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Economic modeling of mechanized and semi-mechanized rainfed wheat production systems using multiple linear regression model

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ABSTRACT

Mathematical modeling of economic indices is a challenging topic in crop production systems. The present study aimed to model the economic indices of mechanized and semi-mechanized rainfed wheat production systems using various multiple linear regression models. The study area was Behshahr County located in the east of Mazandaran Province, Northern Iran. The statistical population included all wheat producers in Behshahr County in 2016/17 crop year. Five input variables were human labor, machinery, diesel fuel, chemical (chemical fertilizers and chemical pesticides) costs, and the income was considered to be the output. The results showed that the cost of wheat production in the semi-mechanized system was higher than that of the mechanized system. In both systems, the highest cost was related to agricultural machinery input. Moreover, seed cost was lower in the mechanized system than that of the semi-mechanized system. The net return indicator was 993.68 $\$\ ha^{-1}$ and 626.71 $\$\ ha^{-1}$ for the mechanized and semi-mechanized systems, respectively. The average benefit to cost ratio was 3.46 and 2.40 for the mechanized and semi-mechanized systems, respectively, demonstrating the greater profitability of the mechanized system. The results of the evaluation of five types of regression models including the Cobb-Douglas, linear, 2FI, quadratic and pure-quadratic for the mechanized and semi-mechanized production systems indicated that in the developed Cobb-Douglas model, the R^2-value was higher than that of the quadratic model while RMSE and MAPE of the quadratic model were determined to be smaller than that of the Cobb-Douglas model. Therefore, the best model to investigate the relationship between input costs and the income of wheat production in both mechanized and semi-mechanized systems was the quadratic model.

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1. Introduction

The agricultural sector as the main source of food supply in Iran plays an important role in implementing the development programs of the country. Wheat is one of the main agricultural crops in Iran and the world. Given the growing population of the world, the achievement to self-sufficiency in this strategic crop is of great importance. Therefore, the increasing production per unit area plays an important role. Wheat production is classified in different ways in terms of the level of the use of agricultural machines, which differs in terms of energy consumption and production costs. Wheat is the most important agricultural crop in Iran and the world and has the highest cultivated area. Global wheat acreage was 222.11 million hectares in 2016–2017 [1]. The total wheat production in the world in the 2017–2018 crop year amounted to about 753 million tons, which is about 55 million tons more than the average of the last ten years (2007–2008 to 2017–2018), which was 698 million tons. In Iran, wheat is the most consumable agricultural crop with the highest acreage amounting to about 6.80 million hectares [1,2] which produced about 15 million tons of wheat in the 2017–2018 crop year, ranked the 12th largest producer of this strategic product in the world [3]. The yield of wheat per hectare, according to the statistics of the US Department of Agriculture in 2017, was 3.39 tons per hectare worldwide, while it is reported to be 2.28 tons per hectare for Iran [1].

Various studies have focused on evaluating mechanized and semi-mechanized crop systems in agricultural production. Heidarzadeh et al. [4] compared agricultural machinery and human labor costs in three mechanized, semi-mechanized and semi-traditional wheat production systems. The results showed that the mechanized system had the highest and the semi-mechanized system had the lowest productivity of agricultural machinery. AghaAlikhani et al. [5] evaluated mechanized and traditional rice cultivation systems and reported that the mechanized system outperformed the traditional one in gross yield and gross income. The economic analysis of wheat production has been subject to various studies in Iran and the world. Khan et al. [6] reported the economic analysis of three crops, i.e. wheat, rice, and barley, in the Australian production system. The research results for wheat showed that the total production costs of this crop were 323 $\$\,ha^{-1}$ and the benefit to cost ratio was 2.82. In a study of wheat production costs in Ardabil province, Iran, the total production cost and benefit to cost ratio were calculated to be 809.44 $\$\,ha^{-1}$ and 1.43, respectively [7]. Ghorbani et al. [8] compared two wheat production systems (rainfed and irrigated) in North Khorasan province, Iran. The results showed that the benefit to cost ratio was equal to 2.56 and 1.97 for rainfed and irrigated farms, respectively. Also, the total cost of wheat production in the rainfed and irrigated farm systems was determined to be 200.81 and 572.35 $\$\,ha^{-1}$, respectively.

In a study of economic indices of wheat production in the family farms in the Republic of Serbia, the results indicated that 76.88 and 23.12 percent of total costs were related to the variable and fixed costs, respectively and fertilization accounting for 35.75 percent of the variable costs was the costliest input [9]. In another study, fertilization and fuel were reported to be the costliest inputs accounting for 48.42 and 29.91 percent of wheat production costs in Foggia, southern Italy, respectively [10]. In a research study to analyze wheat production costs under the raised bed and conventional irrigation systems in Pakistan, the benefit to cost ratio was reported to be, on average, 2.24 and 2.86 for the conventional system and raised bed system in two areas, respectively [11]. In another study, the costs of wheat production with two different tillage and irrigation systems, including conventional tillage with surface irrigation and conservation tillage with sprinkler irrigation, were calculated. The results highlighted that the average productivity of the conservation tillage with sprinkler irrigation (9.32 ± 2.02) was more than that of the conventional tillage with surface irrigation (4.79 ± 1.99). Moreover, the benefit to cost ratio was reported to be 4.40 and 2.05, respectively [12]. The economic analysis of four agricultural crops including wheat, barley, paddy, and maize in Iran during 1986 and 2009 revealed that the chemical pesticides and seed inputs had statistically significant positive impact on the yield [13]. In another study, the economic analysis of zero-tillage wheat was investigated in north-west India. The average total cost was 14.33 $\$\,ha^{-1}$ and 15.54 $\$\,ha^{-1}$, for conventional tillage and zero-tillage wheat, respectively. Also, the benefit to cost ratio was calculated to be 1.31 and 1.43, respectively [14]. In a research on the economic analysis of different crop establishment methods and weed management practices of wheat in India, the benefit to cost ratio of wheat production by using zero tillage was reported to be higher than that of reduced and conventional tillage [15].

