMENTS IN THE NUTRIENT SOLUTION.

Quantity (Na_2CO_3)	Accumulated (Na_2CO_3)	Quantity (H_2O)	Accumulated (H_2O)	pH	EC
Z_1	Z_1	X_1 X_2 X_n	X_1 X_1+X_2 $X_1+X_2+X_n$	a_1 a_2 a_n	b_1 b_2 b_n
Z_2	Z_2	X_1 X_2 X_n	X_1 X_1+X_2 $X_1+X_2+X_n$	a_2 a_3 a_n	b_2 b_3 b_n
Z_3	Z_3	X_1 X_2 X_n	X_1 X_1+X_2 $X_1+X_2+X_n$	a_3 a_4 a_n	b_3 b_4 b_n
Z_n	Z_n	X_1 X_2 X_n	X_1 X_1+X_2 $X_1+X_2+X_n$	a_4 a_5 a_n	b_4 b_5 b_n

The experiment consists of adding a fixed volume of sodium carbonate solution (Z_n) and starting from a pH value (a_n). Subsequently, small amounts of water (x_n) will be added to reduce the electrical conductivity (b_n) until reaching one of the limit values of the solution, in other words, when there is a tendency to a value. The initial quantities of sodium carbonate solution will be varied to try to obtain a fixed pH value. In addition to varying the electrical conductivity with the water and seeing how much this affects the pH. All experiments start with 100 mL of nutrient solution.

b) Training MATLAB

The neural network training was performed by MATLAB software through the Neural Network Start (nnstart) function to configure the different parts of the neural network, as shown in Fig. 2. Subsequently, the input and output data matrices obtained experimentally are added from Table II.

The number of neurons that are in the hidden layer is then selected. The selected training algorithm was Bayesian Regularization because when training the network, obtain the lowest mean square error (MSE) and a correlation (R) closest to 1. Subsequently, the nnstart function produces a block diagram that must be edited, as shown in Fig. 3, to give the inputs and obtain the desired outputs.

2. Simulation in MATLAB

The simulation was done with the Simulink tool of the MATLAB software. A block diagram is made, as shown in Fig. 3. The system inputs are the desired pH and EC values. The system generates the amount of each solution necessary to apply to the nutrient solution to obtain those pH and EC values. The above is for a volume of 100 mL of nutrient solution.

Table III is listed the cases when 14 neurons are used, and the ANN is more accurate concerning the measured data. However, when increasing to 20 neurons, the system loses accuracy concerning the measured value.

Once the ANN's most appropriate number of neurons is established, the MSE and R data are shown in Table IV.

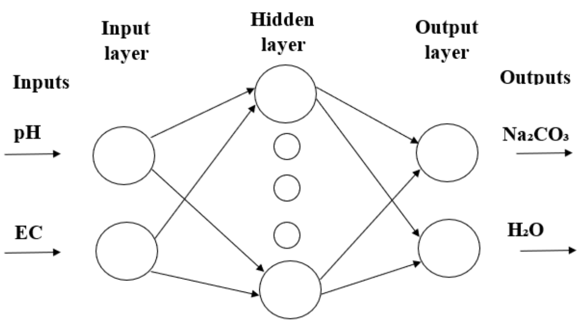

Fig. 2. Neural Network general diagram.

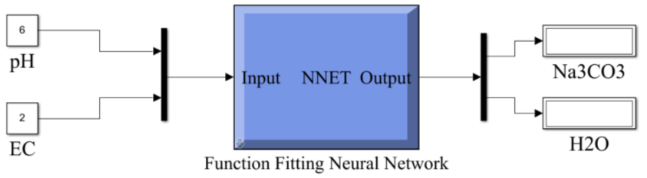

Fig. 3. ANN Simulink simulation.

TABLE III. ERROR IN DIFFERENT NUMBER OF NEURONS IN ANN.

Number of neurons	pH desired	EC desired	Measured volume (mL)	Volume from ANN (mL)	Error
6	6	2.07	140 (Na_2CO_3) 100 (H_2O)	141.4 (Na_2CO_3) 96.62 (H_2O)	1.4 (Na_2CO_3) 3.38 (H_2O)
10	6	2.07	140 (Na_2CO_3) 100 (H_2O)	138.9 (Na_2CO_3) 98.76 (H_2O)	1.1 (Na_2CO_3) 1.24 (H_2O)
14	6	2.07	140 (Na_2CO_3) 100 (H_2O)	139.9 (Na_2CO_3) 98.86 (H_2O)	0.1 (Na_2CO_3) 1.14 (H_2O)
20	6	2.07	140 (Na_2CO_3) 100 (H_2O)	139.2 (Na_2CO_3) 99.03 (H_2O)	0.8 (Na_2CO_3) 0.97 (H_2O)

TABLE IV. RESULTS OF MSE AND R FOR THE ANN.

