Energy Equip. Sys. / Vol. 9/No. 2/June 2021/ 191-207

Energy Equipment and Systems

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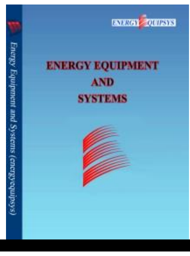

Application of artificial neural network for prediction of energy flow in wheat production based on mechanization development approach

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Article history:

Received : 28 September 2020
Accepted : 15 November 2020

ABSTRACT

Due to the inadequate use of limited energy resources, it is necessary to study the energy consumption patterns in agriculture. The purpose of this study was to investigate the process of energy consumption of wheat in two mechanized and semi-mechanized production systems. The statistical population included all wheat farmers in Mazandaran province in 2018-2019. Multilayer perceptron artificial neural network (MLP) was used to find the best model to predict the wheat yield. The results indicated that the average energy consumption of wheat production in Mazandaran province was 20581.46 MJ ha^{-1}, which was higher in mechanized systems. Chemical fertilizer input by 51.64% had the highest share of energy consumption, which was higher in mechanized systems than semi-mechanized systems. The energy efficiency and energy productivity values for the average production were determined to be 2.02 and 0.14 kg MJ^{-1}, respectively, in which both indices were higher in the mechanized systems. Assessing the energy indices highlighted that energy management of wheat production in mechanized systems was better than semi-mechanized ones. In the study of energy flow modeling in mechanized systems, the model performed best with the tangent sigmoid as the activation function and nine neurons by R^2 value of 0.994. In the semi-mechanized systems, the model had the best performance with logarithmic sigmoid function as the activation function and eight neurons by R^2 value of 0.997.

Keywords: Concentrating Photovoltaic Thermal; Grid-Connected; Residential Heat; Performance Simulation; CO_2 Saving.

1. Introduction

Regardless of the type of energy consumed, humans have always had to consume energy to meet their basic food needs. Today, agriculture is heavily dependent on energy consumption to meet the food demand of the world's growing population. Due to limited energy resources and inappropriate use of different sources, it is necessary to examine the patterns of energy consumption in agriculture [1]. A balance must be struck between the flow of resource use and the amount of agricultural production. Wheat is one of the main food and most important crop in Iran and the world. Given the growing population of the world, achieving self-sufficiency of this product is of paramount importance in this regard as increasing production per unit area plays an important role. Due to the increasing growth of mechanization development in agriculture, wheat production is

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classified in different ways in terms of agricultural machinery usage levels, which differ in terms of inputs consumption and used energy. Since maximizing both income and production is the main objective of the agricultural mechanization sector [2], a review of current agricultural practices and optimization of strategies for inputs and agricultural machinery is essential [3].

Wheat, as the most important agricultural crop in the world, has the largest area under cultivation. The total area and total wheat production in the world in 2018-2019 were 222 million hectares and 753 million tons, respectively [4]. Iran is also the 12th largest producer of this crop in the world with an area of about 6.80 million hectares and production of about 15 million tons [4, 5]. According to the statistics of the Ministry of Agriculture of Iran in the crop year, Mazandaran province by around 66.63 thousand hectares under cultivation and production of 183.7 thousand tons is considered to be one of the most important wheat cultivation areas in Iran [5]. Given the importance of wheat production to meet the country's nutritional needs, achieving greater production in this crop is of great importance. Since the efficient use of energy and inputs is one of the basic principles of sustainable agriculture, attention to the amount of energy consumption and inputs is also necessary [6].

Various studies have been carried out on energy analysis of wheat production in Iran and the world. Results of energy consumption analysis of wheat production in Khorasan Razavi province illustrated that total input and output energies were 32061 and 84443 MJ ha^{-1}, respectively, in which chemical fertilizer by the share of 31.38% had the highest contribution. The energy ratio was 2.63 and direct and non-renewable energies had the highest energy consumption [7]. In the study of wheat production in Kurdistan province, the average energy consumption was reported to be 42998 MJ ha^{-1}, in which electricity by 26136 MJ ha^{-1} had the highest consumption. Energy efficiency and energy productivity values were also reported to be 2.28 and 0.13 kg MJ^{-1}, respectively [8]. In wheat production in Turkey, the total energy consumption was determined to be 23230 MJ ha^{-1}, in which chemical fertilizer by 53.5% had the highest share. Energy efficiency and energy productivity were also calculated as 3.52 and 0.19 kg MJ^{-1} and the share of indirect energies was higher than direct energies [9]. Different studies have been done in the field of mechanized and semi-mechanized production systems. For example, a study compared the efficiency of agricultural machinery and human labor in three mechanized, semi-mechanized and semi-traditional wheat production systems. The results indicated that the mechanized and semi-mechanized systems had the highest and lowest productivity of agricultural machinery, respectively [10]. In the study of wheat production in Behshahr city, the results also showed that consumption of all inputs except agricultural machinery input was higher in the semi-mechanized system than mechanized ones [11]. In a study of mechanized and traditional rice production systems, AghaAlikhani et al reported that the yield and gross income in the mechanized system were higher than the traditional system [12].

Further studies on energy input and output modeling had also presented that artificial neural networks (ANN) were capable of predicting the yield of agricultural products. For example, the results of the artificial neural network application highlighted that the best model for predicting energy flow in paddy production had an input layer with eight inputs, a hidden layer with 25 neurons and an output layer. Besides, comparing the neural network results and the Cobb-Douglas model indicated that the ANN method with the coefficient of determination (R^2) value of 0.99 and the root mean square error (RMSE) of 1.93 kg ha^{-1} was found to be more accurate [13]. In another study, the energy flow and greenhouse gas emissions of potatoes were modeled using an artificial neural network method. The results showed that the neural network with the structure of 12-8-2 and the R^2 value of 0.98 had the best performance in predicting potato output energy [14]. In another study, artificial neural network models and multiple linear regression techniques were used to estimate the yield of rainfed wheat in Kurdistan province. The results showed that the ANN model was able to predict the amount of wheat yield before harvesting using meteorological data accurately [15].

One of the main goals of agricultural mechanization is to increase energy efficiency and productivity. Although Mazandaran province is considered one of the most important wheat cultivation areas in Iran, so far no comprehensive research has been conducted on wheat energy analysis concerning the level of agricultural machinery usage (mechanized and semi-mechanized systems). The purpose of this study is to model the energy flow of wheat production using the mechanization development approach in Mazandaran province.

2. Materials and Methods

The study area was Mazandaran province located in the north of Iran (36°53'N-36°20'N and 53°14'E-54°7" E). This province with a temperate mountainous climate, has an average daily temperature of 17.40 °C, an average rainfall of 653 mm, and relative humidity of 78% [16, 17]. The total area under wheat cultivation in Mazandaran province in 2017-2018 was 54000 hectares and the total number of wheat farmers in the province was 20400. The number of samples was estimated to be 384 people based on Krejcie and Morgan table for both mechanized and semi-mechanized systems. In this region, wheat production has been conducting in different ways in terms of the level of use of agricultural machinery, which differed in the number of inputs consumed. Table 1 shows the differences between the mechanized and semi-mechanized wheat production systems in Mazandaran province.