To the best knowledge of the authors, no comprehensive research has focused on the economic analysis of wheat production considering the level of the application of agricultural machinery. Since one of the main objectives of the agricultural mechanization is increasing the economic efficiency, this research evaluates the economics of mechanized and semi-mechanized crop production of rainfed wheat farms using multiple linear regression models.

2. Materials and methods

2.1. Study area

The study area was Behshahr County (36°20′N-36°53′N and 53° 14′E-54°7″ E) with an area of 3106 km^2 located in the east of Mazandaran province, north of Iran. Mazandaran province has a moderate mountainous climate with an average daily temperature of 17.40 °C, a mean rainfall of 653 mm, and relative humidity of 78% [16]. The statistical population of the study included all wheat producers in Behshahr County during the 2016–2017 crop year. The sample size was estimated using Cochran formula in mechanized and semi-mechanized production systems. Table 1 shows the difference between mechanized and semi-mechanized crop production systems in Behshahr County. Cochran has proposed

Table 1 – The differences between mechanized and semi-mechanized systems for wheat production in Behshahr County.

Operations type	Mechanized	Semi-mechanized
Tillage	Moldboard plow (one-time) and harrow disk (one-time)	Moldboard plow (one-time) and harrow disk (one or two-time(s))
Sowing	Grain drill	Seed spreading by hand or broadcast spreader and harrow disk (one or two-time(s))
Management	Sprayer and fertilizer spreader	Spraying (man-portable) and fertilizer spreader (by hand)
Harvest	Direct harvesting with combine harvester	Indirect harvesting with combine harvester

Eq. (1) to calculate the required sample size in the randomized sampling system [17–19].

$$n = \frac{N(t \cdot s)^2}{Nd^2 + (t \cdot s)^2} \tag{1}$$

where N is the size of the statistical population, t is the value at 95% confidence limit (1.96), s is the standard deviation, d is the acceptable error, and n is the sample size.

Data were collected through questionnaires and interviews with 124 wheat producers. Participants were selected randomly in a structured design based on two mechanized production system (43 participants) and the semi-mechanized system (81 participants). The study considered human labor, machinery, diesel fuel, chemical inputs (chemical fertilizers and chemical pesticides) and seed as inputs and independent variables. The content validity system was used to assess the validity of the questionnaire. Cronbach's alpha coefficient was estimated to evaluate the reliability of the questionnaire [20–22]. Firstly, the variance of scores for each question of the questionnaire and the total variance of the test were calculated and then, its coefficient was determined. The reliability of the questionnaire was determined to be 0.86.

2.2. Economic analysis

For the economic evaluation of the wheat production in Behshahr County, the inputs were first calculated for two mechanized and semi-mechanized production systems, and then the fixed, variable, and total costs were determined per unit area. Also, the value of economic indices was calculated for mechanized and semi-mechanized production systems. Economic indices including total production value, gross return, net return, the benefit to cost ratio, and economic efficiency were calculated as follows [23–25].

$$\text{Total production value} = \text{Wheat yield}\left(\text{kg ha}^{-1}\right) \times \text{Wheat price}\ (\$\ \text{kg}^{-1}) \tag{2}$$

$$\text{Gross return} = \text{Total production value}\left(\$\ \text{ha}^{-1}\right) - \text{Variable production cost}\ (\$\ \text{ha}^{-1}) \tag{3}$$

$$\text{Net return} = \text{Total production value}\left(\$\ \text{ha}^{-1}\right) - \text{Total production cost}\ (\$\ \text{ha}^{-1}) \tag{4}$$

$$\text{Benefit} - \text{cost ratio} = \frac{\text{Total production value}\left(\$\ \text{ha}^{-1}\right)}{\text{Total production cost}\left(\$\ \text{ha}^{-1}\right)} \tag{5}$$

$$\text{Economic productivity} = \frac{\text{Wheat yield}\left(\text{kg ha}^{-1}\right)}{\text{Total production cost}\left(\$\ \text{ha}^{-1}\right)} \tag{6}$$

2.3. Economic modeling

Regression analysis is a statistical analysis system for determining the effect of independent variables on a dependent variable. Linear regression is used to evaluate the linear dependencies of variables [26]. This technique has been widely applied in agricultural studies [27–30]. The linear regression model describes the behavior of the unknown value of y in terms of the values of ×, and the random error e. The linear regression prediction models are expressed in the form of Eq. (7) [31]:

$$y_i = X_i\beta + \varepsilon_i \tag{7}$$

where y_i is a predicted value, $X_t = (1, x_1, x_2, ..., x_8)$ is a vector of descriptive variables, $\beta = (\beta_0, \beta_1, ..., \beta_k)^T$is a vector of coefficients, and $\varepsilon_i$is a random error for different variables. In order to estimate the parameter b, the least squares sense (LSQ) was used. The parameters of $\tilde{\beta} = (\beta_0, \beta_1, \beta_2, \beta_{h(1)}, ..., \beta_{h(T_s)})^T$are the values that minimize the sum of squares of the error variables, which can be written as Eqs. (9) and (10) [31]:

$$\min \sum_{t=1}^{T} \varepsilon_t^2 \tag{8}$$

$$\min \varepsilon^T \varepsilon \quad \text{s.t} \tag{9}$$

$$\varepsilon = \tilde{X}\tilde{\beta} - y \tag{10}$$

By replacing e in the target function, an unconstraint optimization problem is created (Eq. (11)) whose answer is in the form of Eq. (12) with the derivation and replacement of zero.