	Samples	MSE	R
Training	33	5.86866e-1	9.99952e-1
Validation	7	0.00000e-0	0.00000e-0
Testing	7	10.60962e-0	9.98615e-1

III. RESULTS

A. SIMULATION IN MATLAB

For ANN training, 47 data samples were run with different combinations, as shown in Table II. The measured volume of sodium carbonate and water was simulated concerning those calculated by the ANN using the simulation to test the accuracy of the ANN is shown in Fig. 3.

Fig. 4 compares the obtained sodium carbonate volume data with the ANN data. The average error obtained was 1.18 mL.

Fig. 5 compares the data obtained for the volume of water experimentally concerning the data obtained by means of the ANN. The average error obtained is 0.92 mL.

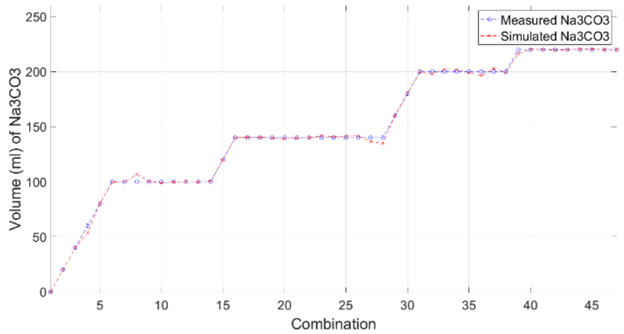

Fig. 4. ANN simulation with the experimental data for sodium carbonate.

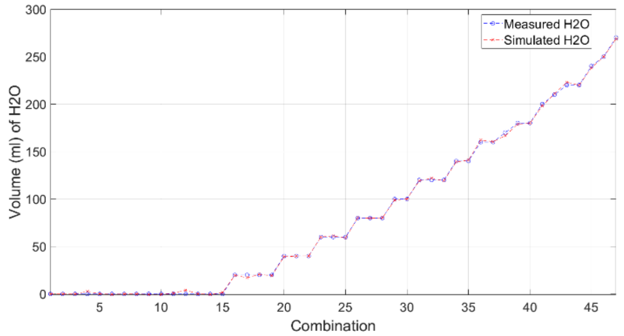

Fig. 5. ANN simulation with the experimental data for water.

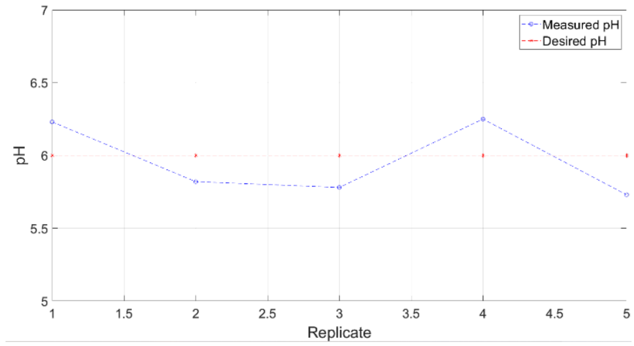

Fig. 6. ANN validation for pH.

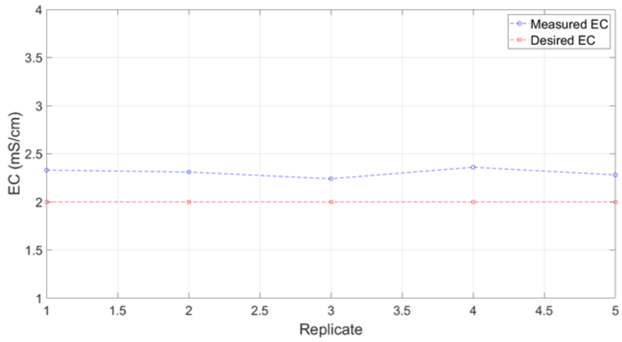

Fig. 7. ANN validation for EC.

B. *EXPERIMENTAL VALIDATION*

1. Experiment design for ANN validation

The validation of the ANN was done with 5 replicates in which the desired pH and EC values were established. The starting point was a volume of 100 mL of nutrient solution; then, a neural network was used to introduce the desired values of these variables. And the resulting volume of solutions was added to the nutrient solution to measure the pH and EC obtained and compared with the desired values.

2. Experiment design for ANN validation

The desired pH and EC values were introduced to the simulator, then the values in ml of the sodium carbonate and water solutions were obtained; the mixture was prepared, and then the measurement of these variables were made. Fig. 6 shows in the red line with asterisks the desired pH of 6 and the blue line with circles, the pH measured in each of the 5 replicates. The average error is 0.23.

