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Full Length Research Paper

Energy efficiency improvement in forage maize production using data envelopment analysis approach

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The objective of this study was to apply the non–parametric method of data envelopment analysis (DEA) to analyze the efficiency of farmers, discriminate efficient farmers from inefficient ones and to identify wasteful uses of energy for forage maize production in Zanjan province, Iran. This method was used based on eight energy inputs including human labour, machinery, diesel fuel, fertilizers, farmyard manure, biocide, electricity and seed energy and single output of forage maize yield. From this study, the following results were obtained: The average values of technical, pure technical and scale efficiency scores of farmers were 0.843, 0.957 and 0.894, respectively. Also, energy saving target ratio for forage maize production was calculated as 7.64%, indicating that by following the recommendations resulting from this study, about 5931.25 MJ ha^{-1} of total input energy could be saved while holding the constant level of forage maize yield. Moreover, the contribution of electricity input from total saving energy was 44.01% which was the highest share followed by chemical fertilizers (23.06%) energy inputs. Optimization of energy use improved the energy use efficiency, energy productivity and net energy by 7.98, 7.59 and 12.21%, respectively. Also, the total CO_2 emissions in forage maize production can be reduced by 5.35% to the value of 1472018 t/ha.

Key words: Data envelopment analysis, optimization, energy efficiency, forage maize.

INTRODUCTION

Energy is one of the most important material bases for the economic growth and social development of a country or region. Scientific forecasts and analysis of energy consumption will be of great importance for the planning of energy strategies and policies (Lianga et al., 2007). The enhancement of energy efficiency (EE) not only helps in improving competitiveness through cost reduction but also results in minimized energy-related environmental pollution, thus, positively contributing towards sustainable development (Nagesha, 2008).

In an economic sector, energy and other sources have been used intensively. Therefore, both the natural resources are rapidly decreasing and the amount of contaminants is considerably increasing. The best way to lower the environmental bhazard of energy use is to increase the energy use efficiency. Efficient use of energy is one of the principal requirements of sustainable agriculture (Esengun et al., 2007). The energy input-output analysis is usually made to determine the energy efficiency and environmental aspects. This analysis will determine how efficient the energy is used. In recently years, many researchers have investigated the energy use for agricultural crop production (Esengun et al., 2007; Banaeian et al., 2010; Mohammadi et al., 2010; Mobtaker et al., 2010; Rafiee et al., 2010).

The energy ratio and specific energy of farmers in crop production systems are indices, which can define the efficiency and performance of farms. Technical efficiency (weighted output energy to weighted input energy ratio) is

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Table 1. Energy equivalent of inputs and output in agricultural production.

Item (unit)	Unit	Energy equivalent (MJ unit^{-1})	References
A. Inputs			
1. Human labour	h	1.96	Rafiee et al. (2010), Mohamadi et al. (2010)
2. Machinery	h	64.80	Kizilaslan (2009), Hatirli et al. (2006)
3. Diesel fuel	l	56.31	Kizilaslan (2009), Mohammadi et al. (2010)
4. Chemical fertilizers			
(a) Nitrogen	kg	66.14	Yilmaz et al. (2005), Esengun et al. (2007)
(b) Phosphate (P_2O_5)	kg	12.44	Yilmaz et al. (2005), Esengun et al. (2007)
(c) Potassium (K_2O)	kg	11.15	Yilmaz et al. (2005), Esengun et al. (2007)
5. Farmyard manure	kg	0.30	Singh (2002)
6. Biocide	kg	120	Mohammadi et al. (2010)
7. Electricity	kWh	11.93	Ozkan et al. (2004)
8. Seed (hybrid)	kg	100	Kitani (1999)
B. Output			
1. Forage maize (DM*)	kg	10.3	Phipps et al. (1976)