In this study, nine inputs of human labor, agricultural machinery, diesel fuel, farmyard manure, chemical fertilizers, water for irrigation, and seed were considered to be inputs and independent variables. Table 2 presents the energy equivalents of different inputs used in this research.

To calculate the consumed energy of agricultural machinery input, first, the effective field capacity of each machine was determined, and then the number of working hours per hectare for them was estimated. The amount of consumed energy of diesel fuel was determined through

$$E_{machinery} = t_m \times EI_{machinery} , \quad (1)$$

where the $E_{machinery}$, t_m and $EI_{machinery}$ were, respectively, the amounts of energy consumed by agricultural machines and equipment (MJ ha^{-1}), the number of working hours (h ha^{-1}) and the energy equivalent of agricultural machinery (MJ h^{-1}) [18].

The amount of energy related to human labor input was calculated using

$$E_{Labor} = t_{Labor} \times EI_{Labor} , \quad (2)$$

Table 1. Differences between the mechanized and semi-mechanized wheat production systems in Mazandaran province

Operations type	Mechanized	Semi-mechanized
Tillage	Tillage equipment	Tillage equipment
Sowing	Grain drill	Seed spreading with hand and harrow disk
Management	Sprayer and fertilizer spreader	Spraying (man-portable) and fertilizer spreader (by hand)
Harvest	Direct harvesting with combine harvester	Indirect harvesting with combine harvester

Table 2. Energy equivalents of inputs and output in wheat production

Particulars	Unit	Equivalent (MJ unit^{-1})	References
Inputs			
1.Human labor	h	1.96	[19]
2.Machinery			
(a) Tractors and equipment	h	62.7	[9]
(b) combine harvester	h	87.63	[9]
3.Diesel fuel	L	56.31	[20]
4.Chemical fertilizers			
(a) Nitrogen (N)	kg	66.14	[21]
(b) Phosphate (P_2O_5)	kg	12.44	[21]
(c) Potassium (K_2O)	kg	11.15	[21]
5.Chemicals			
(a) Herbicides	kg	238	[22]
(b) Insecticides	kg	101.2	[22]
(c) Fungicides	kg	216	[22]
6.Water for irrigation	m^3	1.02	[19]
7.Manure	kg	0.3	[19]
8.Electricity	kWh	3.6	[20]
9.Seed wheat	kg	20.10	[9]
Output			
1.Wheat	kg	14.48	[9]

where E_{Labor}, t_{Labor} and EI_{Labor} were the total energy consumption inputs (MJ ha^{-1}), the number of working hours (h ha^{-1}) and the energy equivalent of human labor input (MJ), respectively [6, 14].

The energy used by electricity input was estimated using

$$E_{Electricity} = W_{Electricity} \times EI_{Electricity}, \tag{3}$$

where $E_{Electricity}$, $W_{Electricity}$ and $EI_{Electricity}$ were the energy consumption (MJ ha^{-1}), used electricity (kWh ha^{-1}) and energy equivalent (kWh), respectively [23, 24]. The amount of energy used by diesel fuel was calculated by

$$E_{Fuel} = Q_{Fuel} \times EI_{Fuel}, \tag{4}$$

where E_{Fuel}, Q_{Fuel} and EI_{Fuel} were energy consumption (MJ ha^{-1}), used diesel fuel (L) and energy equivalent (L), respectively [20, 25].

The amount of water for irrigation was calculated using

$$E_{Irrigation} = Q_{Irrigation} \times EI_{Irrigation}, \tag{5}$$

where $E_{Irrigation}$, $Q_{Irrigation}$ and $EI_{Irrigation}$ were the energy consumption (MJ ha^{-1}), used water (m^3 ha^{-1}) and the energy equivalent of water input (m^3), respectively [26]. Finally, the energy consumed by four inputs of chemical pesticides, chemical fertilizers, farmyard manure and used seed were determined using

$$E_{Input} = Q_{Input} \times EI_{Input}, \tag{6}$$

where G_{Input}, W_{Input} and GI_{Input} were energy consumption by the inputs (MJ ha^{-1}), weight of consumed input (kg ha^{-1}) and energy equivalent (MJ), respectively [20-22]. Energy consumed by seed was considered equal to the energy content of wheat plus the energy required for seed preparation and threshing. The energy indices were used to investigate the pattern of energy consumption in the systems. These indices included energy efficiency, energy productivity, specific energy, and net energy which were estimated using [21, 27-29]

$$Energy\ ratio = \frac{Energy\ Output\ (MJ\ ha^{-1})}{Energy\ Input\ (MJ\ ha^{-1})} \tag{7}$$

$$Energy\ productivity = \frac{yield\ \left(kg\ ha^{-1}\right)}{Energy\ Input\ (MJ\ ha^{-1})} \tag{8}$$

$$Specificenergy = \frac{Energy\ Input\ (MJ\ ha^{-1})}{yield\ \left(kg\ ha^{-1}\right)} \tag{9}$$

and

$$Net\ energy = Output\ energy\,(MJ\ ha^{-1}) - Input\ energy\,(MJ\ ha^{-1}) \tag{10}$$

In this study, one of the most common artificial neural networks was applied to find a proper model to predict the wheat yield called Multi-layer Perceptron network (MLP). This network had nine inputs (energy inputs), a hidden layer and an output layer (wheat yield). The training algorithm was considered to be the Levenberg–Marquardt algorithm. Each layer included one or more neurons and the input and output layers were connected using hidden layers. All connections were defined through weight matrices [30]. The mathematical form of the MLP network was defined as

$$Y = F(\sum_{o=1}^{m} W_{ho}.F(\sum_{i=1}^{n} W_{hi} X_i + b_h) + b_o), \quad (11)$$

where W_{ho} and W_{hi} were the weights between hidden and output layers and between hidden and input layers, respectively. X_i was the input variable that was considered the inputs used for wheat production in this study. m and n were also the number of neurons in hidden and input layers, respectively. Finally, F and Y were the transformation function and the output of the network (wheat yield), respectively [31].

Then the presented models by different production networks were compared and assessed by using the performance analysis criteria including coefficient of determination (R^2), root means square error (RMSE) and the mean absolute percentage error (MAPE). The mathematical form of these criteria was presented as

$$R^2 = \frac{(\sum_{i=1}^{n}(Y_{ai} - \bar{Y}_{ai}) \times (Y_{pi} - \bar{Y}_{pi}))^2}{\sum_{i=1}^{n}(Y_{ai} - \bar{Y}_{ai})^2 \times \sum_{i=1}^{n}(Y_{pi} - \bar{Y}_{pi})^2} \quad (12)$$

and

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Y_{ai} - Y_{pi}}{Y_{ai}}\right| \times 100 \quad (13)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Y_{ai} - Y_{pi})^2}{n}} \quad (14)$$

where Y_{ai} and Y_{pi}were the observed and predicted values and I was the number of patterns. $\bar{Y}_{ai}$ and $\bar{Y}_{pi}$ were also the average of observed and predicted values and n was the number of studied samples. According to the results, a network that had the highest R^2 and the lowest RMSE and MAPE was selected as the best model to predict the wheat yield.

The data analysis and modeling of the relationship between inputs and yield were conducted by using MiniTab and MATLAB V.9.0.0.341360 (2016b) software packages. The graphs were also drawn by Microsoft Excel.