$$\min(\tilde{X}\tilde{\beta} - y)^T(\tilde{X}\tilde{\beta} - y) \tag{11}$$

$$2\tilde{X}^T\tilde{X}a - 2\tilde{X}^T y = 0 \rightarrow \tilde{\beta} = (\tilde{X}^T\tilde{X})^{-1}\tilde{X}^T y \tag{12}$$

where $\tilde{\beta} = (\beta_0, \beta_1, \beta_2, \beta_{h(1)}, ..., \beta_{h(T_s)})^T, \tilde{X} = (\tilde{X}_1, \tilde{X}_2, ..., \tilde{X}_8)^T$ and $y = (y_1, y_2, ..., y_8)^T$. To find the best model, multiple regression models were used. The model can generally be described as Eq. (13) [31].

$$y = \beta_0 + \sum_{i=1}^{K} \beta_i x_i + \sum_{i=1}^{K} \beta_{ii} x_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \beta_{ij} x_i x_j + \varepsilon_0 \quad (13)$$

where y, β_0, β_i, β_{ii} and β_{ij} are the dependent variable, constant coefficient, linear coefficient, quadratic and interaction coefficients, respectively. Moreover, k is the number of studied and optimized term and ε_0 is the error. x_i,x_j, $x_i x_j$ and x_i^2 were also independent variables, interactions, and quadratic phrases, respectively.

Also, to establish a relationship between costs and income, the present study used the Cobb-Douglas regression system because of its simplicity, compatibility with its physical logic, and its upgradeability. This function has been used by other studies in Iran and other countries in the field of energy too [32–35]. The general form of the function is given by Eq. (14). By calculating the logarithms of the sides of Eq. (14), and by placing energy inputs in Eq. (15), the formula is converted into Eq. (16) where a_0 and e_i are constant coefficients and error coefficients, respectively, and $\alpha_1, \alpha_2, \ldots, \alpha_8$ are the regression coefficients of the energy inputs, respectively [34].

$$Y = f(x)\exp(u) \quad (14)$$

$$\ln Y_i = a_0 + \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i \quad i = 1, 2, \ldots, 83 \quad (15)$$

$$\ln Y_i = a_0 + \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \ldots + \alpha_8 \ln X_8 + e_i \quad (16)$$

In this study, the rate of return to scale was used to analyze output variation with the variations of inputs [36–38]. The results of the correlation study between independent variables and income for both mechanized and semi-mechanized production systems are shown in Table 2. The results showed that all variables had a significant correlation with income.

2.4. Model performance evaluation criteria

The capability of regression models to predict crop yield was tested by the root mean square error (RMSE), mean absolute percentage error (MAPE), and the linear correlation coefficient between the values estimated by the regression model and actual values (R^2) as given in Eqs. (17)–(19) [39–41]:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{m} (y_i - \hat{y}_i)^2}{m}} \quad (17)$$

$$MAPE = \frac{1}{m} \sum_{i=1}^{m} \left| \frac{y_i - \hat{y}_i}{y_i} \right| \times 100 \quad (18)$$

$$R^2 = \frac{\left(\sum_{i=1}^{m} (y_i - \bar{y})(\hat{y}_i - \bar{\hat{y}}) \right)^2}{\sum_{i=1}^{m} (y_i - \bar{y})^2 . \sum_{i=1}^{m} (\hat{y}_i - \bar{\hat{y}})^2} \quad (19)$$

where y_i, $\hat{y}_i$ and, $\bar{y}$ denote the actual result, the output of the model, and the average of the data actual for the i^{th} data, respectively. $\bar{y}$ and $\bar{\hat{y}}$ are the actual and predicted outputs of the model, respectively, and m is the number of data.

Data analysis was performed using Minitab 17 and MATLAB V.9.0.0.341360 (2016b) statistical software packages. Regression relationships between inputs and income were established using multiple linear regression models. Also, to evaluate the difference in the data between mechanized and semi-mechanized production systems, analysis of variance and HSD means comparison test were performed.

3. Results and discussion

3.1. Costs and economic indices

In Table 3, input costs and gross return for the wheat production in Behshahr City are shown for mechanized and semi-mechanized production systems. The total production cost of the farms equipped with the mechanized system was determined to be 411.83 \$ ha^{-1} while it was 448.20 \$ ha^{-1} for farms with the semi-mechanized system, indicating a higher amount of wheat production cost in the semi-mechanized system. The value of this index for wheat production in Ardabil province [7] and Australia [6] was 809.44 \$ ha^{-1} and 323\$ ha^{-1}, which represents higher production costs of wheat in Iran in comparison to Australia. The gross return for mechanized and semi-mechanized systems was 1359.71 \$ ha^{-1} and 1074.91 \$ ha^{-1}, respectively. In the mechanized system, due to the use of grain drill at sowing stage and fertilizer spreader during the management stage as well as the direct harvest of the product, we saw an increase in yield and a decrease in crop losses versus the semi-mechanized system. Accordingly, the higher gross return of farms with mechanized systems seems reasonable.

