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Energy Use Forecasting for Wheat Production Utilizing Artificial Neural Networks (ANN)

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Abstract: This study was conducted in order to determine the amount of energy used for wheat production and develop an artificial neural network (ANN) to predict this consumption in Fars province, Iran. For this purpose, the data was collected from 100 wheat growing farmers. The results revealed that total input and output energy for the wheat production were 38985.97 and 97599.18 MJ ha^{-1}, respectively. Energy output-input ratio, energy productivity and specific energy were 2.50, 0.170 kg MJ^{-1} and 5.88 MJ kg^{-1}, respectively. Feed forward network (FFN), generalized feed forward network (GFFN), Elman network, radial basis function (RBF), self-organizing feature maps (SOM) and recurrent network (RNN) were examined by changing the number of hidden layers, neurons and training algorithms. It was found that three top networks for this study were GFFN, FFN and Elman. The best performance was achieved by GFFN with one hidden layer and Levenberg Marquart (LM) training algorithm by $R^2 = 0.95$ and RMSE = 3351.71 MJ ha^{-1}.

Key words: Wheat · Energy ratio · Specific energy · ANN

INTRODUCTION

Agriculture has become an increasingly energy-intensive sector in the last half-century with much of it attributable to the needed inputs. For example, chemical fertilizers and pesticides require much greater energy to manufacture than to apply on-farm [1]. Agriculture is both a producer and a consumer of energy. Through photosynthesis, crops convert solar energy to biomass, thus providing food, feed and fiber [2]. Energy usage in the agricultural production has been increasing faster than that in many other sectors of the world economy because agricultural production has become more mechanized and the use of substitutes for land, such as commercial fertilizers, has increased.

Wheat is one of the top three most producing cereals in the world, ranks the second place after corn and followed by rice. Winter wheat is one of the most major crops that have been planted in Iran. Planted area was 12.96 million ha in 2005-2006. Cereal planted area was 9.37(72.28%) million ha, which includes wheat (73.42%), barley (16.73%), paddy (6.73%) and corn (3.12%). Total harvested cereals in 2005-2006 were 22.40 million tons of which wheat recorded of 65.47% followed by barely (13.20%), paddy (11.66%) and corn (9.67%), respectively [3]. At least 40% of Iran's wheat is rainfed with an average yield of only 0.8 tons ha^{-1}. Even in irrigated farms the average yield of wheat rarely exceeds 3 tons ha^{-1}, which is low in comparison to the world standards [4].

Commercial energy inputs are being used increasingly in developing countries and are resulting in a transition from traditional to more energy-oriented agricultural production methods [5]. It seems that there is a huge gap between industrialized and developing countries in the terms of using energy resources. This problem is even more severe in areas like Iran that have almost a large quantity of oil and natural gas resources at hand with a lower price.

Artificial neural networks (ANNs) are relatively new robust tools that have found extensive utilization in solving many complex real-world problems. They are computational networks which attempt to simulate, in a gross manner, the networks of nerve cell (neurons) of the biological (human or animal) central nervous system. It is indeed a functional imitation of simplified model of the biological neurons and their goal is to produce intelligent data evaluation techniques like pattern recognition, classification and generalization by using simple, distributed and robust processing units called

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artificial neurons or processing elements [6]. The neural network, by its simulating a biological neural network, is in fact a novel computer architecture and a novel algorithmization architecture relative to conventional computers. It allows using very simple computational operations (additions, multiplication and fundamental logic elements) to solve complex, mathematically ill-defined problems, nonlinear problems or stochastic problems [7]. The attractiveness of ANNs comes from their remarkable information processing characteristics pertinent mainly to nonlinearity, high parallelism, fault and noise tolerance and learning and generalization capabilities [8].

Tzilivakis *et al.* [9] evaluated the amount of energy used for sugar beet production in the UK and found that the overall energy input of the UK beet crop ranges between 15.72 and 25.94 GJ ha^{-1}. It produces between 7.3 and 15.0 times as much energy in dry matter at the sugar factory gate as consumed in its production, with an average ratio of 9.7. A study estimated that the amount of energy for corn production in Wisconsin was 1.54 MJ kg^{-1} with corn production level of 9398 kg ha^{-1}. Energy inputs for drying increased this value to 3.88 MJ kg^{-1}. In comparison to Wisconsin, Germany consumed 1.43 MJ kg^{-1} with average of 9330 kg ha^{-1} corn [10].