3.Results and Discussion

3.1. Determination of the share of consumed inputs

Table 3 presents the amounts of consumed inputs and their energy content for each input used in wheat production in two mechanized and semi-mechanized production systems. The average wheat production in Mazandaran province was determined to be 2868.10 kg ha^{-1}, which was higher than the average wheat production in Iran by 2280 kg ha^{-1} and lower than the world average wheat production by 3390 kg ha^{-1} [4]. The results also indicated that the average wheat production for the mechanized systems by 3394.08 kg ha^{-1} was higher than that of the semi-mechanized systems by 2738.31 kg ha^{-1}. In the study of inputs energy consumption, the amount of energy consumed for mechanized and semi-mechanized systems as well as average production was 22519.80, 20103.17 and 20581.46 MJ ha^{-1}, respectively. It showed that wheat production in mechanized systems needed more energy than semi-mechanized systems. The average energy consumed for wheat production in Khorasan Razavi, Kurdistan and Turkey was reported to be 32061 MJ ha^{-1} [7], 42998 MJ ha^{-1} [8] and 233230 MJ ha^{-1} [9], respectively, that the amount of energy consumption in all regions was lower than that of in Mazandaran. Compared to other crops cultivated in Mazandaran province, the average energy consumption of wheat production was lower than that of paddy crop [16] and nectarine [32] and more than that of citrus production [25] and pomegranates [21].

The share of energy inputs for the average wheat production is presented in Fig. 1 and based on system type (mechanized and semi-mechanized) in Fig. 2. Chemical fertilizer input

Table 3. Analysis of energy for wheat production in mechanized and semi-mechanized systems

Particulars	Mechanized		Semi-mechanized		Average	
	Amount (unit ha^{-1})	Energy (MJ ha^{-1})	Amount (unit ha^{-1})	Energy (MJ ha^{-1})	Amount (unit ha^{-1})	Energy (MJ ha^{-1})
1.Human labor	33.97	66.59	45.15	88.49	42.94	84.16
2.Machinery	13.52	918.17	7.72	593.15	8.87	657.48
3.Diesel fuel	95.49	5376.86	56.63	3188.89	64.32	3621.93
4.Chemical fertilizers	2.60	496.69	2.56	488.24	2.56	489.91
(a) Nitrogen (N)	139.08	9198.68	135.02	8929.97	135.82	8983.16
(b) Phosphate (P_2O_5)	63.88	794.69	62.63	779.12	62.88	782.20
(c) Potassium (K_2O)	78.42	874.39	77.06	859.24	77.33	862.24
5.Chemicals	2.60	496.69	2.56	488.24	2.56	489.91
(a) Herbicides	1.15	273.07	1.12	265.75	1.12	267.19
(b) Insecticides	0.77	77.82	0.77	77.85	0.77	77.85
(c) Fungicides	0.68	145.80	0.67	144.64	0.67	144.87
6.Water for irrigation	790.79	806.61	413.80	422.07	488.41	498.18
7.Manure	1921.05	576.32	1358.77	407.63	1470.05	441.02
8.Electricity	197.37	710.53	119.48	430.13	134.90	485.63
9.Seed wheat	134.34	2700.27	194.84	3916.24	182.86	3675.58
Total energy input	-	22519.80	-	20103.17	-	2058146
Total energy output	3394.08	49146.26	2738.31	39650.75	2868.10	41530.07

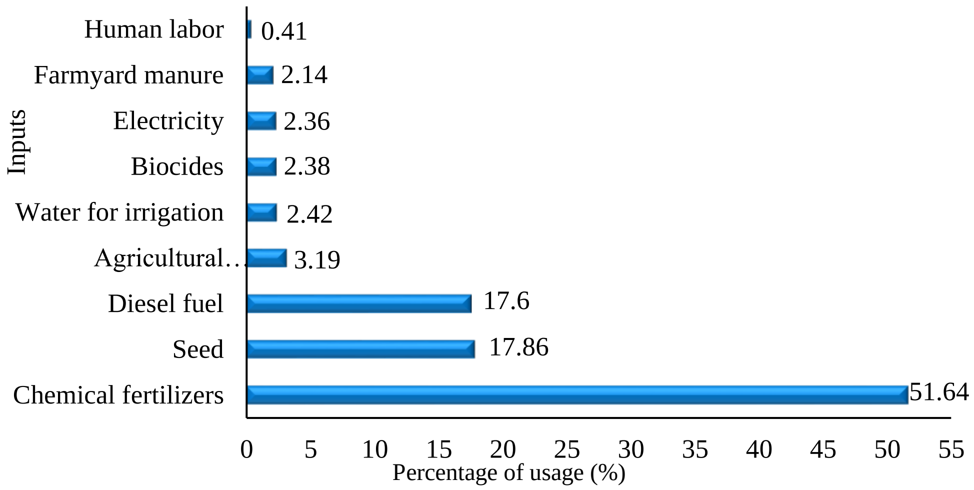

Fig. 1. The percentage of average consumed energy inputs in wheat production in Mazandaran Province

by 10627.59 MJ ha^{-1} and 51.64% had the highest share of energy consumption. The share of this input in the mechanized system by 52.57% was higher than that of the semi-mechanized system by 48.26%. In both production systems, nitrogen fertilizers had the highest energy consumption compared to other fertilizers. In wheat production in Khorasan Razavi and Turkey, chemical fertilizers input by 10060.17 MJ ha^{-1} and 31.38% [7] and 12429.95 MJ ha^{-1} and 53.50% [9], respectively had the highest energy consumption, in which nitrogen fertilizers had the highest share in this input.

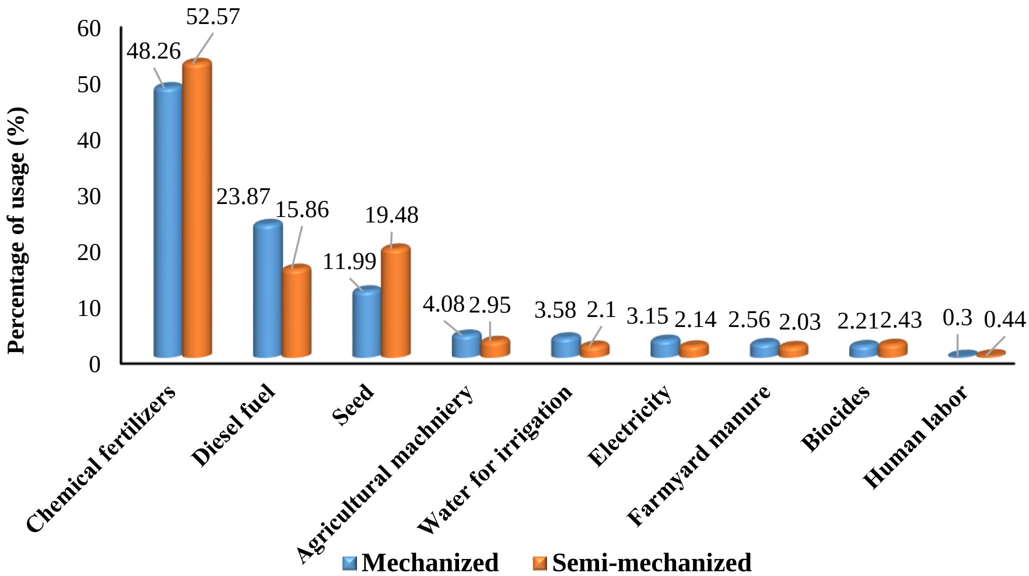

Fig. 2. The percentage of consumed energy inputs in wheat production in mechanized and semi-mechanized systems