another way to explain the efficiency of farmers (Nassiri and Singh, 2009). Data envelopment analysis (DEA) is a non-parametric technique of frontier estimation which has been used and continues to be used extensively in many settings for measuring the efficiency and benchmarking of decision making units (DMUs) (Adler et al., 2002). In recent years, many authors like Chauhan et al. (2006) have applied DEA in agricultural researches approach to determine the efficiencies of farmers with regard to energy use in rice production activities in India. The results revealed that, on the average, about 11.6% of the total input energy could be saved if the farmers follow the input package recommended by the study. Nassiri and Singh (2009) applied DEA technique to determine the efficiencies of farmers with regard to energy use in paddy producers in Punjab state (India). Results revealed that small farmers had high energy–ratio and low specific energy requirement as compared to larger ones at paddy farms. Although, there was high correlation between technical efficiency and energy–ratio, however, comparison between correlation coefficient of farmers in different farm categories and different zones showed that energy–ratio and specific energy are not enhanced indices for explaining all kinds of the technical, pure technical and scale efficiency of farmers. Banaeian et al. (2010) applied the DEA technique to analyze the efficiencies of walnut producers in Hamedan province of Iran. Results revealed 7745 MJ ha^{-1} of the total input energy could be saved if the producers follow the input package recommended by the study. Mousavi–Avval et al. (2011b) employed the DEA technique to analyze the efficiencies of apple producers in Tehran province of Iran. Results indicated that 11.29% of total energy input could be saved if the recommendations of this study are followed. Mohammadi et al. (2011) used DEA approach to analyze the energy efficiency of farmers and to identify the wasteful uses of energy in kiwifruit production in Iran. Results showed that 12.17% of input energy could be saved if the farmers follow the results recommended by this study. Also, optimization of energy use improved the energy use efficiency, specific energy and net energy by 13.86, 12.17 and 22.56%, respectively.

Based on the literature, there was no study on optimization of energy inputs for forage maize production in Iran. So, the aims of this research were to specify energy use pattern for forage maize production, analyze the efficiencies of farmers, rank efficient and inefficient ones and to identify target energy requirement and wasteful uses of energy from different inputs for forage maize production in Zanjan province of Iran.

MATERIALS AND METHODS

The investigation was conducted on a forage maize farm in Zanjan province which is located the north west of Iran within 35° 35′ and 37° 15′ north latitude and 47° 10′ and 49° 28′ east longitude (Anonymous, 2011). In this study, we used the DEA approach to analyze the data for improvement of the energy efficiency in forage maize production. Data were collected from 45 forage maize farms using a face to face questionnaire. Sample farms were randomly selected from the villages in the study area. The simple random sampling method was used to determine survey (Kizilaslan, 2009).

Information was sought on inputs used for production of forage maize including human labour, machinery, diesel fuel, chemical fertilizer, farmyard manure, biocide, electricity and seeds, and the yield as an output. These inputs and output data were multiplied by the coefficient of energy equivalent. The energy equivalents given in Table 1 were used to calculate the input amounts. Also, each farmer called a Decision Making Unit (DMU). Table 2 presents the amounts of energy inputs and output in forage maize production. As can be seen, there was a wide variation in the quantity of energy inputs and output for forage maize production indicating that there

Table 2. Amounts of energy inputs and output in forage maize production.

Item (unit)	Mean energy equivalent (MJ ha^{-1})	SD	Max	Min
Inputs				
Human labour	544.29	86.37	604.50	445.41
Machinery	2073.60	910.14	2805.83	1034.55
Diesel fuel	22918.17	1712.87	23921.88	20941.95
Chemical fertilizers	14378.02	2052.01	16378.02	12378.03
Farmyard manure	4500.00	500.00	5000.00	4000.00
Biocides	528.00	98.85	590.00	414.00
Electricity	29722.76	15480.08	47424.53	18670.70
Seeds	2925.00	87.37	3000.00	2830.00
Total energy input	77589.84	13236.88	92855.75	69768.64
Output				
Forage maize	126175.00	14342.54	141635.30	113300.00

is a great scope for optimization of energy usage and improving the efficiency of energy consumption for forage maize production in the region.

DEA has two models including CCR and BCC models. The CCR DEA model assumes constant returns to scale. It measures the technical efficiency by which the DMUs are evaluated for their performance relative to other DMUs in a sample (Cooper et al., 2007). The BCC DEA model assumes variable returns to scale conditions. Therefore, this model calculates the technical efficiencies of DMUs under variable return to scale conditions. It decomposes the technical efficiency into pure technical efficiency for management factors and scale efficiency for scale factors (Mousavi–Avval et al., 2011b).

