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Modeling energy consumption and greenhouse gas emissions for kiwifruit production using artificial neural networks

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ABSTRACT

The purpose of this study was to apply artificial neural networks (ANNs) for forecasting and sensitivity analysis of energy inputs and GHG emissions of three groups of kiwifruit orchards of different sizes in Guilan Province, Iran. The initial data were collected from 80 kiwifruit producers in Langroud City, Guilan Province. The total energy input and output were estimated at 37.32 GJ ha^{-1} and 43.44 GJ ha^{-1}, respectively. The ANOVA (analysis of variance) results showed significant variance among the different orchard sizes from an energy input point of view. The results revealed that the highest share of energy input was that of nitrogen fertilizer use in kiwifruit production. The main reason for the overuse of nitrogen fertilizer is government subsidies provided for chemical fertilizers, followed by high levels of nitrogen leaching due to high rainfall. The average values of some energy indices, such as energy use efficiency, energy productivity, net energy and energy intensiveness, were calculated as 1.16, 0.61×10^{-3} kg GJ^{-1}, 6.12 GJ ha^{-1} and 3.27×10^{-3} GJ $\$^{-1}$, respectively. The average total GHG emissions were calculated as 1310 kg $CO_{2eq.}$ ha^{-1}. Nitrogen fertilizer had the highest share in GHG emissions for kiwifruit production, with 26.17% of total emissions. The 12-9-9-2 structure ANN model was the best topology for predicting yield and GHG (greenhouse gas) emissions of kiwifruit production in the studied area. The coefficients of determination (R^2) of the best topology calculated were 0.987 and 0.992 for yield and greenhouse gas emissions, respectively, indicating the high correlation in the model. The results of model sensitivity analysis indicated that diesel fuel and nitrogen fertilizer were the most sensitive inputs for kiwifruit yield and greenhouse gas emissions, reflecting the important role of nitrogen fertilizer in the excess energy consumption and greenhouse gas emissions of kiwifruit orchards. According to the current study, it is suggested for new policies to be adopted to reduce nitrogen fertilizer consumption.

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1. Introduction

Kiwifruit is native to southern China where it is declared the national fruit. Other species of Actinidia are native to India, Japan and southeastern Siberia. The cultivation of kiwifruit spread from China starting in the early 20th century (Stirk, 2005). The biggest kiwifruit producers in the world are Italy, New Zealand, Chile, Greece, France and Turkey. After these countries, Iran is the 7th largest kiwifruit producing country with 32 000 million tons in 2013 (FAO, 2013). One of the principal requirements for sustainable agriculture is efficient energy use. Energy use in agriculture has been increasing in response to the growing global population, limited arable land and desire for higher living standards (Abdi et al., 2012). On the other hand, higher energy inputs boost greenhouse gas (GHG) emissions from the agricultural sector. It should be noted that agriculture contributes significantly to atmospheric GHG emissions, with 10–12% of the net global CO_2 (carbon dioxide) emissions (Browne et al., 2011). The scientific community believes global warming will pose one of the major

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environmental challenges in the future, with the bulk of GHG originating from fossil fuel consumption (Sabzevari et al., 2015; Kouchaki-Penchah et al., 2016). Kiwifruit is an economically important fruit crop in northern Iran (Ministry of Jihad-e-Agriculture, 2014), because the northern region of Iran is a suitable, natural habitat for kiwifruit cultivation. Moreover, kiwifruit is regarded as a “disease-resistant” crop (Hawthorne et al., 1982; Sommer et al., 1994). Over the last 30 years, kiwifruit production has amplified in north Iran. The high kiwifruit production in Iran has reached a point that Iran is now well-known on global markets and in recent years this fruit has contributed a large share to agricultural exports. More recently years, Guilan horticulturists have been encouraged to produce more kiwifruit. Increased production leads to greater energy consumption by Iranian kiwifruit orchards due to the added application of inputs, such as fertilizers and fuel. Besides, where there is no clear energy consumption pattern in agricultural production, especially fruit orchards, a lot of energy dissipates in the fruit production cycle. Therefore, it seems necessary to provide a model for the energy consumption of kiwifruit orchards in Guilan Province to prevent excessive energy utilization. For Guilan horticulturists, to increase the yield of imported inputs (biocides and fertilizers) and reduce their import, a decrease in energy consumption will help.

A few studies have investigated the energy consumption and GHG emissions of kiwifruit production. Mohammadi et al. (2010) studied energy use patterns and production of kiwifruit using the Cobb–Douglas method. Their results showed an estimated total energy input of 30.30 GJ ha^{-1} Nikkhah et al. (2015) determined the GHG emissions of a kiwifruit production system. They reported the total GHG emissions from kiwifruit production were about 4520 kg $CO_{2eq.}$ ha^{-1}.