Seed input was the second most consumed energy input by 3675.58 MJ ha^{-1} and 17.86%. The share of this input in the mechanized system by 11.99% was lower than that of in the semi-mechanized system by 19.48%, due to the difference in the amount of seed used for sowing. The average amount of seed consumed in mechanized systems was 134.34 kg ha^{-1} in comparison to that in semi-mechanized systems by 194.84 kg ha^{-1}. The contribution of seed in energy consumption in Mazandaran Province was lower than that of in Kurdistan Province and Turkey by 3833.03 [8] and 4373.77 MJ ha^{-1} [9] and more than Khorasan-Razavi province by 3454.50 MJ ha^{-1} [7], respectively. Diesel fuel input was the third-highest energy-consuming input by 3621.93 MJ ha^{-1} and 17.60%. The share of this input in the mechanized system by 23.87% was more than the semi-mechanized systems by 15.86%. In wheat production in Khorasan-Razavi and Kurdistan provinces, diesel fuel consumption was the third-highest energy-consuming inputs 5156.49 MJ ha^{-1} [7] and 4107.81 MJ ha^{-1} [8].

Agricultural machinery input was the fourth input in energy consumption by 657.48 MJ ha^{-1} and 3.19%, which was higher in the mechanized system by 4.08% than the semi-mechanized system by 2.95%. In wheat production in Khorasan-Razavi [7] and Kurdistan provinces [8] as well as Turkey [9], the share of this input in production was reported to be 3.51%, 3.26%, and 5.50%, respectively; which was considered as low energy-consuming inputs in wheat production. The four inputs of water for irrigation, pesticides, electricity and farmyard manure were in the next ranks in terms of energy consumption by the share of 2.42%, 2.38%, 2.36%, and 2.14%, respectively. In both production systems, these four inputs were among the low energy-consuming inputs. Human labor input had the lowest energy consumption by 84.16 MJ ha^{-1} and 0.41%, respectively. In wheat production in Khorasan-e-Razavi [7] and Kurdistan [8] provinces in Iran and Turkey [9], the share of human labor input was reported to be 0.14%, 0.45%, and 0.22%, respectively, that was the least energy-consuming input.

3.2. Energy indices

Table 4 presents the results of investigating energy indices in wheat production. Energy efficiencies for mechanized, semi-mechanized systems were obtained to be 2.18 and 1.97, respectively; while the average production was obtained to be 2.02. This finding indicates that, in terms of energy consumption, the mechanized production system was more efficient than the semi-mechanized system. The values of this index for wheat production in

Khorasan-e-Razavi [7], Kurdistan [8] and Turkey [9] were reported to be 2.63, 2.28 and 3.52, respectively. In all three regions, energy efficiency was higher than in that of Mazandaran province, which could be due to different crop growth conditions in different regions.

Energy productivity for mechanized and semi-mechanized systems and average production were 0.15, 0.14 and 0.14 kg MJ^{-1}, respectively. The results highlighted that for every megawatt of energy consumed in production, more wheat was produced by the mechanized system than a semi-mechanized system. The value of this index for wheat production in Khorasan-e-Razavi and Kurdistan provinces was reported to be 0.13 kg MJ^{-1} [7, 8] and in Turkey was 0.19 kg MJ^{-1} [9]. The specific energy index was also determined to be 6.64, 7.34 and 7.18 MJ kg^{-1} for the mechanized and semi-mechanized systems as well as average production, respectively, indicating that for each kilogram of wheat produced in these systems, the mechanized system consumed less energy than the semi-mechanized system. The net energy index for mechanized and semi-mechanized systems in addition to average production was estimated to be 26626.46, 19547.58 and 20948.61 MJ ha^{-1}, respectively, in which this index for the mechanized system was more than another one. Overall, the results of energy indices indicated that energy management of wheat production in the mechanized system was better than the semi-mechanized system.

Figure 3 and Table 4 present the percentages and values of direct, indirect, renewable and non-renewable energies in wheat production in Mazandaran province. The results showed that in both production systems, the share of indirect and non-renewable energies was higher than the direct and non-renewable energies. In the mechanized production systems, the inputs of agricultural machinery, farmyard manure, chemical fertilizers, and pesticides were higher than the semi-mechanized production system. Therefore, the contribution of indirect energies in the mechanized system by 12858.94 MJ ha^{-1} was more than the semi-mechanized system by 12057/35 MJ ha^{-1}. In other studies, the share of indirect energies was reported to be higher than that of direct energies [7, 9, 33]. The share of non-renewable energies in the mechanized system was 18370.02 MJ ha^{-1} and 81.57% and in the semi-mechanized system, it was 15268.74 MJ ha^{-1} and 75.95%, respectively, which was significantly higher than renewable energies. In other similar studies, the share of non-renewable energies was higher than that of renewable energies [6, 7, 14, 34].

Table 4. Energy indices in mechanized and semi-mechanized production systems

Indices	Unit	Mechanized		Semi-mechanized		Average	
		Value	Percentage	Value	Percentage	Value	Percentage
Energy efficiency	–	2.18	-	1.97	-	2.02	-
Energy productivity	kg/MJ	0.15	-	0.14	-	0.14	-
Specific energy	MJ/kg	6.64	-	7.34	-	7.18	-
Net energy	MJ/ha	26626.46	-	19547.58	-	20948.61	-
Direct energy	MJ/ha	9660.86	42.90	8045.83	40.02	8365.47	40.65
Indirect energy	MJ/ha	12858.94	57.10	12057.35	59.98	12216.00	59.35
Renewable energy	MJ/ha	4149.79	18.43	4834.43	24.05	4698.93	22.83
Non-renewable energy	MJ/ha	18370.02	81.57	15268.74	75.95	15882.53	77.17

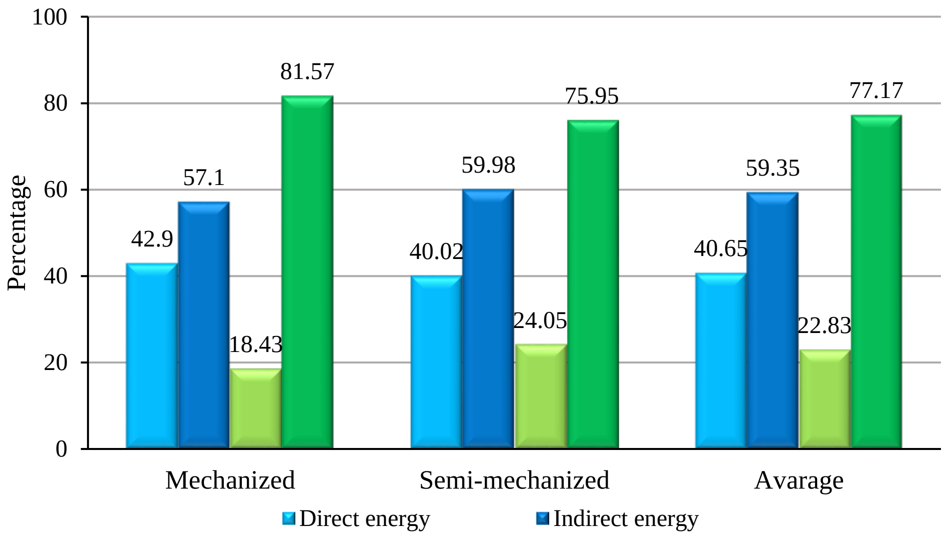

Fig. 3. The share of energy indices in wheat production in mechanized and semi-mechanized production systems