Technical efficiency

The technical efficiency (*TE*) can be expressed generally by the ratio of sum of the weighted outputs to sum of weighted inputs. The value of technical efficiency varies between zero and one; where a value of one implies that the DMU is a best performer located on the production frontier and has no reduction potential. Any value of *TE* lower than one indicates that the DMU uses inputs inefficiently (Mousavi–Avval et al., 2011b). Using standard notations, the technical efficiency can be expressed mathematically as the following relationship:

$$TE_j = \frac{u_1 y_{1j} + u_2 y_{2j} + \cdots + u_n y_{nj}}{v_1 x_{1j} + v_2 x_{2j} + \cdots + v_m x_{mj}} = \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{s=1}^{m} v_s x_{sj}} \quad (1)$$

where, u_r, is the weight given to output n; y_r, is the amount of output n; v_s, is the weight given to input n; x_s, is the amount of input n; r, is number of outputs ($r = 1, 2, \ldots, n$); s, is number of inputs ($s = 1, 2, .., m$) and j, represents jth of DMUs ($j = 1, 2, \ldots, k$). To solve Equation 1, linear program (LP) was used, which was developed by Charnes et al. (1978):

$$\text{Maximize} \quad \theta = \sum_{r=1}^{n} u_r y_{ri} \quad (2)$$

$$\text{Subjected to} \quad \sum_{r=1}^{n} u_r y_{ri} - \sum_{s=1}^{m} v_s x_{sj} \le 0 \quad (3)$$

$$\sum_{s=1}^{m} v_s x_{sj} = 1 \quad (4)$$

$$u_r \ge 0, \quad v_s \ge 0, \quad and \quad (i \;\; and \;\; j = 1, 2, 3, \ldots, k) \quad (5)$$

where, θ is the technical efficiency and i represents ith DMU (it will be fixed in Equations 2 and 4 while j increases in Equation 3. The aforementioned model is a linear programming model and is popularly known as the CCR DAE model which assumes that there is no significant relationship between the scale of operations and efficiency (Avkiran, 2001). So, the large producers are just as efficient as small ones in converting inputs to output.

Pure technical efficiency

Pure technical efficiency is another model in DEA that was introduced by Banker et al. (1984). This model called BCC and calculates the technical efficiency of DMUs under variable return to scale conditions. Pure Technical efficiency could separate both technical and scale efficiencies. The main advantage of this model is that scale inefficient farms are only compared to efficient farms of a similar size (Bames, 2006). It can be expressed by Dual Linear Program (DLP) as follows (Mousavi–Avval et al., 2011b):

$$\text{Maximize} \quad z = uy_i - u_i \quad (6)$$

$$\text{Subjected to} \quad vx_i = 1 \quad (7)$$

$$-vX + uY - u_0 e \le 0 \quad (8)$$

$$v \ge 0, \quad u \ge 0, \quad \text{and} \quad u_0 \;\; \text{free in sing} \quad (9)$$