The electrical conductivity of the desired value was 2 mS/cm, Fig. 7 shows in the red line with squares the desired value, and in the blue line with circles, the values measured in each of the 5 replicates. The average error obtained was 0.304 mS/cm.

C. *DISCUSSION*

ANNs have many applications, such as estimation models, in which the aim is to predict the dynamic behavior of a system. There are different methodologies and techniques for modeling these systems, and they can be applied to most systems with training data, obtaining improvements to conventional methods. For example, in [14], in a surface and subsurface drip irrigation system, various AI approaches were used to simulate the distribution of nitrate in the soil. In [9], a composite WOA-ANN algorithm was applied and optimized using BRF-FS; statistical methodologies, diagnostic analysis, and external validation were performed to evaluate the Machine Learning (ML) based models. Statistical analysis showed that BRF-FS is the best way to optimize the WOA-ANN composite model, obtaining an R=0.962, RMSE=0.029 mg/L, MAE=0.024, and U95%=0.056, improving the conventional ANN pressure by 30%.

Another example, such as [10], shows an ANN based on the Bayesian model, which estimates the crop yield. Furthermore, it provides the uncertainty of the input and model parameters, while it can forecast variables based on an ensemble structure. An RMSE of 24.21 Ton/ha was obtained as the lowest result compared to other ANN models such as MLP or ANFIS. In addition, a better p-value of 0.94 and an r of 0.12 were obtained. Therefore, the results are more reliable than other models.

In this work, an artificial neural network (ANN) was designed to control the pH and EC; in a nutrient solution designed to stress the crop to obtain an increase in antioxidants. Sodium carbonate to increase pH and water to decrease electrical conductivity were used as solutions to modify these variables. These two solutions were used due to the characteristics of the nutrient solution, which has a low pH of 3.74 and a high EC of 6.46 mS/cm. Therefore, adjusting these variables is required to increase the pH and lower the EC.

The ANN was simulated by comparing it with the experimental data, in which 47 combinations were made with different pH and EC values. The simulation yielded volume values in mL of sodium carbonate and water to be added to a nutrient solution. The average error obtained for sodium carbonate is 1.18 mL and 0.92 mL for water. The neural network validation was achieved by 5 replicates where a pH value of 6 and an EC of 2 was fixed; the volume obtained was added to 100 mL of nutrient solution, and then the pH value and EC obtained in each replicate were averaged. The average error obtained in pH is 0.23 and in EC is 0.304 mS/cm.

ANNs are used to make estimation models for many areas of interest. Examples [9] and [10] show ANN model optimization methodologies for estimating agriculture-related issues. The errors obtained show better results than conventional methods, as in the case of this work, as it improves the calibration process of a nutrient solution carried manually and through an ANN optimized by the Bayesian method. These enhance the accuracy and reduction of solutions to calibrate the nutrient solution to be applied in crops in the region, mainly intended for use in hydroponics.

ANN implementations for the control of nonlinear systems have shown good accuracy [15]. As a future work of this paper, an ANN will be implemented to control pH and EC in a nutrient solution for crops in the region. As an example in [16], a LabVIEW simulation of a hydroponic nutrient solution control using a mandani fuzzy inference system (FIS) is presented. The controlling variables are pH, EC, and level solution. The algorithm demonstrated better efficiency than conventional calibration nutrient solution systems.

In [17], a fuzzy logic controller for adjusting the pH and EC of the nutrient solution in a hydroponic system is presented in another example of the application of intelligent control. The control system is embedded in a raspberry pi3 board, regulating four pumps, where each one provides an alkaline solution, acid solution, water, and high EC solution, respectively. The pH presented an error of 0.2 for a reference of 6.3, and the EC presented an error of 0.1 for a reference of 1.

IV. CONCLUSIONS

Hydroponics in agriculture has become an important activity because it does not require the use of soil. This methodology allows the quick preparation of a nutrient solution with the desired pH and EC values necessary for the plant to take advantage of the nutrients.

An ANN with the Bayesian model was proposed in this design work, in which an estimation model was proposed to calibrate a nutrient solution for hydroponic agriculture in crops of the region. This model avoids the farmer's uncertainty in calibrating the solution with the appropriate pH and EC values. For this purpose, the ANN was trained by adding solutions to modify these variables and provide learning to the neural network. The results obtained had an acceptable accuracy, thus reducing errors by the user or technician.

For future work in this article, more solutions to the current ones will be used. A control system will be designed to add solutions employing actuators and provide the crop with a nutrient solution with adequate pH and EC conditions.

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