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ORIGINAL ARTICLE

A Model for the Estimation of Yield and Investigation on Factors Affecting Irrigated Wheat Production in Various Tillage Methods (Using Artificial Neural Networks)

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ABSTRACT
This study was conducted to estimate the yield and investigate the factors affecting irrigated wheat yield in different tillage methods in Iran using neural networks. Data were collected from 330 farms in 12 different regions of Isfahan, Fars and Khuzestan provinces in Iran by using face to face questionnaire method. Information collected from each field includes climate, soil texture, EC of soil, soil structure, crop rotation, crop residues management method, tillage method, depth of tillage, the amount of (nitrogen, phosphorus and potash) fertilizers consumed, method and efficiency of the amount of water used (as input variables of the neural network) and biomass yield (total seed yield and straw) as the output variable of neural network algorithm. Multilayer Perceptron (MLP) Neural Network of feed forward kind was used in this study. The results showed that the proposed model can predict the biomass yield with a determination coefficient of 90% for different tillage methods. Thus based on managerial inputs relating to soil and irrigation, the mentioned model was proposed as a good approximation of the yield. Sensitivity analysis was carried out using the method of variations of coefficient of determination. As the results showed, the inputs of the management of residues, climate, crop rotation and tillage technique had the highest sensitivity coefficient in the model of achieving the yield. Among the management factors (crop residues management, tillage method, irrigation method and crop rotation), the most effective factor was residue management and the next important factors were crop rotation and tillage method. In conservation systems, tillage method selection with crop residues management at the farm level and also selecting the appropriate crop rotation are aimed at achieving the best results. The least important parameters in the model of assessing the biomass yield were type of soil texture and the irrigation efficiency. Among the factors related to the soil, the soil structure was the most important factor in this model, the effect of which was much lower than the rest of factors.
Key words: *ANN, Iran, Sensitivity,Tillage,Wheat yield prediction.*

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INTRODUCTION

Conducting conservation tillage is essential for prevention of soil erosion in sustainable agriculture, particularly in arid and semi-arid areas. Conservation tillage is generally defined as tillage methods that while keeping a part of or the entire previous crop residues on the soil surface, reduce the depth and the intensity of the tillage (reduced tillage) or minimize it (no tillage).
Different tillage methods and planting through changes in physical and mechanical conditions of the roots and seed beds, i.e. moisture, ventilation, strength and thermal characteristics of the soil can affect on the process of seedling emergence and the crop yield [2].
Application of useful technologies such as conservation tillage systems as one of the requirements of sustainable agriculture can lead to slowing the destruction of agricultural lands and increasing

sustainable agricultural production [11]. Tillage system should be selected in such a way that while preserving water and soil resources and reducing energy consumption, provides the suitable conditions for seed germination, seedling emergence and the growth and development of roots and thereby achieves the optimal performance.

In Iran, due to further instability problems in soil and water resources arisen from conventional tillage operations, replacement, expansion and promotion of different kinds of conservation tillage systems such as no tillage and reduced tillage have been included on the agenda of the Ministry of Jihad Keshavarzi. It is obvious that encouraging farmers to use various conservation methods according to facilities provided for them can be a major step in achieving the target. The most tangible and the most important output for farmers is the yield eventually received by them. Thus, if the farmers and the agricultural authorities can be assisted by investigation of the effective factors affecting on predicting their crop yields, they can be encouraged to use protection methods. In recent years, there is an increasing tendency toward the use and development of artificial neural networks (ANN) in various fields of agriculture and its related modeling and predictions. Prediction and simulations of various crop yields can be mentioned as some of the applications of this method. Liu et al used a feed-forward, back propagation ANN model to determine the relationship between the yield of rain-fed corn and the factors affecting on the yield including soil, climate and management. Their results showed that the most sensitive factor was the rainfall of the last days of July [6].