Monisha *et al.* [11] used ANNs for corn and soybean yield prediction in Maryland. ANN corn yield models for Maryland resulted in r^2 and RMSEs of 0.77 and 1036 versus 0.42 and 1356 for linear regression, respectively. ANN soybean yield models for Maryland resulted in r^2 and RMSEs of 0.81 and 214 versus 0.46 and 312 for linear regression, respectively. They stated that ANN models proved to be a superior methodology for accurate predicting corn and soybean yields under typical Maryland climatic conditions.

Many researchers have studied energy consumption pattern for different crops and situations, because the way of energy consuming and its productivity deserves high attention. Regarding the energy scarcity and wheat importance in Iran, this study was carried out to develop a proper ANN in order to forecast energy consumption for wheat production in Iran.

MATERIALS AND METHODS

Study Area and Energy Used Assessment: This study was conducted in order to determine the amount of energy consumption for wheat production and develop an ANN to predict this consumption in the Fars province. The province is located in the south of Iran, within 27° 03° and 31° 40° north latitude and 50° 36° and 55° 35° east longitude. The data was collected from 100 wheat growing farmers. For collecting the proper data covering the energy consumption pattern, appropriate questionnaire were designed and completed through face to face interviews.

Table 1: Energy equivalents of inputs and outputs in agricultural production

Input (unit)	Energy equivalent (MJ $unit^{-1}$)	Reference
Liquid chemical (L)	102.00	12
Granular chemical (kg)	120.00	12
Human power (h)	1.96	5
Machinery (kg)	62.70	13
Nitrogen (kg)	66.14	14
Phosphorus (kg)	12.44	14
Potassium (kg)	11.15	14
Manure (kg)	0.30	13
Zinc sulphate (kg)	20.90	13
Diesel (L)	56.30	13
Wheat seed (kg)	14.70	5

The amount of different inputs were evaluated per hectare and multiplied by their energy equivalents. The energy equivalents of inputs and output used in this study are given in Table 1.

The total energy requirements in agriculture can be divided into direct and indirect parts and also renewable and non-renewable energies. Direct energy includes fuel, human power and electricity and indirect energy consists of the energy used in manufacturing, packaging and transporting fertilizers, pesticides and farm machinery. Renewable energies are: human power, seed and manure and non-renewable energies are: fuel, electricity, fertilizers, pesticides and farm machinery [5]. Energy efficiency parameters calculated as shown below [15]:

Energy Ratio: Energy output/energy input (1)

Specific Energy: Energy input/grain yield output (MJ kg^{-1}) (2)

Energy Productivity: Grain yield output/energy input (kg MJ^{-1}) (3)

Net Energy Gain: Energy output-energy input (MJ ha^{-1}) (4)

ANN Development: Hornik *et al.* [16] demonstrated that ANNs with one hidden layer could approximate any function given to that sufficient degrees of freedom (i.e., connection weights) are provided.

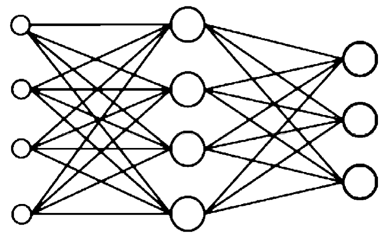

Fig. 1: Typical feed forward neural network [18]

However, Kartam and Flood [17] stated that many functions are difficult to be approximated with one hidden layer. Since the structure of ANN determined by trial and error, we examined different networks with different architectures using NeuroSolutions 5. Feed forward network (FFN), generalized feed forward network (GFFN), Elman network, radial basis function (RBF), self-organizing feature maps (SOM) and recurrent network (RNN) were examined by changing the number of hidden layers, neurons and training algorithms. Two different algorithms, Momentum and Levenberg Marquart (LM) were used as training algorithms. 50% (50 data) of collected data in this study was used for training, 25% (25 data) for cross validation and 25% (25 data) for test. Energy consumption in the form of machinery, diesel fuel, fertilizer, chemical, seed, electricity and human power were defined as input columns and output energy was defined as desired output. Root mean square error (RMSE) and R^2 were used to evaluate the effectiveness of each network. The best condition would be as $R^2 = 1$ and RMSE = 0.

Multilayer perceptrons (MLPs) are layered feed forward networks typically trained with static back propagation. Their main advantage is that they are easy to use and that they can approximate any input/output map [16]. A typical feed forward neural network with one input, output and hidden layer is shown in Fig. 1 [18].

