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An improved back propagation neural network prediction model for subsurface drip irrigation system☆

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ABSTRACT

A crop yield-irrigation water model, based on an improved genetic algorithm (GA)-back propagation (BP) neural network prediction algorithm, has been developed in this study. It mainly uses the improved BP neural network based on the GA algorithm to develop the yield-irrigation water model for predicting the corn yield for different irrigation systems under subsurface drip irrigation. The model with the GA-BP algorithm gives more accurate predictions of the yield. The average error is only 0.71%. The GA-BP algorithm also speeds up the convergence of the network, improves the accuracy of the prediction, and describes the relationship between the yield and irrigation water under subsurface drip irrigation more accurately. Hence, the model can be used to design irrigation systems under subsurface drip irrigation more accurately.

1. Introduction

Subsurface drip irrigation (SDI) is one of the typical applications of micro-irrigation technology. It is a more efficient delivery system if water and nutrient applications are managed properly [1]. When it is under the low pressure condition, the water and nutrient can be supplied precisely to the root zone of the crops by embedding drip irrigation emitters in the active layer of the plant root system [2,3]. As there is little disturbance of the soil structure by SDI, it reduces the surface evaporation and deep seepage losses, eliminates surface runoff [4], and improves the efficiency of absorption of water and nutrients by the crops [5]. Therefore, SDI has been widely used on fruits, vegetables and other economic crops [6]. There are also pilot studies on the application of SDI on field crops.

However, to fully realize the water saving and yield increasing potential of SDI, it is necessary to develop a scientific SDI system [7–9]. The relationship between the crop yield and irrigation water can provide a quantitative basis for a reasonably optimized irrigation system [10,11]. However, the correlation between the crop yield and irrigation water is complex. Many studies have developed models between the crop and water based on limited irrigation experiments [11–13]. In these models, not only there are clear differences in the mathematical structures, but the expressions of the model parameters are also different. Although these models under certain conditions can meet the precision requirement of the yield forecast, however, due to the differences in the model structures and parameter expressions of the regional and time domain

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characteristics, these models cannot be applied to other areas. Further, as the relationship between the crop yield and irrigation water is complex and nonlinear, and its mechanism is not clear, these are some of the limitations on the applications of these models.

Artificial neural networks (ANN), in particular, BP (back propagation) network model has the self-organizing, adaptive and self-learning function, with a strong ability to deal with nonlinear problems [14–16]. It is very propitious to recurrent changes and detect patterns in complex agronomic irrigation systems [17–19]. Neuro-Drip combines an ANN with a statistical description of the spatio-temporal distribution of the added water from a single drip emitter to provide easily accessible, rapid illustrations of the spatial and temporal subsurface wetting patterns [20]. Karasekreter et al. (2013) used ANNs to develop a new system of irrigation ratios and time intervals, which achieved a 20.46% water saving and 23.9% energy saving [21]. Dursun (2014) used a soil moisture distribution map to develop an efficient improved photovoltaic irrigation system via the ANNs method. The system enabled the reduction of the orchards daily water and energy consumptions both by 38% [22]. However, there are shortcomings in the BP network model, such as trap in a local minimum and no convergence of shock [23]. Genetic algorithm (GA) is a calculation model which uses a global optimization search algorithm to mimic the natural biological evolution process, [24]. With the combination of BP neural networks and GA, it improves the BP learning training, optimize network power threshold, and promotes the rapid convergence and improves the efficiency and precision of the model [25]. In this study, an improved BP neural network prediction model based on GA has been used to develop the crop yield-irrigation water relationship model, which is to optimize a SDI system.

This paper is organized as follows. In Section 2, the yield-water model under SDI based on normal BP algorithm is introduced. In Section 3, the yield-water model under SDI based on GA-BP algorithm is discussed in details. In Section 4, the application and analysis of the yield-water model under SDI based on GA-BP algorithm model is described in details.

2. The yield-water model under SDI based on normal BP algorithm

2.1. Experiment design and data selection

2.1.1. Experiment design

The field experiment was conducted in Fuxin City (41°41N42°56N and 121°01E122°56E) in western Liaoning Province in China. It was conducted in 2014 at the Key Laboratory of Liaoning Water-Saving Agriculture. The location is in a warm temperate zone with hot summers and cold winters and experiences continental monsoons. The annual average temperature and sunshine are 7.2 °C and 2865.5 h, respectively.

A permanent rain shelter was constructed over the experimental plots to provide continuous protection from rain. A large plastic sheet was put on top of the roof of the rain shelter. This sheet was laid down to cover plots on rainy days and rolled up on sunny days, ensuring that conditions remained ecologically similar to the adjacent unsheltered field area.

In the experiments, the irrigation water has been set as one of the parameters, and the irrigation quota has been set at four levels. The field capacity used in the experiments are 50

2.1.2. Data selection

The relationship between the crop yield and water is nonlinear. At present, its mechanism is unclear. So, it is more suitable to use a BP neural network to develop the model. For the crops and water relationships, there is a variety of methods to describe the relationships. The most common methods describe the relationship between the ultimate yield and the irrigation water at each stage.

According to the growth characteristics of corn, its growth period can be divided into four stages, i.e. seedling stage, jointing stage, tasseling stage, and filling stage. The corn subsurface drip irrigation experiment was water treatment control in accordance with the jointing stage, tasseling stage and filling stage, and corn grain yield for economic yield. So, the input layer takes three neurons according to the three input variables corresponding to the irrigation at the three stages. The output layer takes one neuron according to one output variable corresponding to the yield of corn.

When the experiment was finished, the yield and the amount of irrigation water during the stage, tasseling stage, filling stage were analyzed statistically. Then, the next step was to develop the model. To make the network with good convergence and mapping capability, the following equation was used to normalize the data to [0, 1]:

$$x_i^{'} = \frac{x_i - x_{min}}{x_{max} - x_{min}} \tag{1}$$

Where $x_{\max}$ and $x_{\min}$ are the maximum and minimum of the irrigation amount or yield, x_i is the sample, $x_i^{'}$ is the normalized value.

2.2. Data modeling

The normal BP network model is a three or more layer neural network, which includes an input layer, a middle layer (hidden layer) and an output layer. The BP learning algorithm is essentially using a network error sum of squares as the objective function. It minimizes the objective function value according to the gradient method, i.e. using the gradient search technology to minimize the error of the mean square value between the actual output and the desired output of the network.