Using topographical features including elevation, slope, slope direction, curvature, specific contributing area and moisture index as explanatory variables, Green et al compared Spatial Analysis Neural Network (SANN) method with the multiple linear regressions (MLR) technique for the estimation of rain-fed wheat yield. They showed that using topographic features as the inputs, the Root Mean Square Error (RMSE) in SANN with 5 variables was 0.59 and for MLR with 4 or 5 explanatory variables, it was 0.72 [3]. Ji et al used artificial neural networks for predicting rice yield in Fujian province of China. They also compared the neural network models with multiple linear regression models. Climatic variables and the local precipitation data were used for each of the models. The results showed that the neural network model predicted the performance more accurately than the regression model. R^2 and RMSE obtained for the ANN model were 0.67 and 891 respectively compared to 0.52 and 1977 for the regression model [5].

Maxwell Martin developed a study on the combined use of artificial neural network models and the genetic algorithm. This study aimed to predict the corn crop yield in the southeastern of the United States with artificial neural network modeling using the genetic algorithm inputs. This study shows that these data (large-scale meteorological parameters) can be used for modeling the crop yield. Based on the results of this study, using a combination of artificial neural networks and genetic algorithms could be a useful tool in agricultural applications [7].

Ghodsi et al used the artificial neural network for prediction of wheat production in Iran. Neural network inputs were the amount of precipitation, guaranteed purchase price, the area under cultivation, subsidies, the insurance rates, imports, population, added value of agricultural sector and its outputs, wheat production. Using different training techniques, they studied six artificial neural network models and finally they selected a model using training technique of CGP: Polak-Ribiére conjugate gradient with respect to the minimum associated relative error (MAPE). Predicting the wheat yield between 2002 and 2006 using the selected network indicated that the selected model is an appropriate model for prediction of the wheat yield [1].

Mehnatkesh et al in their study for determining the straw and grain yield of winter wheat used comparison of artificial neural network and multiple linear regression. Another goal of their study was to determine the most important factors related to soil, rainfall, topography and management factors affecting the yield. They showed that the neural network can explain 69% and 84% of the variability of the grain yield and total yield, respectively. The results also showed that the most effective factors for the grain yield were precipitation, weeds, the soil nitrogen and plan curvature and the most effective factors for the whole yield were plan curvature, precipitation, catchment area, and potassium present in the soil [8].

Yazdanpanah used artificial neural network to predict the yield of rain-fed wheat in Iran. In this study, the input parameters included daily precipitation, the average minimum and maximum temperatures, evapotranspiration, sunshine hours, the number of rainy days, relative humidity, and the number of days with heat and cold stresses. According to the results of this study, the most effective input was precipitation, because its elimination increased the amount of RMSE [12].

In the provinces of Fars, Khuzestan and Esfahan, 80% of cultivated farming lands have been devoted to the cultivation of irrigated wheat. But, no significant research has been conducted in order to predict the irrigated wheat yield and the factors affecting on it so far. Most research conducted in this field in Iran has been conducted on rain-fed wheat. Also the parameters considered for estimating and evaluating the

wheat yield in numerous studies of ANN were typically the quantitative meteorological and climatic parameters and some quantitative parameters associated with soil and management. So far, no study considering different tillage techniques and with respect to managerial factors of tillage techniques (such as residues management) as well as soil quality parameters (such as soil texture and structure) has been carried out. Therefore, this study was carried out with these objectives: (1) prediction of the irrigated wheat yield using artificial neural networks and (2) determining the most important factors affecting on it with respect to management factors related to conservation tillage systems and natural factors provided for farmers such as soil texture.

MATERIALS AND METHODS

This study was carried out in 2011-2012 agricultural year in the fields of Isfahan, Fars and Khuzestan provinces in central and southern parts of Iran. All the three provinces are located in warm and dry regions of Iran. Conservation tillage methods have been carried out in all the three provinces as the leading provinces during the past few years.

The statistical population of this study consisted of (irrigated) wheat growers of different areas of the provinces who have attempted to implement conservation tillage techniques in their farms due to the promotion of Jihad Agriculture Organization. In the desired provinces, these procedures included using different direct planting tools (no tillage) and doing tillage using devices for low depth (less than 10 cm) including packer chisel the chisels with/without roller. Furthermore, in order to compare and analyze the data, the data were collected from a number of farms under conventional tillage. In this study, two-stage cluster sampling method was used and finally 330 farmers were selected.

Some questionnaires with the required content of information were provided to obtain the required information.