Generalized feed forward networks are a generalization of the MLP such that connections can jump over one or more layers. In practice, however, generalized feed forward networks often solve the problem much more efficiently.

Radial basis function (RBF) networks are nonlinear hybrid networks typically containing a single hidden layer of processing neurons. These networks tend to learn much faster than MLPs.

Self-organizing feature maps (SOFMs) transform the input of arbitrary dimension into a one or two dimensional discrete map subject to a topological (neighborhood preserving) constraint.

RESULTS AND DISCUSSION

Energy Consumption: The outcome of energy assessment for wheat production in Fars province is given in Table 2. Total energy input and output were 38985.97 and 97599.18 MJ ha^{-1}, respectively.

The share of direct and indirect energy consumption was almost equal by 18256.83 (46.83%) for direct and 20729.14 MJ ha^{-1} (53.17%) for indirect energies. On the other hand, the shares of renewable and non-renewable energy were 14.29% and 85.71%, respectively. Energy output-input ratio, energy productivity and specific energy were 2.50, 0.170 kg MJ^{-1} and 5.88 MJ kg^{-1}, respectively. The top three energy consumers were fertilizer, electricity and diesel fuel. These parts consumed

Table 2: Energy used status for wheat production in Fars province

	Average (MJ ha^{-1})
1-Machinery	1505.99(3.86%)*
1-1- land preparation	486.515[32.31%]**
1-2- planting	289.945[19.25%]
1-3- fertilizer application + spraying	200.517[13.31%]
1-4- harvesting	529.013[35.13%]
2- Diesel fuel	8061.19(20.68%)
2-1- land preparation	3749.436[46.51%]
2-2- planting	2667.762[33.09%]
2-3- fertilizer application + spraying	245.133[3.04%]
2-4- harvesting	1398.859[17.35%]
3- Fertilizer	14175.37(36.36%)
3-1- Nitrogen	13033.247[91.94%]
3-2- Phosphorous	423.464[2.99%]
3-3- Potassium	208.969[1.47%]
3-4- Manure	462.432[3.27%]
3-5- Other (zinc sulphate, iron, etc).	47.258[0.33%]
4- Human Power	489.19(1.25%)
5- Seed	4620.16(11.85%)
6- Chemicals	427.62(1.1%)
7- Electricity	9706.45(24.89%)
- Total input energy	38985.97(100%)
- Direct energy	18256.83(46.83%)
- Indirect energy	20729.14(53.17%)
- Renewable energy	5571.78(14.29%)
- Non-renewable energy	33414.19(85.71%)
-Total output energy	97599.18
- Energy output-input ratio	2.50
- Energy Productivity (kg MJ^{-1})	0.170
- Specific energy (MJ kg^{-1})	5.88
- Net energy gain (MJ ha^{-1})	58613.21
- Yield (kg ha^{-1})	6639.39

*Figures in round brackets are percentage of total energy consumption.

**Figures in square brackets are percentage of energy consumptions in machinery, fuel and fertilizer parts

Table 3: Result of tested Artificial Neural Networks (ANN) for energy prediction for wheat production

Network model	Training algorithm	Layers	No. of neurons	Transfer function	RMSE (MJ ha^{-1})	R^2
FFN	LM*	1st hidden	9	Sigmoid	3797.28	0.83
		2st hidden	9	Sigmoid		
FFN	MOM**	1st hidden	4	Tanh	3408.29	0.91
		2st hidden	4	Tanh		
GFFN	LM	1st hidden	15	Sigmoid	3351.71	0.95
GFFN	LM	1st hidden	9	Tanh	4521.88	0.67
		2st hidden	11	Tanh		
GFFN	LM	1st hidden	7	Sigmoid	3858.56	0.81
		2st hidden	9	Sigmoid		
		3rd hidden	11	Sigmoid		
Elman	LM	1st hidden	12	Sigmoid	3735.48	0.85
		2st hidden	18	Sigmoid		
RBF	LM	1st hidden	4	Sigmoid	4028.97	0.79
RBF	MOM	1st hidden	4	Tanh	5716.74	0.36
SOM	MOM	1st hidden	4	Tanh	3828.93	0.82
RNN	MOM	1st hidden	4	Tanh	5703.16	0.37