where, z and u_0 are scalar and free in sign. u and v are output and

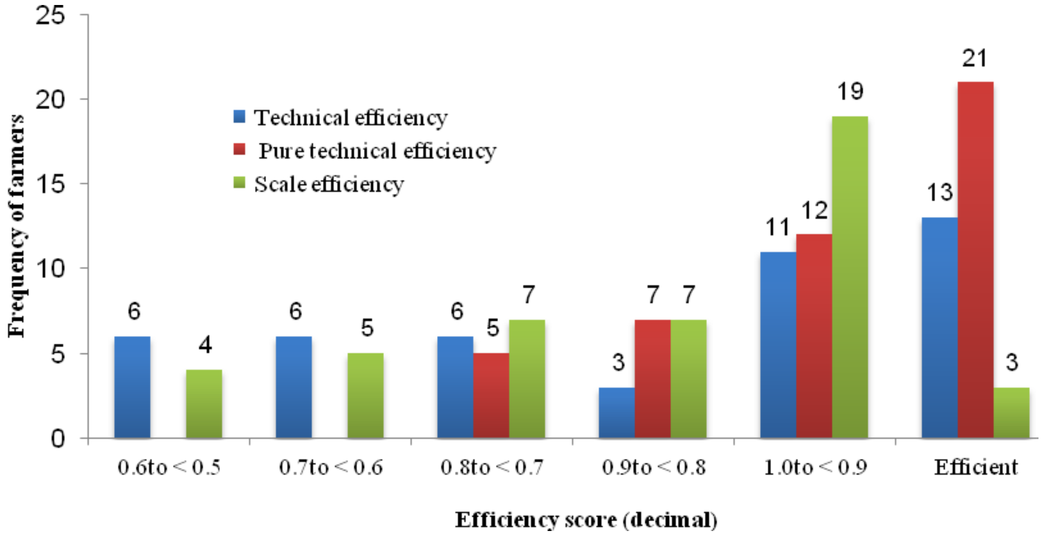

Figure 1. Efficiency score distribution of Forage maize producers.

inputs weight matrixes, and *Y* and *X* are corresponding output and input matrixes, respectively. The letters x_i and y_i refer to the inputs and output of *i*th DMU.

Scale efficiency

Scale efficiency shows the effect of DMU size on efficiency of system. Simply, it indicates that some part of inefficiency refers to inappropriate size of DMU, and if DMU moved toward the best size the overall efficiency (technical) can be improved at the same level of technologies (inputs) (Nassiri and Singh, 2009). If a DMU is fully efficient in both the technical and pure technical efficiency scores, it is operating at the most productive scale size. If a DMU has the full pure technical efficiency score, but a low technical efficiency score, then it is locally efficient but not globally efficient due to its scale size. Thus, it is reasonable to characterize the scale efficiency of a DMU by the ratio of the two scores (SarIca and Or, 2007). The relationship among the scale efficiency, technical efficiency and pure technical efficiency can be expressed as (Chauhan et al., 2006):

$$\text{Scale efficiency} = \frac{\text{Technical efficiency}}{\text{Pure technical efficiency}} \quad (10)$$

In the analysis of efficient and inefficient DMUs, the energy saving target ratio (ESTR) index can be used which represents the inefficiency level for each DMUs with respect to energy use. The formula is as follows (Hu and Kao, 2007):

$$ESTR_j = \frac{(\text{Energy saving target})_j}{(\text{Actual energy input})_j} \quad (11)$$

Where energy saving target is the total reducing amount of input that could be saved without decreasing output level and *j* represents *j*th DMU. The minimal value of energy saving target is zero, so the value of ESTR will be between zero and unity. A zero ESTR value indicates the DMU on the frontier such as efficient ones and on the other hand for inefficient DMUs, the value of ESTR is larger than zero, means that energy could be saved. A higher ESTR value implies higher energy inefficiency and a higher energy saving amount (Hu and Kao, 2007). In order to calculate the efficiencies of farmers and discriminate between efficient and inefficient ones, the Microsoft Excel spread sheet and Frontier Analyst software were used.

RESULTS AND DISCUSSION

Efficiency estimation of farmers

The results of BCC and CCR DEA models are illustrated in Figure 1. The results revealed that many of the farms in the sample are operating at near or full efficiency for all the model specifications. These results are similar to the results of Fraser and Cordina (1999) and Mohammadi et al. (2011). From the total of 45 farmers considered for the analysis, 21 farmers (46.67%) had the pure technical efficiency score of 1. Moreover, from the pure technically efficient farmers, 13 farmers (28.89%) had the technical efficiency score of 1. From efficient farmers, 3 once had a scale efficiency of unity. From efficient farmers, 13 were the fully efficient farmers in both the technical and pure technical efficiency scores; indicating that they were globally efficient and operated at the most productive scale size; however, the remainder of 8 pure technically efficient farmers were only locally efficient ones; it was due to their disadvantageous conditions of scale size. From inefficient farmers, 11 and 12 have their technical and pure technical efficiency scores in the 0.9 to 0.99 range. It means that the farmers should be able to produce the same level of output using their efficiency score of its current level of energy input when compared to its benchmark which is constructed from the best performers with similar characteristics.