Data collected from each farm included: regional climate, soil texture, EC of soil, soil structure, crop rotation, residues management method, tillage method, depth of tillage operations, the amount of fertilizer consumed (including nitrogen, phosphorus and potash), techniques, efficiency and the amount of water consumed, biomass yield (total grain and straw yield).

Based on variation in the target areas, each of the qualitative parameters were classified according to the following method:

Climate: cold, temperate, cold and dry, hot and dry and warm.

Soil texture: heavy, medium and light.

Soil structure: poor (lacking structure and organic materials), mass (lacking structure), compact, with average, good compaction and with a good compaction and high organic content.

Residues management method: with no residues (grazing or burning or any method that removes the whole residues from land), with medium residuals (15% to 30% of residuals remaining) and with preserved residuals (maintaining more than 30% of the residuals).

Tillage method: no-tillage, low-tillage and conventional.

Irrigation method: flood irrigation and pressurized irrigation.

After selecting the required data, a neural network was designed for this study. Conducted researches shows that feed forward Multilayer Perceptron network (MLP) is one of the most widely used types of networks in solving engineering problems and it is usually considered as a global approximator [4].

The first step in selecting the neural network is determining the input and output variables of the model. 14 factors (including climate, soil texture, EC of soil, soil structure, crop rotation, residues management method, tillage depth, the amount of fertilizers used (nitrogen, phosphorus and potash, each individually as an input) and the method, efficiency and the amount of water used were selected as input variables. The output variable was the biomass yield (total grain and straw yields).

In the next stage all the collected data were used to form the data matrix. This matrix consisted of 330 rows and the input and output parameters had formed its columns.

To determine the number of hidden layers of network, initially with the assumption of having a hidden layer, the optimal number of neurons was determined. Testing a number of different neurons, the network was trained at different stages and the mean value of squared errors was recorded after each test. Comparing different values of errors in different trainings, this result is obtained that a network with 20 neurons in the hidden layer had the lowest errors, and therefore it is the best considered neural network.

S1 data set containing 70% of the farms i.e. 230 rows of data was allocated for network training, and S2 and S3, each containing 15% of the data consisted of 50 rows of the data were allocated to test and 50 rows were allocated to validation. In order to obtain the best ANN in this study, a network with the specifications given in Table 1 was used.

Table 1. Architecture of the ANN – MLP model

Learning Method	Number of neurons in hidden layer	First Transfer function	Second Transfer function	The number of training epoches
CGP*	16	Tansing	Purlin	100

*: Polak-Ribiere conjugate gradient

Matlab 7.6 software was used for modeling.

For uniformity of data values prior to training neural networks, initially PCA (Principle Component Analysis) method was used for separation of data and thus enhancing the accuracy of the estimation. Then, the obtained input data were standardized. In order to standardize the data, equation (1) was used.So, the scales are removed.

(1)

$$X_n = X - \mu / \sigma$$

in which

X_n: the standardized data,

X: the original data,

μ: the mean of the original data and

σ: standard deviation of the original data.

In order to investigate the effects of the input parameters on the output values, sensitivity analysis using coefficient of determination variations method was used. In this method, one of the input parameters was removed each time and keeping the values of other parameters constant, the corresponding determination coefficient was calculated using the trained neural network model. Then ΔR and the significance of input variable were calculated using the following equations.

(2)

(3)

$$P_i = \Delta R_i / R^2$$

in which:

R^{i*}: R^2 value when i-th input parameter is removed,

R^2: Coefficient of determination for all the parameters,

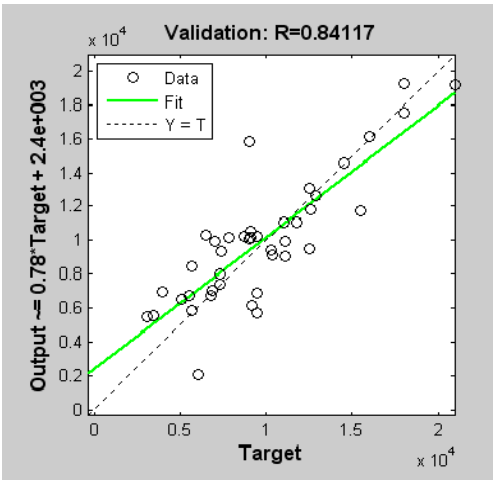
P_i: the significance of i-th input variable.