*,** LM = Levenberg Marquart and MOM= Momentum

about 82% of total input energy. Energy consumption in the form of fertilizer was ranked first. Fertilizer consumed 36.36% of total input energy of which about 92% was belonging to nitrogen. Unfortunately, during the study it was found that there was a positive tendency to use more fertilizer, especially nitrogen. It has predicted that the demand for fertilizer will increase to 6200 thousand tons by 2017-2018 (Anonym. 2006). In such situation most of farmers neither have used any manure, nor have they kept crops residues. Although farmers are forbidden from burning wheat residue, most of them have burned the wheat residues every year so that they have enough time to planting summer crops. Electricity contributed to the total input energy by 25%. Energy in the form of electricity was high, because most of farmers have used surface irrigation methods and there were a lot of water losses in conveyance and use.

In such problematic situation land leveling, improved irrigation methods, balanced fertilization, treated seeds, using IPM (Integrated Pest Management) practices to control various diseases and pests and encouraging farmers to plant green manures in fallow farms would improve agricultural system in Iran.

ANN Energy Prediction: Table 3 shows the results of test corresponding to the some networks configurations. Some of networks with improper results are not given. It was found that Levenberg Marquart (LM) was better than Momentum as training algorithms for most of

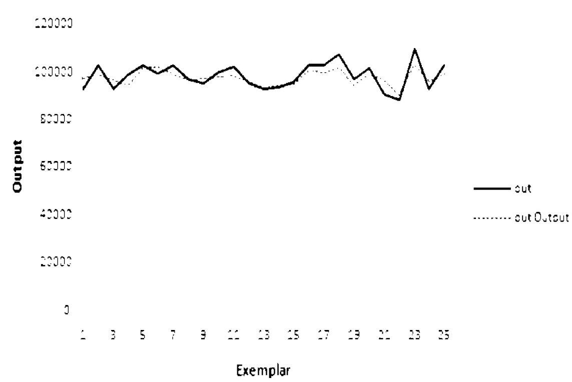

Fig. 2: Desired and actual network output for GFFN-LM, $R^2 = 0.95$

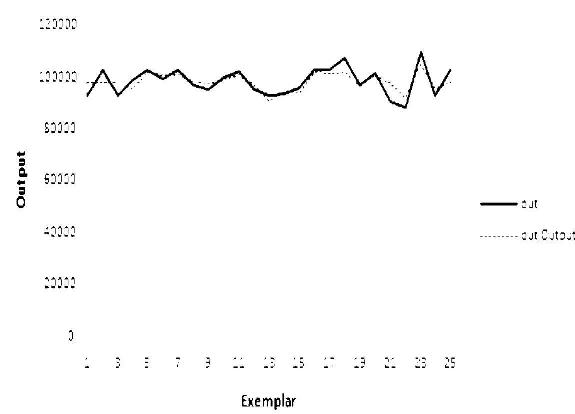

Fig. 3: Desired and actual network output for FFN-MOM, $R^2 = 0.91$

Fig. 4: Desired and actual network output for Elman-LM, $R^2 = 0.85$

networks in this study. As can be seen in Table 3 the best performance was achieved by GFFN with one hidden layer and LM training algorithm by $R^2 = 0.95$ and RMSE = 3351.71 MJ ha^{-1} and then by FFN with two hidden layers and Momentum training algorithm by $R^2 = 0.91$ and RMSE = 3408.29 MJ ha^{-1} and Elman network with two hidden layers and LM training algorithm by $R^2 = 0.85$ and RMSE = 3735.48 MJ ha^{-1}, respectively. The desired and actual network outputs for these three networks are shown in Fig. 2, 3 and 4, respectively.

CONCLUSION

This study was conducted in order to determine the amount of energy used for wheat production and develop an ANN to predict this consumption in Fars province, Iran. Total energy input and output were 38985.97 and 97599.18 MJ ha^{-1}, respectively. Three main energy consumers were fertilizer, electricity and diesel fuel by using 82% of total input energy.

Utilizing Artificial Neural Networks (ANN) for the prediction of the energy used for wheat production revealed that the best networks for this study were GFFN with one hidden layer and LM training algorithm by $R^2 = 0.95$ and RMSE = 3351.71 MJ ha^{-1} and then by FFN with two hidden layers and Momentum training algorithm by $R^2 = 0.91$ and RMSE = 3408.29 MJ ha^{-1} and Elman network with two hidden layers and LM training algorithm by $R^2 = 0.85$ and RMSE = 3735.48 MJ ha^{-1}, respectively.

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