3.3.Modeling the energy flow in mechanized production systems

To model the energy flow of wheat production in the mechanized system, energy inputs in this system were considered as inputs of the neural network model. The results of comparing RMSE and R^2 values of the model with different numbers of neurons and different activation functions are shown in Fig. 4 and 5, respectively. Based on these figures, the model performs best in the activation function of the tangent sigmoid with nine neurons in which the RMSE and R^2 values were reported to be 1092.10 MJ ha^{-1} and 0.994, respectively. Therefore, the best model for predicting the energy output of mechanized wheat production had the structure of 9–9–1 (nine inputs, nine neurons in a hidden layer and one output) and Table 5 presents the model specifications. Khoshnevisan et al. reported that the best topology of the MLP for prediction of wheat grain yield was 11-32-10-1 by RMSE and R^2 values of 0.90 and 0.920, respectively [35].

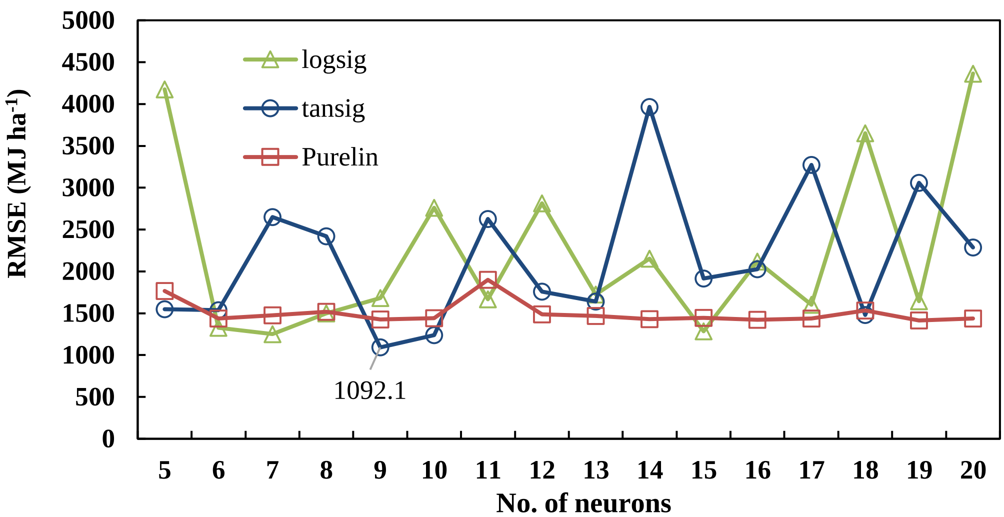

Fig.4. Different values of RMSE in different number of neurons and three activation functions to model the energy flow of wheat production in the mechanized system

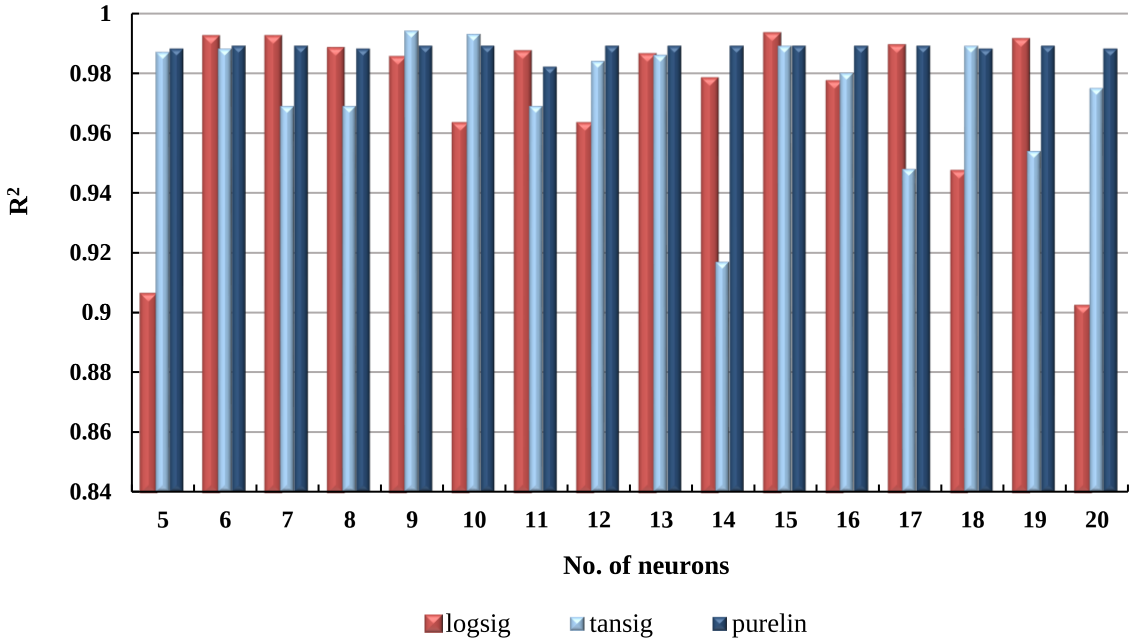

Fig. 5. The variation of R^2 values of MLP network in different number of neurons and three activation functions to model the energy flow of wheat production in the mechanized system

Table 5. The specifications of the selected model to predict the energy flow of wheat production in the mechanized system

Characteristics	Parameters
No. of inputs	9
No. of neurons in the hidden layer	9
Activation function	Tangent sigmoid
Network structure	9-9-1, Back-propagation
Training algorithm	Levenberg–Marquardt
No. of samples	76

Figure 6 indicates the performance of the developed MLP model for modeling the energy flow of wheat production in the mechanized production system. In this figure, the error reduction process is shown in three training, validation and test datasets with blue, green and red lines, respectively. This figure can be an indicator of the network training process. Besides, the validation error presents a criterion for the generalizability of the network. Once the validation error reduction process is stopped, the network training process will also stop [36]. Besides, errors of test datasets are also used to evaluate the model during and after the training process. According to Fig. 6, the best validation performance was obtained at the 29^{th} epoch with the RMSE of 2185522.025 and the training process was stopped at the 35th epoch.

Figure 7 illustrates the difference between the predicted and observed values (neural network error of the selected model) in three stages of training, validation, and test in the mechanized production system. Based on this figure, it can be concluded that the fitting error values of the data are distributed evenly and normally.

Figure 8 also presents the training conditions of the proposed model. Based on this figure, model gradient values, Mu values, and validation checks were obtained as 381327.62, 1000, and 6 in the 35^{th} epoch, respectively.

