Development of Artificial Neural Network Model for Soil Nitrate Prediction

F Rohman¹, D Setiawan¹, Y D Prasetyatama¹, L Sutiarso¹

¹ Departement of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, Jl. Flora No. 1 Bulaksumur, Sleman, Yogyakarta 55281

Corresponding author’s email address: fatkhul.rohman@mail.ugm.ac.id

Abstract. Nitrate is the main form of nitrogen absorbed by plants. Leaching of nitrate can contaminate groundwater. The measurement of soil nitrate with conventional methods is less practical, takes a long time, and requires a lot of costs. Measurement of variables that affect the presence of soil nitrate can be an alternative solution. The application of prediction models is proven to save time and cost. Complexity problems can use the ANN model. This study aims to developed prediction models for soil nitrate use the ANN model. The measurable parameters such as solution volume, soil moisture, and soil electrical conductivity were used as input parameters for the model prediction development. The samples use oven-dry soil that was added nitrate solution with several variations. The measurement of parameters was carried out in three replications. The training and validation of the ANN model resulted in RMSE values of 1.0840029 and 1.000646 then R² values were 0.973 and 0.970. The ANN model can be an alternative to predict soil nitrate at different monitoring volumes.

Keywords: Soil Nitrate, ANN, Sensor

1. Introduction
Nitrogen is a macronutrient essential for plant growth and is a major pollutant for agricultural practices [1]. Nitrogen can be absorbed by plants in the form of (NO₃⁻) and ammonium (NH₄⁺). Most of the nitrogen in the soil is absorbed by plants in the form of nitrate ions because there has been a change from ammonium to nitrate [2]. Nitrate is the main source of nitrogen uptake in plants [3]. Besides, nitrate is the most mobile form of nitrogen and its leaching is a major source of contamination of groundwater [4]. So it is important to monitor soil nitrate as an effort to prevent groundwater contamination and optimize plant productivity [5]. Soil nitrate measurement using conventional methods in the laboratory is less practical, takes a long time and is destructive [6]. The development of rapid measurement of soil nitrate is estimated based on soil conductivity properties using time domain reflectometry (TDR) [7, 8]. The use of TDR has limitations due to the high cost [7]. The use of selective ion electrodes for fast nitrate measurement in the field is still under development and is constrained by the low cost [9].

Modeling is an efficient means of predicting nitrate levels [10]. The application of models to predict nitrate has been proven to save time and money with fairly accurate results [11]. An approach can be made by linking the parameters that affect soil nitrate for modeling. Several studies have shown that the soil water content and soil electrical conductivity (EC) have a positive correlation with nitrate concentrations [6, 8]. So there is the potential for modeling to predict soil nitrate based on soil moisture and soil electrical conductivity (EC).
Determination of the concentration and distribution of nitrate is a complex nonlinear problem, the artificial neural network model (ANN) can be an alternative solution [12]. The ANN model is proven to be able to predict the solute transport parameters from the basic soil properties [13]. In the study [14], the ANN model can be used to predict nitrate contamination in groundwater with good accuracy. The study [11] used an ANN model to predict nitrate contamination in groundwater using pH, electrical conductivity (EC) and groundwater level variables. This model is proven to predict nitrate concentration. In the study [12], it was shown that the ANN model is quite accurate, easy, and efficient to estimate the distribution of nitrate in soils which are given water and nutrients through drip irrigation. Based on the description above, an ANN model will be developed to predict soil nitrate by measuring parameters use sensors and portable tools.

2. Materials and Methods

2.1. Experimental Site
This study was carried out in Laboratory of Farm Structure and Environmental Engineering, Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada.

2.2. Materials and Tools
The materials used are the sandy soil samples from sub-surface constructed wetland in Piyungan, Bantul, Yogyakarta; potassium nitrate (KNO$_3$); and aquades. The tools used are container (8.5 cm diameter and 7.5 cm of high); erlenmeyer, baker glass, capacitive sensor (include arduino Mega 2560) and soil Electrical Conductivity (EC) tester.

2.3. Research Procedure

2.3.1. Materials Preparation
The preparation of the nitrate solution refers to the standard methods of the American Public Health Association (APHA) (1992) [15]. The soil used is dry soil that has been oven at 105 °C for 24 hours. The soil is crushed and then sieved and then weighed as much as 500 grams as a test material.

2.3.2. Data Collection
Data collection begins by mixing the soil and nitrate solution with various concentrations by stirring for 2 minutes. Then the instrument is planted on the soil sample and the response value is recorded. This test uses 500 grams of soil samples with variations in nitrate concentrations from 0 ppm, 25 ppm, 50 ppm, 75 ppm until 250 ppm. Variations volume of nitrate solution use 50 ml, 75 ml, and 100 ml. The measurable parameters such as solution volume, soil moisture, and soil electrical conductivity were used as input parameters for the model prediction development. The measurement of parameters was carried out in three replications.

