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INFORMATION PROCESSING IN AGRICULTURE 1 (2014) 14–22

journal homepage: www.elsevier.com/locate/inpa

Development of an intelligent system based on ANFIS for predicting wheat grain yield on the basis of energy inputs

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A R T I C L E I N F O

Article history:
Received 25 July 2013
Received in revised form
2 April 2014
Accepted 17 April 2014
Available online 24 April 2014

Keywords:
Wheat yield
Energy consumption
Prediction
ANFIS
ANN

A B S T R A C T

Energy is regarded as one of the most important elements in agricultural sector. During the last decades energy consumption in agriculture has increased, so finding the relationship between energy consumption and crop yields in agricultural production can help to achieve sustainable agriculture. In this study several adaptive neuro-fuzzy inference system (ANFIS) models were evaluated to predict wheat grain yield on the basis of energy inputs. Moreover, artificial neural networks (ANNs) were developed and the obtained results were compared with ANFIS models. For the best ANFIS structure gained in this study, R, RMSE and MAPE were calculated as 0.976, 0.046 and 0.4, respectively. The developed ANN was a multilayer perceptron (MLP) with eleven neurons in the input layer, two hidden layers with 32 and 10 neurons and one neuron (wheat grain yield) in the output layer. For the best ANN model, R, RMSE and MAPE were computed as 0.92, 0.9 and 0.1, respectively. The results illustrated that ANFIS model can predict the yield more precisely than ANN.

1. Introduction

Wheat (*Triticum* spp.) is one of the most-produced cereals which provides 70–90% of all calories and 66–90% of the protein consumed in developing countries and is the leading source of vegetable protein in human food, having a higher protein content than either maize (corn) or rice and the other major cereals. In terms of total production tonnages used for food, it is currently second to rice as the main human food crop and ahead of maize, after allowing for maize's more extensive use in animal feeds. It is now cultivated widely all over the world under a wide range of climatic conditions [1]. In 2010 world production of wheat was 651 million tons, making it the third most-produced cereal after maize (844 million tons) and rice (672 million tons) [2]. Iran with 150 million tons of wheat production in 2010 held the fourth rank among Asian countries.

The role of energy in agricultural production is so significant and important because different forms of energy are employed during production season and modern agriculture requires an energy input at all stages of agricultural production such as direct use of energy in farm machinery, water management, irrigation, cultivation and harvesting [3]. Also

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Peer review under the responsibility of China Agricultural University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.inpa.2014.04.001

post-harvest energy use includes energy for food processing, storage and in transport to markets. In addition, there are many indirect or sequestered energy inputs used in agriculture in the form of mineral fertilizers and chemical pesticides, insecticides and herbicides. Mechanized-crop production and intensive agricultural practices cause that energy consumption in agricultural sector increase dramatically [4]. Assessing the relationship between the energy inputs and outputs can help to achieve sustainability in agricultural production [5]. Due to the fundamental importance of energy issue in agriculture, several studies have been conducted on worldwide production of field crops including wheat [6], potato [7], canola [8], greenhouse crops [9–11], prune [12], soybean [13], etc. to analyze the energy input–output and to investigate their relationship.

To find the relationship between inputs and outputs of a production process artificial intelligence (AI) has drawn more attention rather than mathematical models to find the relationships between input and output variables by training, and produce results without any prior assumptions. Artificial neural network (ANN) models as a form of AI which was inspired by the studies of the human neuron can be applied to overcome the non-linearity problem and to analyze bio-physical data and they are usually used to model complex relationships between inputs and outputs, to find patterns in data, or to capture the statistical structure in an unknown joint probability distribution between observed variables [14]. ANNs have the potential to be better, quicker, and more practical alternative to the traditional methods, for modeling [15]. In the recent years, ANN modeling technique has been employed to show the robustness of AI versus regression methods. Zangeneh et al. [16] drew a comparison between parametric and ANN approaches for economical assessment of potato production. In another study, Safa and Samarasinghe [17] used ANN for determination and modeling of energy consumption in wheat production. ANN model and multiple linear regression (MLR) model were compared and it was concluded that ANN model can predict energy consumption relatively better than the MLR model.