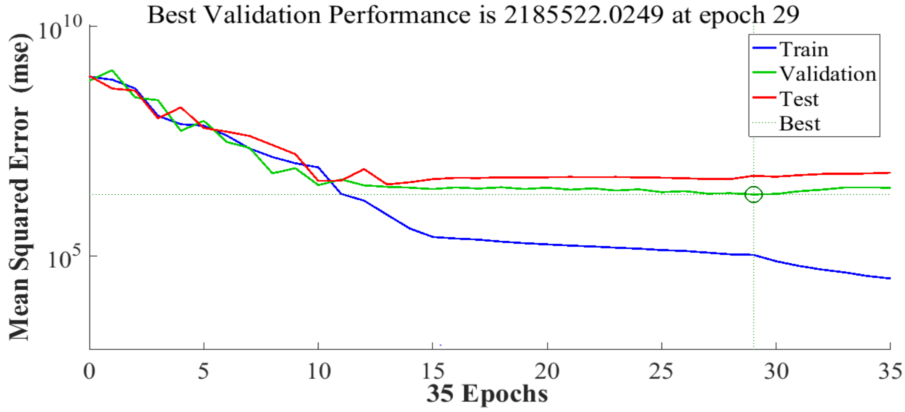

Fig. 6. Performance diagram of the MLP model developed to model energy flow of wheat production in the mechanized production system

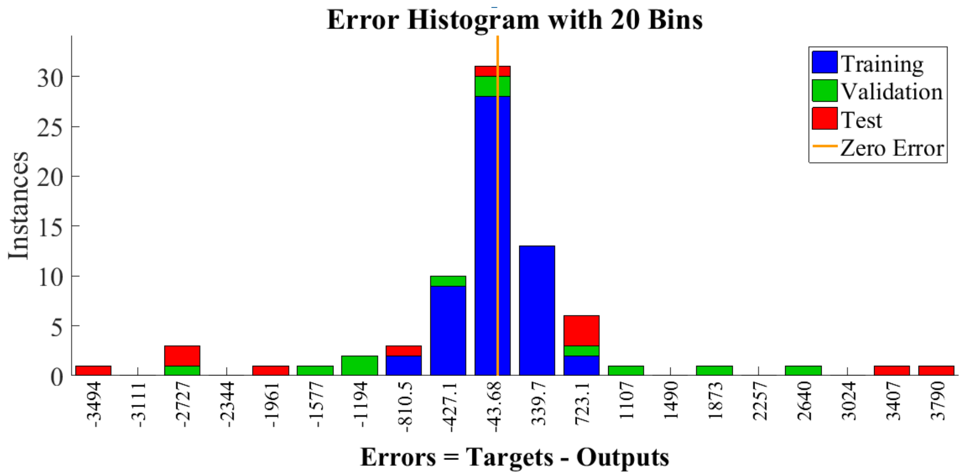

Fig. 7. The diagram of errors of the MLP model to predict the energy flow of wheat production in the mechanized system

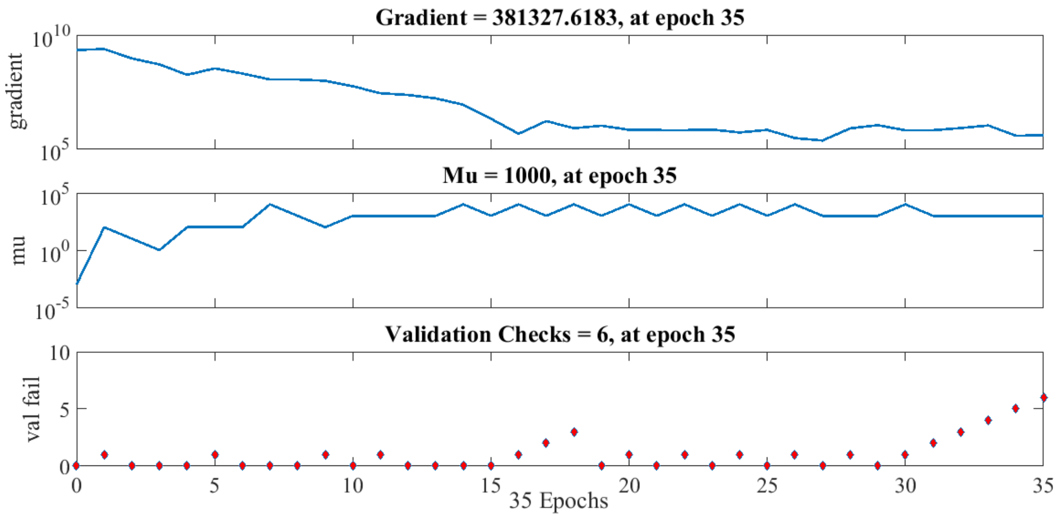

Fig. 8. The training conditions proposed to model the energy flow of wheat production in the mechanized system

Finally, a comparison of the predicted and observed values is given in Fig. 9. Based on this figure, given that most of the points on the diagram are located near the 45-degree line, it can be concluded that the proposed neural network model has a high ability to predict the output energy of wheat production in the mechanized production system.

3.4. Modeling the energy flow in the semi-mechanized system

Modeling of energy flow of wheat production in the semi-mechanized system was investigated using an MLP model. The results of comparing RMSE and R2 values of models with the different number of neurons and different activation functions are presented in Fig. 10 and 11, respectively. The results presented that the model performs best in the logarithmic sigmoid activation function with eight neurons in which the RMSE and R2 values are reported as 408.10 MJ ha-1 and 0.997, respectively. Therefore, the best model to predict the amount of energy output in a semi-mechanized wheat production system had the structure of 9–8–1 (nine inputs, eight neurons in the hidden layer, and one output), which its specifications are presented in Table 6.

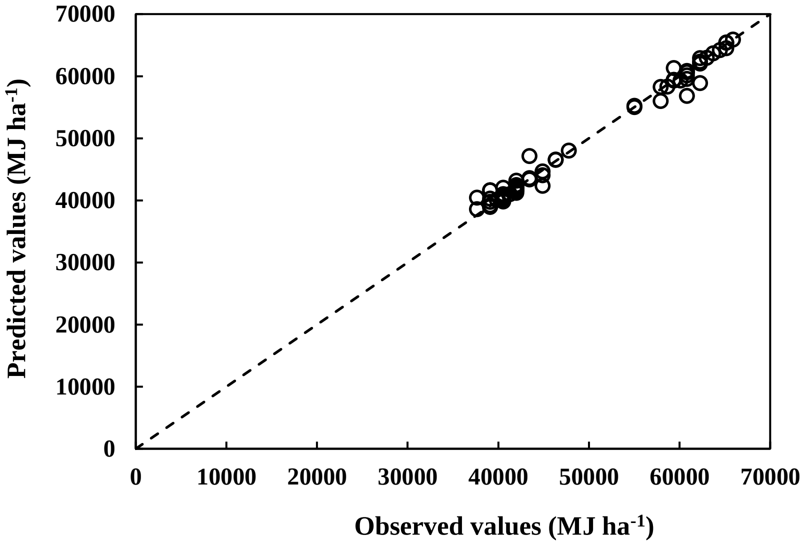

Fig.9. The comparison between estimated and observed values to model the energy flow of wheat production in MP systems