$$\Delta R_i = R^2 - R^{i*}$$

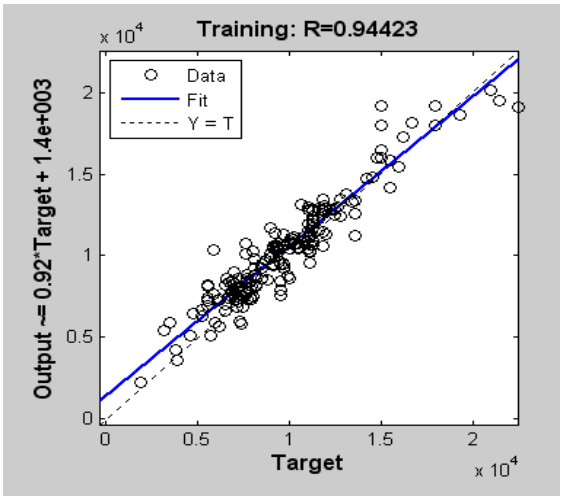
RESULTS AND DISCUSSION

Figure 1 (A: D) shows the diagram of predicted values of the model compared to the observed values for training, testing and validation data. The overall determination coefficient is 90% which indicates that the artificial neural network predicts 90% of the biomass yield as real.

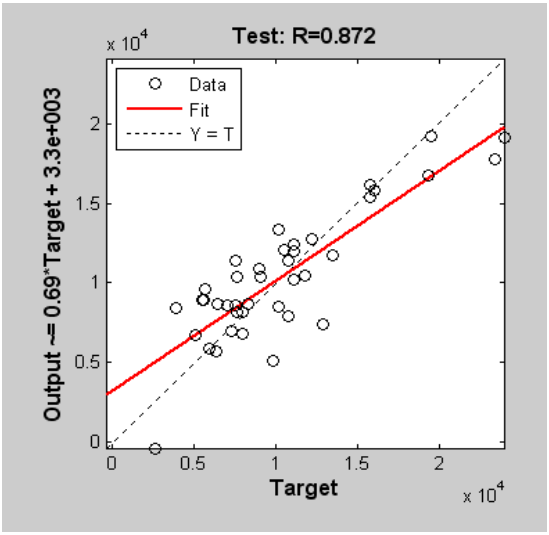
These results indicate that this model can effectively predict the biomass yield values. Therefore, the mentioned model is recommended as a good yield approximator based on management inputs of factors related to soil and irrigation.



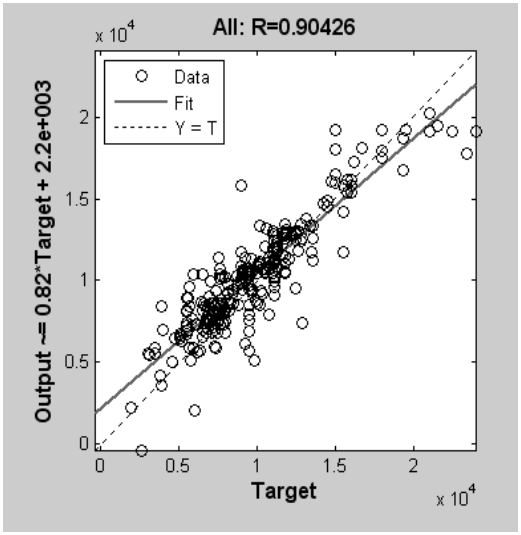
A



B



C



D

Fig. 1) Scatter plot between observed and predicted biomass yield for training (A), validation (B), test (C) and all (D)parameters.

The sensitivity analysis of the relative sensitivity coefficient for output parameters compared to the input parameters shown in Figure 2.