Fig. 1 shows the share of each input's cost in wheat production. In general, the semi-mechanized system was costlier than the mechanized system. This was due to the use of more inputs in the semi-mechanized system. The results of an evaluation of three different wheat production systems (i.e., mechanized, semi-mechanized and semi-traditional systems) in Iran have also indicated that the costs of the semi-mechanized system were more than those of the mechanized system [4]. In the variable cost section, the cost of all inputs, except for the machinery, was higher in the semi-mechanized system than in the mechanized one. So, in the

Table 2 – Correlation coefficients of studied variables.

	X_1	X_2	X_3	X_4	X_5
$Y_{Mechanized}$	0.375^b	0.370^b	0.503^a	0.641^b	0.520^a
$Y_{Semi\text{-}mechanized}$	0.334^a	0.404^a	0.614^a	0.244^b	0.257^b

a: significant at 1%, b: significant at 5%, c:significant at 10%.
X_1: Seed, X_2: Machinery, X_3: Diesel, X_4: Chemicals, X_5: Human labor.

Table 3 – The economic analysis of wheat production in Behshahr County for mechanized and semi-mechanized production systems.

Items	Unit	Mechanized		Semi-mechanized	
		Value	Percent of total	Value	Percent of total
1. Human labor	$ ha^{-1}	29.22^{b}	9.08	47.82^{a}	13.66
2. Machinery	$ ha^{-1}	176.37^{a}	54.82	141.33^{b}	40.36
3. Diesel Diesel	$ ha^{-1}	3.94^{a}	1.22	4.33^{a}	1.24
4. Chemicals	$ ha^{-1}	62.64^{a}	19.47	75.06^{a}	21.43
5. Seed	$ ha^{-1}	49.57^{b}	15.41	81.61^{a}	23.31
Gross value of production	$ ha^{-1}	1359.71		1074.91	
Total cost of production	$ ha^{-1}	411.83		448.20	

Different letters in the columns indicate a significant difference among treatments at 5% level.

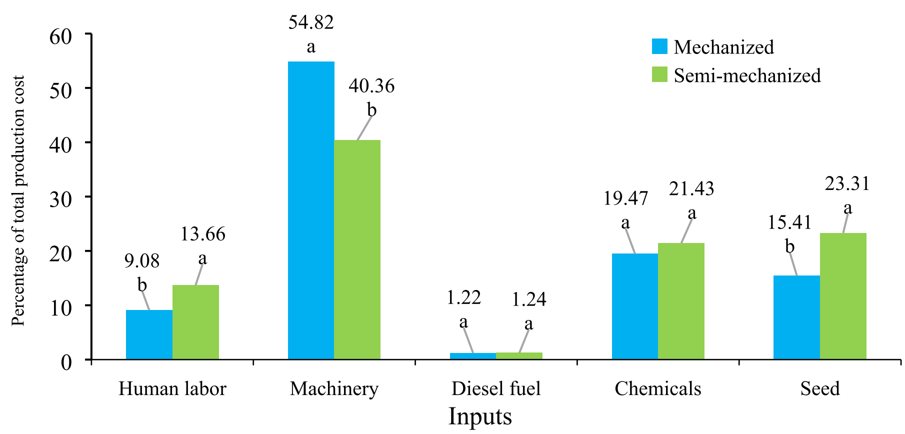


Fig. 1 – The contribution of the cost of each input to wheat production costs in the mechanized and semi-mechanized systems. Different letters in the columns indicate a significant difference among treatments at 5% level.

semi-mechanized system, the average cost of human labor and seed inputs was about 60% higher than in the mechanized system, which was statistically significant ($p < 0.05$). In both production systems, machinery accounted for the highest cost with 54.82% in the mechanized system and 40.36% in the semi-mechanized system. In the mechanized system, seed at an average seeding rate of 132 kg ha^{-1} was the third costliest input (49.57 $ ha^{-1}). But in the semi-mechanized system, seed costs (81.61 $ ha^{-1}) at an average seeding rate of 197 kg ha^{-1} were the second highest. The reason for this difference is the cost of using grain drills in mechanized systems and hand spreading in semi-mechanized systems. The average contribution of the rest of the inputs to total production costs is shown in Table 3, where the diesel fuel had the lowest contribution to the production costs in both systems.

In Table 4, the share of different machine operations is shown in the total machinery cost for the mechanized and semi-mechanized systems. In the mechanized production system, the use of grain drill equipment, combine harvester and moldboard plow were 31.25, 25.34 and 25.31 percent, respectively. In the semi-mechanized production system, the use of moldboard plow, combine harvester, and harrow disk had the highest costs accounting for 32.21, 32.12 and 22.73 percent, respectively. The cost of using harrow disk

Table 4 – The contribution of the costs of different machinery operations to total machinery costs in the mechanized and semi-mechanized systems.

Operations type	Mechanized		Semi-mechanized	
	Value	Percent of total	Value	Percent of total
Moldboard plow	44.64^{a}	25.31	45.53^{a}	32.21
Disk Harrow	18.77^{b}	10.64	32.13^{a}	22.73
Grain drill	55.12	31.25	0	0
Spraying	8.70^{a}	4.93	8.23^{a}	5.82
fertilizer spreader	4.47^{b}	2.53	10.05^{a}	7.12
Combine Harvester	44.69^{a}	25.34	45.39^{a}	32.12
Total	176.37^{a}	100	141.33^{b}	100

Different letters in the columns indicate a significant difference among treatments at 5% level.