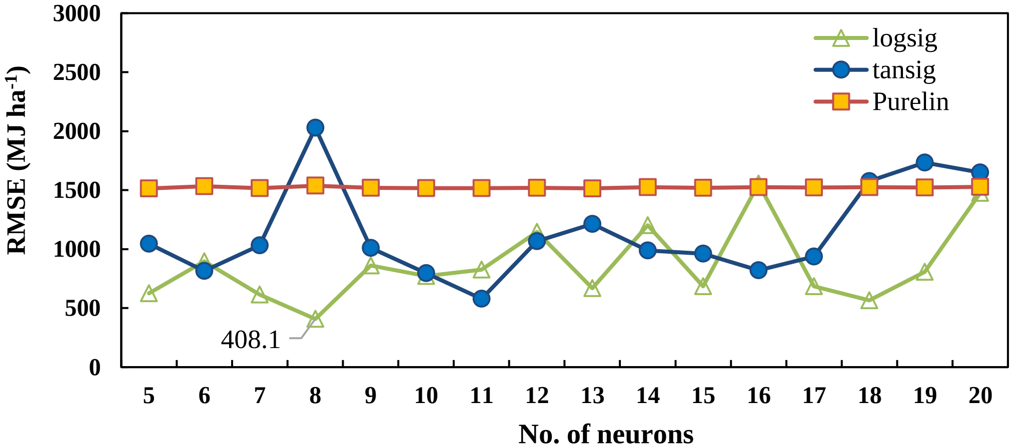

Fig. 10. Different values of RMSE in different number of neurons and three activation functions to model the energy flow of wheat production in the semi-mechanized system

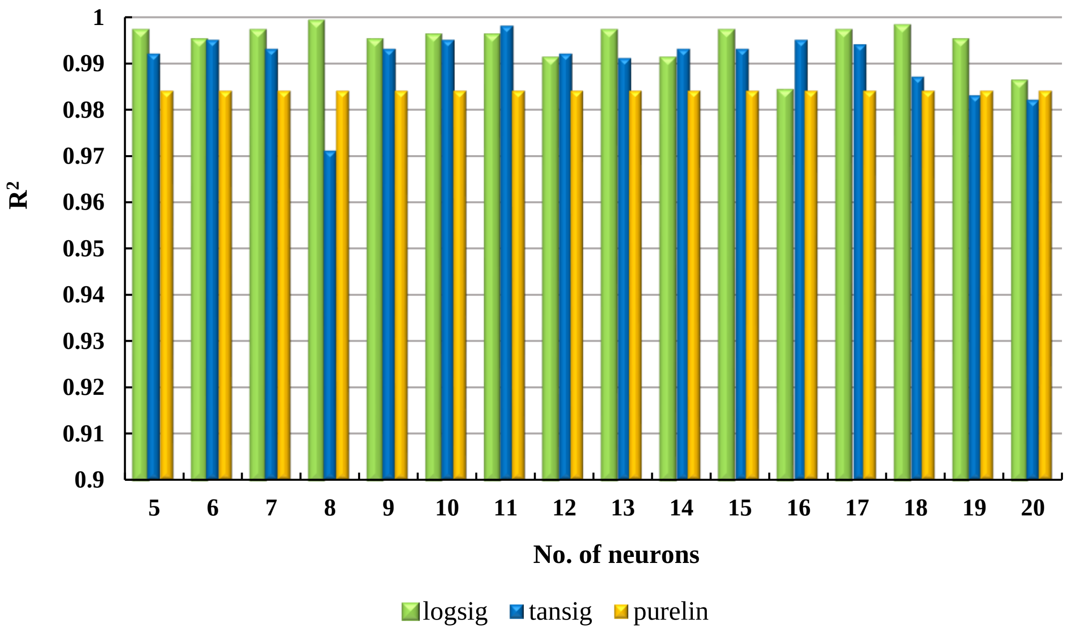

Fig. 11. The variation of R^2 values of MLP network in different number of neurons and three activation functions to model the energy flow of wheat production in the semi-mechanized system

Table 6. The specifications of the selected model to predict the energy flow of wheat production in the mechanized system

specifications	Parameters
No. of inputs	9
No. of neurons in the hidden layer	8
Activation function	Logarithmic sigmoid
Network structure	9-8-1, Back-propagation
Training algorithm	Levenberg–Marquardt
No. of samples	308

The performance of the developed MLP model to predict the energy flow of wheat production in a semi-mechanized system is shown in Fig. 12. The error reduction process is shown in three training, validation and test datasets with blue, green and red lines, respectively. This figure can be an indicator of the network learning process, in which validation error can be considered as a criterion for the generalizability of the network. Errors of test datasets were also used to evaluate the model during and after the training process. According to Fig. 12, the best validation performance is obtained at the 50th epoch with the RMSE of 66496.3033 and the training process was stopped at the 56^{th} epoch.

Figure 13 indicates the difference between the predicted and observed values in three stages of training, validation and test in the semi-mechanized production system. Based on this figure, it can be concluded that the fitting error values of the data are distributed evenly and normally near zero point.

Figure 14 also illustrates the training conditions of the proposed model. Based on this figure, model gradient values, Mu values, and validation checks were obtained as 54321.9027, 100, and 6 in the 56^{th} epoch, respectively.

The comparison of the predicted and observed values is given in Fig. 15. Based on this figure, given that most of the points on the diagram are located near the 45-degree line and lower than 10%, it can be concluded that the proposed MLP model had the proper performance to predict the output energy of wheat production in the semi-mechanized production system.

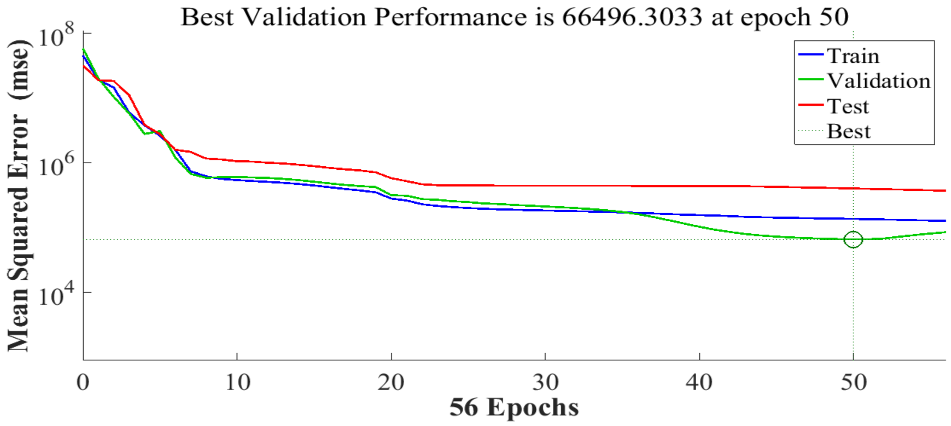

Fig. 12. Performance diagram of the MLP model developed to model energy flow of wheat production in the semi-mechanized production system