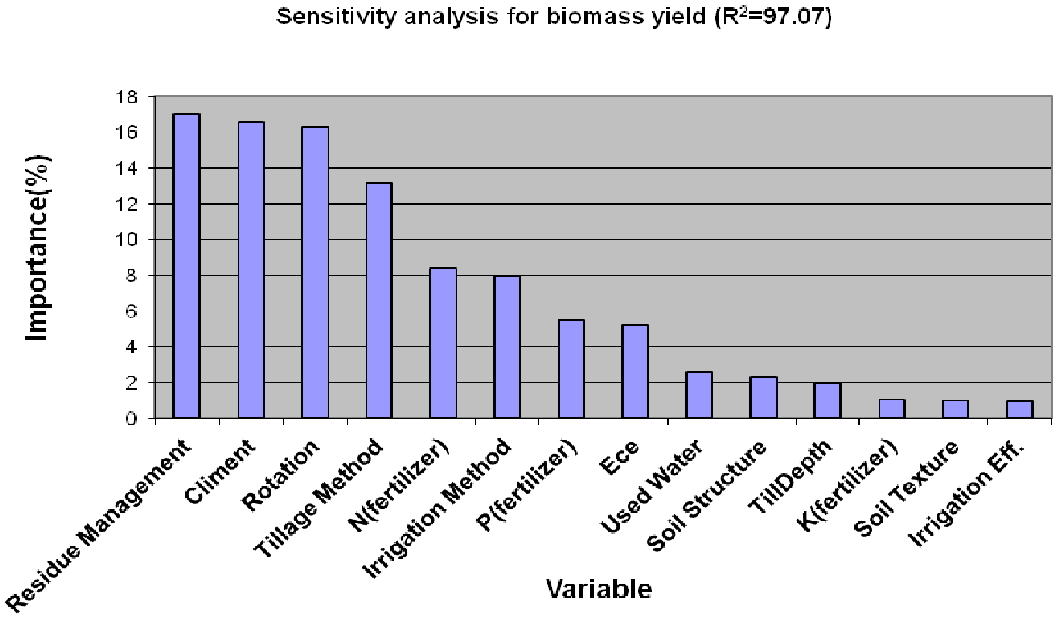


Fig. 2) Relative sensitivity coefficient of the input variables for predicting biomass yield

According to this diagram, the effect of each input parameter used in MLP model can be clearly observed on the desired output amount. The sensitivity analysis provides a useful understanding of individual variables effects on the yield. Using sensitivity analysis, we can easily recognize which parameters should be considered as the most important and the least important parameters in MLP [9].

As the results showed, the inputs of residues management, climate, crop rotation and tillage method had the highest sensitivity coefficient in the model of achieving the yield. Among the management factors (residues management, tillage method, irrigation method and crop rotation) the most effective factors were residues management, rotation, tillage method, respectively. In systems, tillage method selection is associated with residues conservation management at the farm level and selecting the appropriate rotation in order to achieve the best results. Since the approach to deal with the residues and also the selection of a suitable crop rotation are the requirements for the implementation of conservation

procedures, simultaneous influence of these factors indicates the need for careful determination of the levels of these parameters in the field to achieve a more desirable yield level.
The least important parameter in the model of assessing the biomass yield was soil texture type and the irrigation efficiency.
Among the factors related to soil, the most important factor in this model was soil structure, the effect of which was much less important than the other factors.
Using conservation tillage systems in Iran is growing day by day, therefore, further research that can assist the farmers in selecting the best applicable method in their farms can be an effective step for making good decisions. The most tangible output factor of fields for the farmers is the crops yields. This study showed the significance of the effect of applied tillage technique and its related important factors on the yield.
ANN tool was used to predict the biomass yield of the wheat yield.
- Since neural networks do not usually have good extrapolation power and cannot operate well beyond the scope of training models, therefore this point should be taken into consideration while selecting the models [10]. Thus, this model can be used only for the study areas and other regions with the same topography, climate, soil and management practices.
- The neural network model with 1-20-1 architecture was selected as the best model for predicting the yield. MLP was selected as the best training method for the relationship between the input parameters (management and soil) and the output parameters with the minimum RMSE (0.0007).
- Sensitivity analysis of managerial input parameters, residues management, crop rotation and soil structure among the factors related to soil, have the highest sensitivity on the output yields.
- According to the results of this study, ANN is a useful tool for prediction of wheat yield using input parameters related to soil and management in different tillage methods. Therefore, using the results of this study, the farmers can be provided with the necessary knowledge to select the method of tillage, irrigation method and the appropriate crop rotation as well as proper residues management in their fields.

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