Table 5 – Economic indices of wheat production in Behshahr County for the mechanized and semi-mechanized systems.

Items	Unit	Mechanized	Semi-mechanized
Sale price	$\$ kg^{-1}$	0.41	0.41
Variable cost of production	$\$ ha^{-1}$	321.74	350.15
Fixed cost of production	$\$ ha^{-1}$	90.09	98.04
Total cost of production	$\$ ha^{-1}$	411.83	448.20
Gross value of production	$\$ ha^{-1}$	1359.71	1074.91
Benefit to cost ratio	–	3.46^a	2.40^b
Economic productivity	$kg\ \$^{-1}$	10.36^a	7.38^b
Gross return	$\$ ha^{-1}$	1082.01^a	724.75^a
Net return	$\$ ha^{-1}$	993.68^a	626.71^a

Different letters in the columns indicate a significant difference among treatments at 5% level.

and fertilizer spreader in the semi-mechanized system was about two times more than that of the mechanized system, which was statistically significant ($p < 0.05$). This difference is associated with the application of fertilizer spreaders in sowing operation and the use of harrow disks to mix seeds with soil in semi-mechanized systems. Indeed, the average frequency of the use of fertilizer spreaders and harrow disks in the mechanized system was 1.19 and 1.08 times per hectare, whilst they were 1.92 and 2.14 times per hectare in the semi-mechanized system, respectively.

Table 5 presents the economic indices for mechanized and semi-mechanized systems. The net return was 993.68 $\$ ha^{-1}$ and 626.71 $\$ ha^{-1}$ in the mechanized and semi-mechanized production systems, respectively. The average benefit to cost ratio was 3.46 for the mechanized system and 2.40 for the semi-mechanized system, indicating greater profitability of the mechanized production system. This index for wheat production in Khorasan Razavi was reported as to be 2.17 [23]. Compared to other indices in the region, the index for pomegranate fruit in Behshahr County was reported to be 5.57, which illustrates greater profitability of pomegranate crops compared to wheat production [42]. The economic productivity index for the mechanized and semi-mechanized production systems was calculated to be 10.36 $kg\ \$^{-1}$ and 7.38 $kg\ \$^{-1}$, respectively. The value of this index for the wheat production in Khorasan Razavi [23] and rice in Mazandaran [43] was reported at 5.11 $kg\ \$^{-1}$ and 1.12 $kg\ \$^{-1}$, respectively. Higher economic productivity in the mechanized production system showed that for each dollar of the wheat production cost, more crop has been produced in the mechanized system.

3.2. *Multiple linear regression modeling*

3.2.1. *Model selection*

Table 6 presents the results of the evaluation of five types of regression models, including Cobb-Douglas, linear, 2FI, quadratic and pure-quadratic, for the mechanized and semi-mechanized production systems. The analysis of three criteria, i.e., R^2, RMSE, and MAPE, showed that the best model to investigate the relationship between input costs and income of wheat production in both mechanized and semi-mechanized systems was a quadratic model. In the Cobb-Douglas model, the R^2-value was more than that of the quadratic model, while RMSE and MAPE of the quadratic model were determined to be less than that of the Cobb-Douglas model. This indicated that the quadratic model outperformed the Cobb-Douglas model in determining income. Most studies have only used the linear Cobb-Douglas model, but in this research four types of regression models were investigated [42–45]. In the following, both the Cobb-Douglas and the quadratic models have been investigated to better compare the results for the mechanized and semi-mechanized systems as well as to compare the results of this research with similar studies.

3.3. *Cobb-Douglas modeling*

Table 7 illustrates the results of using the Cobb-Douglas function to determine the relationship between input costs and income of the mechanized and semi-mechanized systems. The R^2-value for Eq. (16) was 0.82 and 0.76 in the mechanized and semi-mechanized systems, respectively. The R^2-value

Table 6 – The comparison of different models for the mechanized and semi-mechanized systems.

Model	RMSE	MAPE	R^2
Mechanized system			
Linear	116.24	6.73	0.60
Interaction	103.78	6.19	0.68
Pure-quadratic	113.38	5.98	0.68
Quadratic	**93.45**	**5.53**	**0.74**
Semi-mechanized system			
Linear	86.02	6.34	0.48
Interaction	68.77	5.02	0.67
Pure-quadratic	80.76	5.30	0.55
Quadratic	**53.90**	**3.77**	**0.80**

Table 7 – Regression coefficients for the costs of inputs and income.

Item	Mechanized		Semi-mechanized	
	Coefficient	t-ratio	Coefficient	t-ratio
Model : $\ln Y_i = a_0 + a_1 \ln x_1 + a_2 \ln x_2 + a_3 \ln x_3 + a_4 \ln x_4 + a_5 \ln x_5 + e_i$				
Human labor (X_1)	0.177	2.69[b]	0.030	0.32
Machinery (X_2)	0.123	0.66	0.451	3.14[a]
Diesel fuel (X_3)	0.317	2.78[a]	0.472	5.88[a]
Chemicals (X_4)	0.303	2.91[a]	−0.261	−2.39[b]
Seed (X_5)	0.164	0.68	0.363	1.99
R^2	0.82		0.76	
Durbin Watson	2.08		1.87	
RTS	1.084		1.055	

a Indicates significance at 1% probability level.
b Indicates significance at 5% probability level.