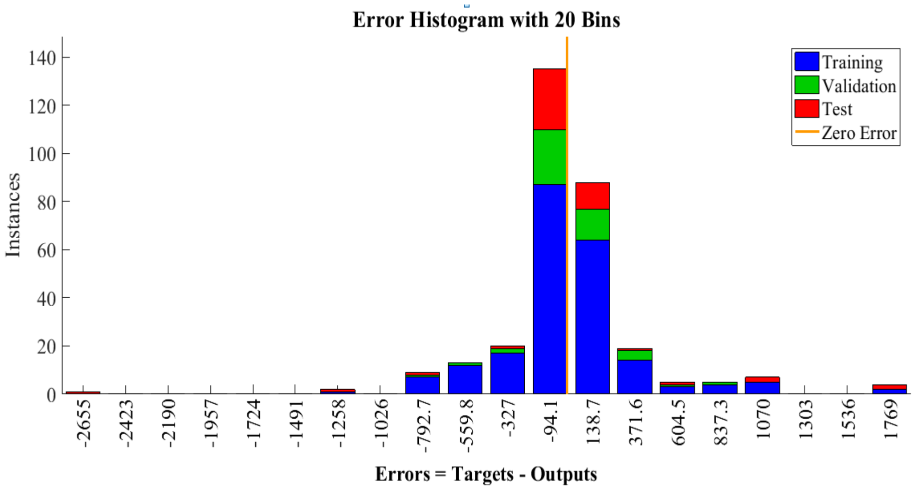

Fig. 13. The diagram of errors of the MLP model to predict the energy flow of wheat production in the semi-mechanized system

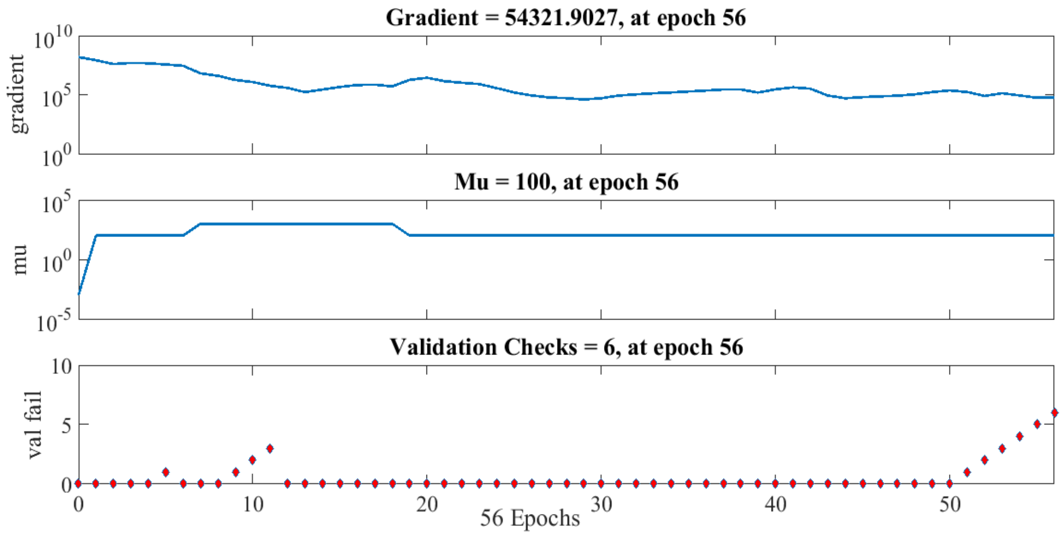

Fig. 14. The training conditions proposed to model the energy flow of wheat production in the semi-mechanized system

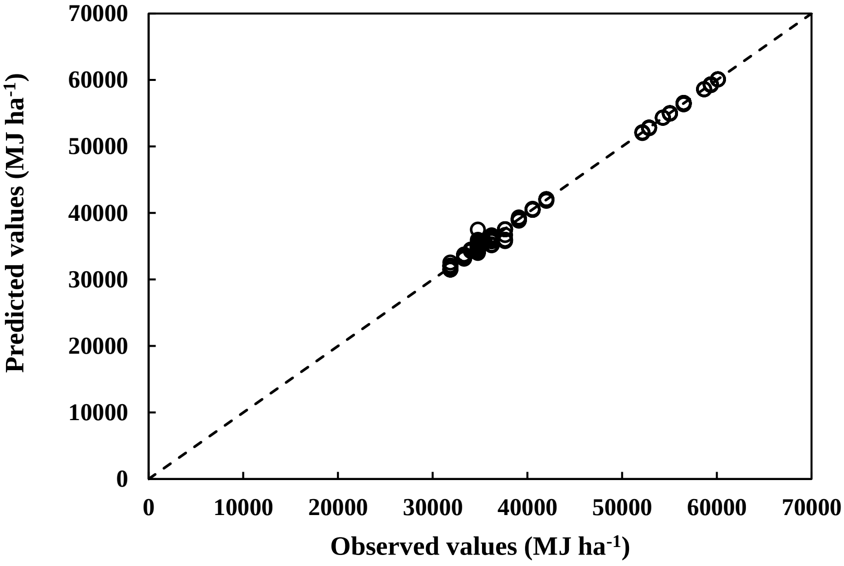

Fig. 15. The comparison between predicted and observed values to model the energy flow of wheat production in the semi-mechanized system

Conclusion

The purpose of this study was to investigate the energy consumption of wheat in two mechanized and semi-mechanized production systems in Mazandaran province. In the study of energy consumption, the average energy consumption of wheat production in Mazandaran province was 20581.46 MJ ha^{-1} which was higher in the mechanized system by 22519.80 MJ ha^{-1} than the semi-mechanized system by 20103.17 MJ ha^{-1}. Chemical fertilizers input with energy consumption of 10627.59 MJ ha^{-1} had the highest share of energy consumption with 51.64%. The share of this input in the mechanized system by 52.57% was higher than in the semi-mechanized system by 48.26%. Lack of proper tests on soil and plant leaves to determine the optimum use of chemical fertilizers and excessive use of this input increased the contribution of this input to the total energy. The two inputs of seed and diesel fuel followed chemical fertilizers by the share of 17.86% and 17.60%, respectively. In the study of energy indices, energy efficiency and energy productivity for average production were determined to be 2.02 and 0.14 kg MJ^{-1}, respectively, which were higher in the mechanized system. In both production systems, the share of indirect and non-renewable energies was higher than that of direct and renewable energies. Overall, the results of energy indices showed that the energy management of wheat production in mechanized systems was better than semi-mechanized ones. In the study of modeling the energy flow of wheat production in the mechanized system, the model performance was best in the tangent sigmoid activation function with nine neurons in which the RMSE and R^2 values were 1092.10 MJ ha^{-1} and 0.994, respectively. The best model for predicting the output energy had the structure of 9–9–1. In the study of modeling the semi-mechanized system, the findings presented that the model had the best performance in the logarithmic sigmoid activation function with eight neurons in which the RMSE and R^2 values were 408.10 MJ ha^{-1} and 0.997, respectively. Therefore, the best model had a structure of 9-8-1.

Acknowledgment

The authors would like to acknowledge the support provided by the Islamic Azad University, Qaemshahr branch, for funding this work.

Conflict of Interest

The authors declare no conflicts of interest.

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