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Application of ANFIS to predict crop yield based on different energy inputs

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ABSTRACT

In this paper, adaptive neuro-fuzzy inference system (ANFIS) was used to predict the grain yield of irrigated wheat in Abyek town of Ghazvin province, Iran. Due to large number of inputs (eight inputs) for ANFIS, the input vector was clustered into two groups and two networks were trained. Inputs for ANFIS 1 were diesel fuel, fertilizer and electricity energies and for ANFIS 2 were human labor, machinery, chemicals, water for irrigation and seed energies. The RMSE and R^2 values were found 0.013 and 0.996 for ANFIS 1 and 0.018 and 0.992 for ANFIS 2, respectively. These results showed that ANFIS 1 and ANFIS 2 could well predict the yield. Finally, the predicted values of the two networks were used as inputs to the third ANFIS. The results indicated that the energy inputs in ANFIS 1 have a greater impact on the final yield production than other energy inputs. Also, the RMSE and R^2 values for ANFIS 3 were 0.013 and 0.996, respectively. These results showed that ANFIS 1 and the combined network (ANFIS 3) could both predict the grain yield with good accuracy.

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1. Introduction

Wheat is one of the strategic crops of Iran. Determining the relationship between energy inputs and outputs can be an important step to achieve sustainable agriculture aims. Various types of energy are used for production in economic and development fields of each country. Because of the depletion of some energy resources and non-renewability of them, finding a solution to reduce energy consumption per production unit is essential to reach sustainable development and to save interest of future generation. Energy productivity can lead to the fulfillment of sustainable development aims. Effective application of energy resources is important in productivity and sustainability of rural life [1]. The pattern of energy consumption and contribution of each energy input differ according to agricultural systems, growth season and other conditions. Thus, paying attention to the relationship of energy inputs and yield, using functional forms is very important [1]. In the past, mathematical models were used to find the relationships between inputs and outputs of a production process. But this classic logic approach requires an exact definition of the mathematical model equations to describe the phenomenon [2,3].

Today, it is known that fuzzy logic, an Artificial Intelligence (AI) method, offers the mathematical framework. Because the fuzzy logic allows for a simple knowledge representation of the production process in terms of IF-THEN rules [4]. Fuzzy logic allows us to solve problems not well defined and for which it is difficult, or even impossible to find a solution [2,3].

Artificial neural networks (ANNs), another AI method, was used according to the natural neural network of human brain. Many researchers have reported the proper ability of ANN versus regression method such as study

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Nomenclature

ER	energy ratio	n	number of questionnaires
EUE	energy use efficiency	Z_s	predicted value
E_o	output energy	Z_o	measured value
E_i	input energy	$\overline{Z}_o$	average value off experimental data
EP	energy productivity	MSE	mean square error
Y	yield of crop	MAE	mean absolute error
SE	specific energy	SSE	sum squared error
NE	net energy	R	correlation coefficient
x	the observed value	P	probability

done by Rahimi and Abbaspour [5]. They used artificial neural network and stepwise multiple range regression methods for prediction of tractor fuel consumption. Their results showed that ANN provided better prediction accuracy compared to stepwise regression. Adaptive neuro-fuzzy inference system (ANFIS) is a beneficial method to solve non-linear problems [6]. ANFIS, which is a combination of ANN and fuzzy systems, has the benefits of the two models [6–8]. This technique is particularly useful in the engineering applications where classical approaches fail or they are too complicated to be used [9]. The ANFIS method is ideal for interpretation of non-linear systems, like soil–plant–air systems [10]. Some researchers have applied ANFIS in agricultural research. ANFIS was used for soil erosion estimation by Akbarzadeh et al. [11]. Arkhipov et al. applied ANFIS technique to yield modeling [10]. Avci compared the wavelet families for texture classification by using wavelet packet entropy adaptive network based fuzzy inference system [12]. Krueger et al. evaluated ANFIS application for exploring complex root distribution patterns under field conditions [13]. Their results showed that that the fuzzy method offers a viable alternative to more traditional statistical techniques. Fahimifard et al. applied ANFIS to predict the poultry retail price [14]. Adaptive neuro-fuzzy inference system (ANFIS) has been applied in landslide susceptibility analysis to produce their maps [15,16]. A review of published literature reveals that ANFIS has been used successfully in geotechnical engineering applications [17]. Some non-linear models such as artificial neural networks, the adaptive neuro-fuzzy inference system and a non-linear regression technique have been applied in similar studies [18–22].

The main objective of this paper is to evaluate ANFIS application for predicting grain yield of irrigated wheat under field conditions in Abyek town of Ghazvin province, Iran.

2. Materials and methods

2.1. Data preparation

The study area included 8171.217 ha of winter wheat fields in Abyek town of Ghazvin province, Iran. This area has been located in 35°54′55″ to 36°01′41″ northern latitude and 50°27′25″ to 50°34′40″ eastern longitude. The required information was collected from the questionnaires filled in through face-to-face interviews with 193 farmers, using simple random sampling method during 2010–2011 cropping season. The energy equivalent to each input and output in crop production has been presented in Table 1. The energy inputs include labor, machinery, electricity used to pump the water for irrigation, diesel fuel, water for irrigation, fertilizer, chemicals (pesticide, herbicide and fungicide) and seed. The references of each energy equivalent have also been cited.

The following relationships were used to calculate the energy ratio (energy use efficiency), energy productivity, specific energy and net energy [30,31]:

$$ER(EUE) = \frac{E_o(\text{MJ ha}^{-1})}{E_i(\text{MJ ha}^{-1}} \tag{1}$$

$$EP(\text{kg MJ}^{-1}) = \frac{Y(\text{kg ha}^{-1})}{E_i(\text{MJ ha}^{-1})} \tag{2}$$

$$SE(\text{MJ kg}^{-1}) = \frac{1}{EP} \tag{3}$$

$$NE(\text{MJ ha}^{-1}) = E_o(\text{MJ ha}^{-1}) - E_i(\text{MJ ha}^{-1}) \tag{4}$$

where $ER(EUE)$ denotes dimensionless energy ratio (energy use efficiency), E_o and E_i are energy output and input (MJ ha^{-1}), respectively, EP is energy productivity (kg MJ^{-1}), Y is the yield of crop (kg ha^{-1}), SE is specific energy (MJ kg^{-1}), and NE is the net energy (MJ ha^{-1}). To increase the accuracy and speed of model performance, the data were normalized to 0–1 range by the following formula [32]:

$$X_{norm} = \frac{x - x_{min}}{x_{max} - x_{min}} \tag{5}$$

where X_{norm} is the normalized value, x is the observed value, x_{min} and x_{max} are the maximum and minimum values of variable.

2.2. Adaptive neuro-fuzzy inference system

The foundation of ANFIS is the data driven from fuzzy modeling approach. This allows for the model extraction from the input/output data represented as Fuzzy Inference System (FIS) [33,13]. This is a rule-based system with three components: membership functions of input–output

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