showed that 82 and 76 percent of the variations of income in the mechanized and semi-mechanized systems could be explained by independent variables (input costs). The Durbin-Watson statistics for the mechanized and semi-mechanized systems was determined to be 2.08 and 1.87, respectively, implying that there was no autocorrelation between data for the two systems at the 5% probability level. The rate of return to scale (RTS) in both mechanized and semi-mechanized systems was calculated to be 1.08 and 1.05, respectively. This suggests that in both systems, the rate of return to scale had increasing trends, which means that higher cultivated area in a unit will contribute to saving production costs. In the mechanized system, the effect of diesel fuel cost and chemical inputs on income was statistically significant ($p < 0.01$), and the cost of diesel fuel with a regression coefficient of 0.32 was the most effective variable in income variations. So, for every one percent increase in fuel consumption, income would grow by 0.32 percent. In the semi-mechanized system, the effect of diesel fuel cost and machinery on income was significant ($p < 0.01$), which had the highest effect on income variations by regression coefficients of 0.47 and 0.45, respectively. In the economic analysis of pomegranate production in Mazandaran, the diesel fuel input with the regression coefficient of 0.17 was the most effective in income [42].

3.3.1. *Quadratic model*

To determine the best quadratic model, the coefficients that were not significant were excluded from the model and the best model was selected for both systems. Table 8 shows the coefficients of the final model for both mechanized and semi-mechanized production systems. In analyzing and determining the best model for the mechanized system, all coefficients except for the coefficients of diesel fuel (x_3) and seed (x_5) were significant at the 1% and 5% probability levels. While coefficients of the costs of these inputs were not significant in the model, their interaction was significant ($p < 0.05$). The R^2-value was determined to be 0.73 for the model, which indicates the goodness of the model to predict the income of the mechanized system. Furthermore, based on the determined coefficients, it can be concluded that the human labor, machinery and chemical cost inputs and the interaction of seed and diesel fuel costs had a direct effect on the income, while the diesel fuel and seed cost inputs and second-order

Table 8 – Estimated coefficients of the selected regression model for the mechanized and semi-mechanized wheat production systems.

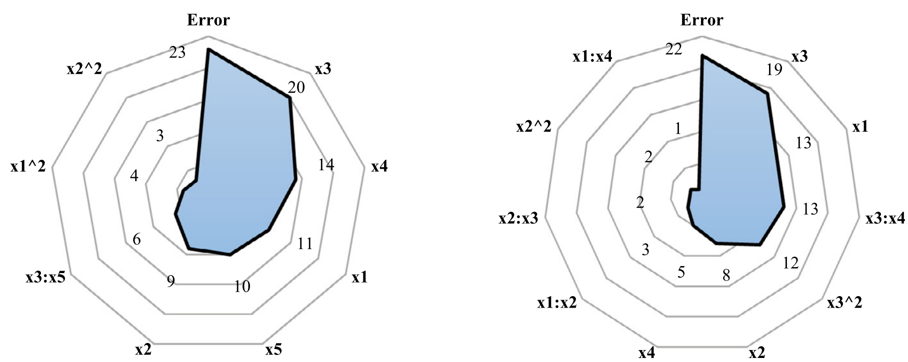
Mechanized system			Semi-mechanized system		
Term	Estimate	t-Stat	Term	Estimate	t-Stat
(Intercept)	−10293.36	−2.39[b]	(Intercept)	−4616.13	−1.3[b]
x_1	372.46	2.49[b]	x_1	156.32	3.16[a]
x_2	25.81	1.89[b]	x_2	15.78	0.45[c]
x_3	−157.82	−1.01[c]	x_3	−2127.91	−4.21[a]
x_4	8.55	2.98[a]	x_4	49.57	2.84[b]
x_5	−33.00	−1.71[c]	x_1x_2	−1.41	−3.77[a]
x_3x_5	10.78	2.16[b]	x_1x_4	0.58	3.53[a]
x_1^2	−3.84	−2.49[b]	x_2x_3	9.33	2.11[b]
x_2^2	−0.07	−1.84[b]	x_3x_4	−22.6	−7.29[a]
–	–	–	x_2^2	0.23	1.82[b]
–	–	–	x_3^2	315.37	5.49[a]

$y_{\text{Mechanized}} \sim 1 + x_1 + x_2 + x_4 + x_5 + x_3x_5 + x_1^2 + x_2^2$ ($R^2 = 0.73$).
$y_{\text{Semi-mechanized}} \sim 1 + x_1 + x_3 + x_4 + x_1x_2 + x_1x_4 + x_2x_3 + x_3x_4 + x_2^2 + x_3^2$ ($R^2 = 0.78$).
a Indicates significance at 1% probability level.
b Indicates significance at 5% probability level.

term of human labor and machinery costs had a reverse effect on the income in mechanized systems. In examining the best model for the semi-mechanized system, all coefficients except for the coefficient of machinery cost input (x_2) were significant at the 1% and 5% probability levels. Although the effect of the coefficient of this input on the model was not significant, its interaction with the human labor (x_1) and diesel fuel (x_3) coefficients as well as the second-order term of the machinery input was significant. The R^2-value was determined to be 0.88 for the model, which indicates the good ability of the model to determine income in semi-mechanized systems. Moreover, according to coefficients, it can be concluded that human labor, machinery, chemical cost inputs and interaction of human labor and chemical cost, as well as machinery and fuel cost as well as second-order term of machinery and diesel fuel costs had a direct effect on the income, while diesel fuel cost input, interaction of human labor and machinery costs, as well as diesel fuel and chemical costs, had a reverse effect on the income in semi-mechanized systems.