2.3.3. Artificial Neural Network Modeling
The ANN model developed is a back-propagation type ANN model with a supervised learning method. The data used for model development is 99 data and 29 data for model testing. The ANN model developed uses MATLAB application (R2014b).

2.3.4. Model Validation
Model performance testing aims to test the level of accuracy between the predicted values and the observed values. The test was carried out in two ways, namely the root mean square error (RMSE) test and the coefficient of determination ($R^2$). Root mean square error (RMSE) is a test to measure model performance by measuring the magnitude of the prediction error between the observed value and the predicted value. The lower the RMSE value, the more accurate the model developed is. The formula for calculating the RMSE value can be seen in equation (1).
\[ \text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (O_i - P_i)^2} \]  

Where, \( n \) is the number of data, \( O_i \) is observation value to-\( i \), and \( P_i \) is prediction value to-\( i \).

The coefficient of determination (\( R^2 \)) is used to measure the proportion of the variation in the predicted value when compared with the observed value. The largest coefficient of determination is 1 and the smallest is 0. The prediction result of the model is considered good if the value is \( R^2 = 1 \) or \( R^2 \approx 1 \). The value of \( R^2 \) is searched by making a scatter graph of the observation value with the predicted value in Microsoft Excel. In the graph, a trendline is added then the linear regression type is selected and displays the \( R^2 \) value.

3. Result and Discussion

The ANN model architecture used is shown in Figure 2. According to [16], the relationship between complex variables requires more than 1 hidden layer to get accurate results. In addition, [17] stated that the value for the number of hidden layer neurons is 1 to 2\( n \) + 1 (\( n \) is the number of input neurons).

\[ \text{Figure 1. The Architecture of ANN model} \]

Based on this, the developed network has 2 hidden layers with 3 nodes in the input layer, 3 nodes in hidden layer 1, 3 nodes in hidden layer 2, and 1 node in the output. The type of training used is the training type \textit{trainlm} (Levenberg-Marquardt) with a maximum number of iterations of 1000, learning rate of 0.01 and the smallest Root Mean Square Error (RMSE) of 0.00001. The next stage is network training by entering 8 variations of activation functions to get the best ANN model architecture.

The results of developing the ANN model can be seen in Table 1. The varied activation functions are \textit{logsig} and \textit{tansig} because they are activation functions that describe the characteristics of the model with non-linear and widely used input-output relationships [18]. In Table 1, it can be seen that the \textit{tansig}-\textit{logsig}-\textit{tansig} activation function is the best activation function which produces the smallest RMSE value and the largest \( R^2 \) value. The graph of observation and prediction from the results of the training and the results of data validation is seen in Figure 3.

\[ \text{Tabel 1. Comparison of training and validation results of ANN models with various variations of activation functions} \]

| Activation function | training | validation |
|---------------------|----------|------------|
| \textit{logsig-logsig-logsig} | RMSE = 1,1962065, \( R^2 = 0.966 \) | RMSE = 1,188437, \( R^2 = 0.957 \) |
| \textit{logsig-logsig-tansig} | RMSE = 1,1476791, \( R^2 = 0.969 \) | RMSE = 1,179865, \( R^2 = 0.957 \) |
| \textit{logsig-tansig-tansig} | RMSE = 1,1512728, \( R^2 = 0.969 \) | RMSE = 1,180728, \( R^2 = 0.957 \) |
In Figure 2 can be seen a graph comparing the average EC value on different nitrate concentrations (0 ppm, 25 ppm, 50 ppm, 75 ppm, 100 ppm, 125 ppm, 150 ppm, 175 ppm, 200 ppm, 225 ppm, and 250 ppm) with the difference in treatment solution volume of 50 ml, 75 ml and 100 ml. From the graph, it shows that the EC value is influenced by the increase in the volume of water and nitrate contained in the solution.

The results in the Figure 3 are in accordance with previous research that shows that soil water content and soil electrical conductivity (EC) have a positive correlation with nitrate concentrations. [6, 8]. Groundwater content and electrical conductivity data from bulk soil solutions were used to calculate the temporal and spatial distribution of soil nitrate concentrations and changes in nitrate at different monitoring volumes [19]. EC measurements have a close relationship with soil properties and
conditions. In addition, soil EC measurement is also easy to do, has low operating costs, and is faster than other soil measurement methods [20].

4. Conclusion
The training and validation of the ANN model resulted in RMSE values of 1,0840029 and 1,000646 then $R^2$ values were 0.973 and 0.970. The ANN model can be an alternative to predict soil nitrate at different monitoring volumes.

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