The adaptive neuro-fuzzy inference system (ANFIS), another AI method, is a combination of ANN and fuzzy systems that uses the learning capability of the ANN to derive the fuzzy if-then rules with appropriate membership functions worked out from the training pairs, which in turn leads to the inference [18,19]. ANFIS has been employed in various agricultural studies. Akbarzadeh, Mehrjardi [20] developed an ANFIS model for soil erosion estimation. In another research, conducted by Krueger, Prior [21], ANFIS model was evaluated to characterize root distribution patterns under field conditions. Kisi and Shiri [22] compared ANN and ANFIS models for prediction of long-term monthly air temperature using geographical inputs. They illustrated that the maximum and minimum determination coefficient values were calculated as 0.995 and 0.921 for ANN model and computed as 0.999 and 0.876 for ANFIS model. Some studies show that there is a positive relationship between energy usage and productivity [10,17,23,24].

The aim of this study was to develop several ANFIS models to predict wheat yield on the basis of energy inputs. Moreover, the ANN models were developed and generalized to predict wheat grain yield based on the energy inputs and furthermore, the results were compared with ANFIS models.

2. Materials and methods

2.1. *Selection of case study region and data processing*

Initial data for this study were collected from 260 wheat farms in Fereydonshahr region, situated in Isfahan province, Iran. This province is located in the center of Iran within 30–42° and 34–30° north latitude and 49–36° and 55–32° east longitude. The average of annual rainfall in this region is 600 mm, the mean annual temperature is 5 °C and soil texture in the region is typically 48% clay, 40% silt and 11% sand. Data were obtained in the 2011–2012 production year. The sample size was determined using Cochran method which was elaborated in detail by Mobtaker, Keyhani [25], so 260 wheat farmers were randomly selected and inquired using a face to face questionnaire method.

To convert energy inputs to their energy equivalents, energy conversion factors, which are presented in Table 1, were employed. Input energies utilized for wheat production comprises machinery, human labor, diesel fuel, pesticides, chemical fertilizers, farmyard manure (FYM), electricity, water for irrigation and seeds, while the grain produced was regarded as output energy. In questionnaires a question about the agricultural machineries, which were used during the production season, was asked from farmers and then by calculating machinery weights and applying the following formula, the machinery energy was computed [26].

$$ME = \frac{ELG}{TC_a} \quad (1)$$

where 'ME' is the machine energy (MJ ha^{-1}), 'G' the weight of machine (kg), 'E' the production energy of machine (MJ kg^{-1} yr^{-1}) that is shown in Table 1, 'L' the useful life of machine (year), 'T' the economic life of machinery (h) and 'C_a' the effective field capacity (ha h^{-1}) [7].

2.2. *Adaptive neuro-fuzzy inference system (ANFIS)*

Fuzzy inference algorithm as the foundation of ANFIS is a method in which fuzzy rules are employed to deduce a new approximate fuzzy set conclusion while taking fuzzy set as premise. Fuzzy inference system (FIS) is primarily applied to the cases that either the systems are hard to be precisely modeled or the description about the studying issues is vague and equivocal [27]. An ANFIS is used to map input characteristics to input membership functions (MFs), input MF to a set of if-then rules, rules to a set of output characteristics, output characteristics to output MFs, and the output MFs to a single-valued output or a decision associated with the output [28,29].

A typical ANFIS structure, which can be seen in Fig. 1, includes 5 layers. Layer 1: Every node i in this layer is an adaptive node with a node function,

$$O_i^1 = \mu_{A_i}(x), \quad (2)$$

where x is the input to node i, A_i represents the linguistic label associated with this node function, and O_i^1 is the membership function of A_i that specifies the degree to which the given x