3.3.2. Percentage of contribution

Using the sum of squares obtained from the ANOVA table, the percentage of contribution (PC) for each variable was calculated for the selected model. The results of the PC of the variables for the selected models in both mechanized and semi-mechanized systems are shown in Fig. 2. The results of the PC of the variables for the selected mechanized model



(a). Mechanized model (PC of Model = 76.95%) **(b).** Semi-mechanized model (PC of Model = 77.87%)

Fig. 2 – Percentage of contributions for mechanized and semi-mechanized models.

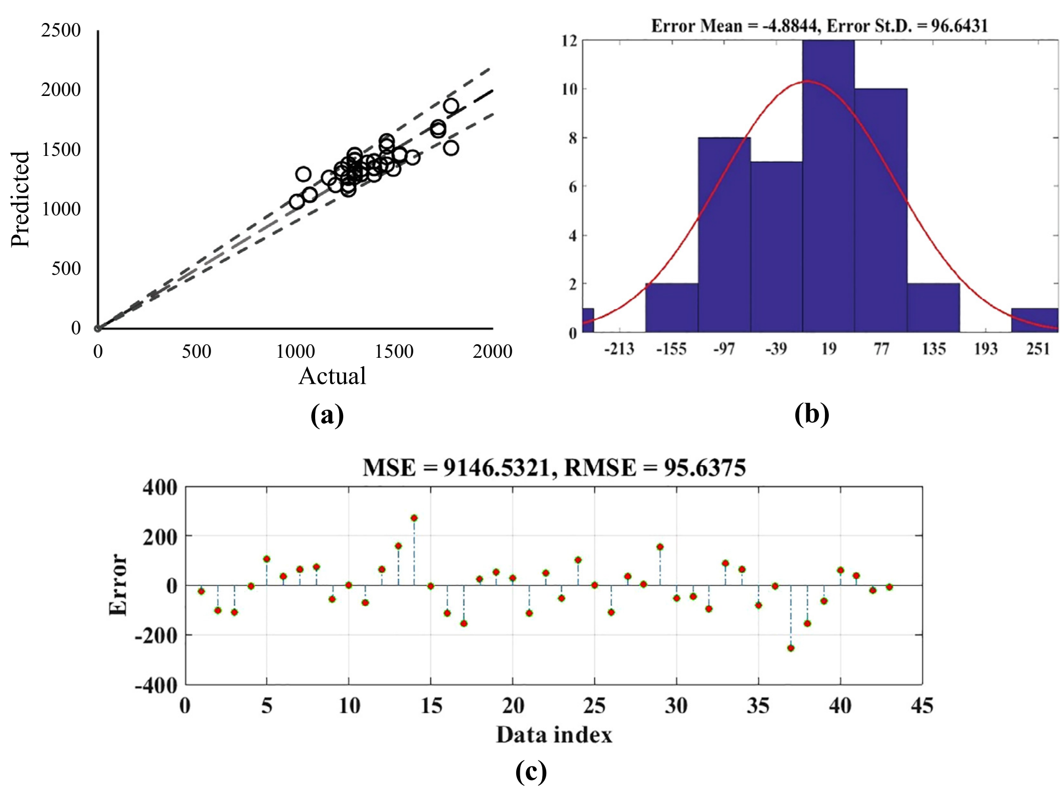


Fig. 3 – Diagnostics plots of the model adequacy for the mechanized system.

showed that the terms of diesel fuel cost and chemical inputs had the highest contributions of 20% and 14%, respectively, and the second-order term of the machinery input accounting for 3% of the model had the lowest contribution. The error also contributed about 23% to the model. The results of the PC of the variables for the semi-mechanized model showed that the diesel fuel cost with 19% and the interactive effect of seed costs and chemical inputs with 1% had the highest and lowest contribution to the model, respectively.

3.3.3. *Diagnostics of the model adequacy*

In this section, the accuracy of the selected model for both mechanized and semi-mechanized production systems (Fig. 3) is investigated. According to Fig. 3(a), it can be seen that the predicted values are very close to actual values, and almost all points are located near the 45° line, which indicates the good performance of the model. Therefore, the selected model had been able to accurately predict the income in the mechanized system at a high level. Fig. 3(b) specifies how to distribute the error, according to which the error distribution in the training set followed a normal distribution. In Fig. 3(c), the difference between actual and predicted values for each sample is given. According to this figure, the largest difference in the mechanized system was less than 250 $, but most of the difference was between 100 and 150 $.

The results of the accuracy investigation of the selected model for the semi-mechanized system are illustrated in Fig. 4. According to Fig. 4(a), the predicted values of the model obtained in the semi-mechanized production system were very close to the actual values, and almost all points were located near the 45° line, implying the good performance of the model. Fig. 4(b) specifies how to distribute the error in a semi-mechanized system model, according to which the error in the training set was distributed normally. In Fig. 4(c), the difference between the actual and the predicted values for each sample is given according to which the maximum difference in the semi-mechanized system was about 200 $, but most of the difference was between −100 and 100 $.

3.3.4. *Analysis of actual and predicted values*

The results of the statistical properties of actual and predicted values for both mechanized and semi-mechanized production systems are shown in Table 9. The evaluation of the predicted and actual values for the model obtained in both production systems revealed minor differences in values indicating the acceptable performance of the selected model. The difference between the average of the actual and predicted data was less than USD 5, reflecting the high accuracy of the model presented in both mechanized and semi-mechanized systems. Moreover, according to Table 9, in the mechanized system, the model tended to overestimate the income and the minimum and maximum values predicted by the model was determined to be greater than the actual values. But in the semi-mechanized system, the model tended to underestimate the income and the minimum and maximum value predicted by the model was determined to be smaller than the actual values.