An artificial neural network (ANN) is a huge parallel and distributed information processing system that has certain performance characteristics resembling the biological neural networks of the human brain (Momenzadeh et al., 2011). ANN can be used as an alternative to analytical approaches, as ANN offers advantages including no required knowledge of internal system parameters and compact solutions for multivariable problems. This algorithm can also be used as an alternative, reliable methodology for making dependable predictions to improve energy use and GHG emissions. Several researchers have focused on different horticultural crops, especially in humid areas, in terms of modeling energy and GHG emissions. Khoshnevisan et al. (2013) applied an ANN in modeling GHG emissions and energy inputs for strawberry production in Guilan Province, Iran. Taghavifar and Mardani (2015) examined an ANN model for predicting energy use and GHG emissions of apple production in another area of Iran with different temperatures. Nabavi-Pelesaraei et al. (2016) applied neural networks in modeling energy use and GHG emissions of orange production in Guilan Province, Iran.

The main purpose of this study is to predict kiwifruit production yield and GHG emissions on the basis of input energy using ANNs. Even though a number of new mathematical functions have been proposed for modeling energy consumption and GHG emissions for kiwifruit production, in this investigation the main aim is to overcome high nonlinearity by applying a soft computing method. Therefore, several ANN models are developed and qualitative parameters are utilized to predict the models' accuracy.

2. Materials and methods

This study was conducted in Guilan Province, which is located in the north of Iran between 36°34′ and 38°27′ north latitude and 48°53′ and 50°34′ east longitude. The weather in this province is humid with high annual rainfall. The total horticultural area in Guilan Province is 87 533 ha, with kiwifruit orchards comprising 20%. In Guilan Province, Langroud City is the main kiwifruit producer with 40% (Ministry of Jihad-e-Agriculture, 2014). Data were collected from 80 orchards in Langroud for the horticulture yield period of 2013–2014 using a face-to-face questionnaire. The questionnaire included several questions about the use of various inputs (fuel, electricity, fertilizers, biocides, etc.), the amount of land cultivated by gardeners, kiwifruit yield per year, total working hours of labor over the total stages (from land preparation to kiwifruit harvest), total working hours of machinery and equipment, etc. A brief summary of the sample questionnaire is provided in Table 1.

In this study, the Cochran formula was applied to estimate the size of the required sample.

This method was described by Cochran (1977) as follows:

$$n = \frac{\frac{z^2pq}{d^2}}{1 + \frac{1}{N}\left(\frac{z^2pq}{d^2} - 1\right)} \quad (1)$$

where n is the required sample size, N is the number of orchards per target population (equal to 90 based on a report by the Ministry of Jihad-e-Agriculture (2014)), z is the reliability coefficient (equal to 1.96, which represents the 95% confidence level), p is the estimated proportion of an attribute that is present in the population (equal to 0.5), q is 1−p (equal to 0.5), and d is the permitted error ratio deviation from the population average (equal to 0.05). Consequently, the calculated sample size in this study was 73, but it was considered to be 80 to ensure accuracy; the samples were selected randomly.

In Guilan Province, input energy sources consist of human labor, chemical fertilizers (nitrogen, phosphate, potassium and sulfur), biocides (pesticides and fungicides), machinery, diesel fuel, electricity and farmyard manure, while kiwifruit yield is the only farm output. To survey energy consumption in the production of various agricultural products such gardening products, it should be revealed whether the energy consumption value covers the stages of production and supply. For this reason, a clear boundary for the production system should be defined and the energy consumption value for the total activities done within the determined boundary of the production system should be achieved. In this study, these activities comprise tillage and land preparation, all activities during the growing season resulting in increased product yield including fertilization, spraying, etc., and activities that lead to energy consumption for the eventual kiwifruit orchard harvest. Energy consumption beyond the system boundaries, such as for processing after harvest, is not calculated in this study. In the agriculture sector, the input and output energy sources are limited and all have standard energy coefficients. Accordingly, the energy amount of each input and output can be calculated by multiplying the physical amount with the energy coefficient. In this research, the energy input coefficients were achieved from previous studies, which are given in Table 2. These coefficients are fixed and not related to product type. For example, human labor and diesel fuel in the production of various products are of the same nature and have constant coefficients for the conversion to their energy consumption equivalents. Thus, the difference in energy consumption for agricultural production is the input value. For this reason, determining the energy consumption for kiwi production using standard coefficients shows a certain pattern of energy consumption in kiwifruit production. It also enables comparing the results with other studies using standard energy coefficients for the calculation of energy consumption. The energy requirements of the inputs and outputs are calculated by multiplying the

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