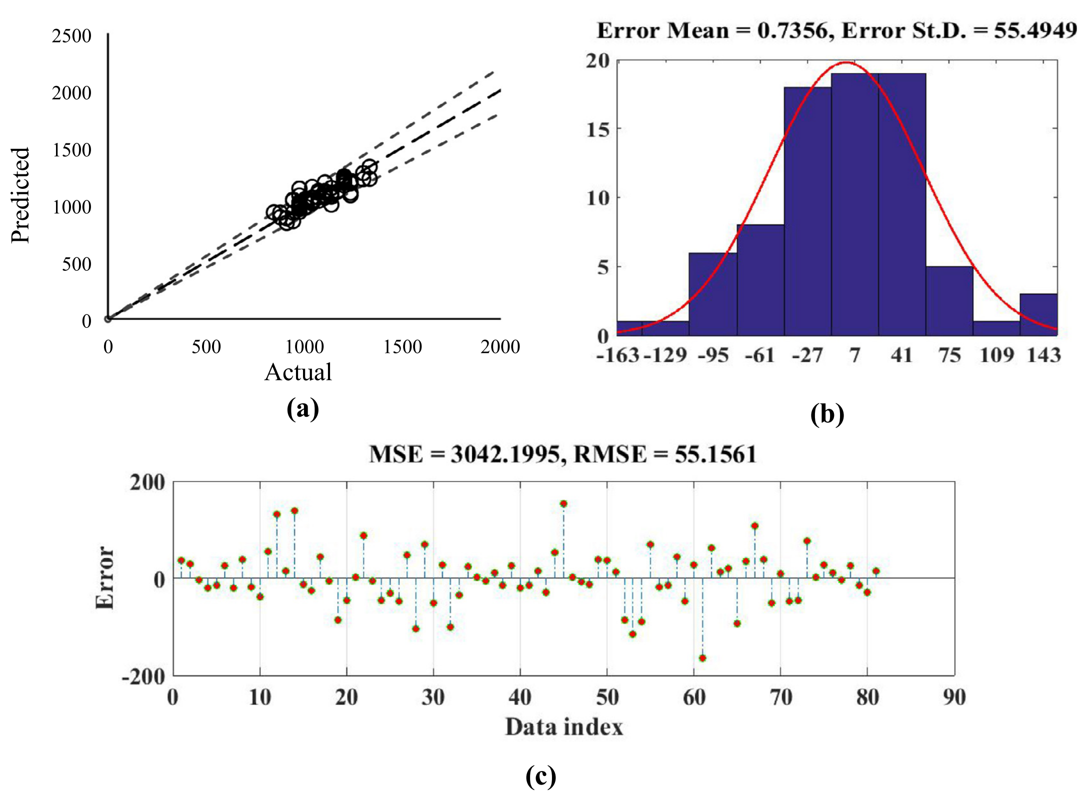


Fig. 4 – Diagnostics plots for the model adequacy for semi-mechanized system.

Table 9 – Statistical properties of the actual and predicted variables for the mechanized system.

Variable		Average	SD	Sum	Min	Max	Kurtosis
	Mechanized system						
Yield	Actual	1359.71	185.20	58467.50	1007.50	1787.50	3.23
	Predicted	1364.59	154.92	58677.53	1063.67	1866.82	4.54
	Semi-mechanized system						
Yield	Actual	1074.91	119.72	87067.50	845.00	1332.50	2.45
	Predicted	1074.17	106.94	87007.92	841.37	1330.29	2.72

4. Conclusion

Economic modeling of crop production is complex in the agricultural sector. The present study evaluated various multiple linear regression models including Cobb-Douglas, linear, 2FI, quadratic, and pure-quadratic to develop an optimal model for mechanized and semi-mechanized rain-fed wheat production systems. The results highlighted that wheat production cost in the semi-mechanized system was higher than that of the mechanized system. In the semi-mechanized system, the average cost of human labor and seed was about 60% higher than that of the mechanized system. In both systems, machinery had the highest production costs. The cost of using harrow disk and fertilizer spreader in the semi-mechanized system was about twice more than that of the mechanized system. In the study of economic indices, the net return for farms with the mechanized system was higher than that in farms using the semi-mechanized system. The average benefit to cost ratio was 3.46 for the mechanized production system and 2.40 for the semi-mechanized production system, indicating greater profitability of farms with mechanized production systems. The results of the evaluation of five types of regression models including Cobb-Douglas, linear, 2FI, quadratic, and pure-quadratic for mechanized and semi-mechanized production systems presented that the R^2-value in the Cobb-Douglas model was higher than that of the quadratic model, while RMSE and MAPE values for the quadratic model were determined to be less than that of the Cobb-Douglas model in both systems. Therefore, the quadratic model was considered the best model to investigate the relationship between input costs and the income in both mechanized and semi-mechanized systems. The results of the percentage of contribution of variables for the mechanized and semi-mechanized systems showed that the diesel fuel consumption had the highest contribution accounting for 20 and 19 percent, respectively. In examining predicted and actual values for the model obtained in both production systems, there were minor differences in values indicating the acceptable performance of the selected models.

Declaration of Competing Interest

The authors declare that there is no conflicts of interest.

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