The summarized statistics for the three estimated measures of efficiency are presented in Table 3. The

Table 3. Average technical, pure and scale efficiency of forage maize farmers.

Particular	Average	SD	Min	Max
Technical efficiency	0.843	0.218	0.531	1
Pure technical efficiency	0.957	0.138	0.751	1
Scale efficiency	0.894	0.157	0.582	1

Table 4. Optimum energy requirement and saving energy for forage maize production.

Input	Optimum energy requirement (MJ ha^{-1})	Saving energy (MJ ha^{-1})	Saving energy (%)	Contribution to the total savings energy (%)
Human labour	520.21	24.08	4.42	0.41
Machinery	1995.11	78.49	3.79	1.32
Diesel fuel	21711.18	1206.99	5.27	20.35
Chemical fertilizers	13010.15	1367.87	9.51	23.06
Farmyard manure	3957.21	542.79	12.06	9.15
Biocides	502.51	25.49	4.83	0.43
Electricity	27112.22	2610.54	8.78	44.01
Seed	2850.00	75.00	2.56	1.27
Total energy	71658.59	5931.25	7.64	100

results revealed that the average values of technical, pure technical and scale efficiency scores were 0.843, 0.957 and 0.894, respectively. Moreover, the technical efficiency varied from 0.531 to 1, with the standard deviation of 0.218, which was the highest variation between those of pure technical and scale efficiencies. The wide variation in the technical efficiency of farmers implies that all the farmers were not fully aware of the right production techniques or did not apply them at the proper time in the optimum quantity (Mohammadi et al., 2011).

Mohammadi et al. (2011) applied DEA technique to determine the efficiencies of farmers in kiwifruit production in Iran. They reported that, the technical, pure technical and scale efficiency scores were as 0.942, 0.993 and 0.948, respectively. In another study, the efficiency of soybean production was analyzed and these efficiency indices were reported 0.853, 0.919 and 0.926, respectively (Mousavi–Avval et al., 2011a).

Optimum energy requirement and saving energy

The optimum energy requirement and saving energy of various farm inputs for forage maize productions based on the results of BCC model are given in Table 4. The results revealed that the total optimum energy requirement for forage maize production was 71658.59 MJ ha^{-1}. Also, the percentage of total saving energy in optimum requirement over total actual use of energy was calculated as 7.64%, indicating that by following the recommendations that resulted from this study. On the average, about 5931.25 MJ ha^{-1} of total input energy could be saved while holding the constant output level of forage maize yield. In a research conducted in Tehran province of Iran, energy use and economic evaluation were considered for corn silage production. The results showed that total energy requirement for corn silage production was 68,928 MJ ha^{-1} (Pishgar et al., 2011). Singh et al. (2004) concluded the existing level of productivity in wheat production in Punjab and reported that it could be achieved by 22.3, 20.8, 9.8, 7.1 and 15.9% reducing the energy input over the actual energy input in zones 1, 2, 3, 4 and 5, respectively. In another study, Mohammadi et al. (2011) reported that on the average, about 12% of the total input energy for kiwi fruit production in Iran could be saved.

In the last column of Table 4, the shares of the various sources from total input energy saving are presented. Results revealed that the highest contribution to the total saving energy was 44.01% for electricity followed by chemical fertilizers (23.06) and diesel fuel (20.35) energy inputs, respectively. Also, the shares of human labour, machinery, biocides and seed energy inputs were relatively low, indicating that they have been used in the right proportions by almost all the farmers. Mousavi–Avval et al. (2011a) reported that the contribution of electricity and seed energy inputs by 78.08 and 0.05% from total energy saving in soybean production were the highest and lowest, respectively.

The high contribution of saving electrical energy resulted from the low efficiency of ancient irrigation methods, which led to waste of a lot of water and energy in the form of electricity. The high contribution of fertilizer

Table 5. Improvement of energy indices for forage maize production.

Item	Unit	Present quantity	Optimum quantity	Difference (%)
Energy use efficiency	-	1.63	1.76	7.98
Energy productivity	kg MJ^{-1}	0.79	0.85	7.59
Specific energy	MJ kg^{-1}	1.27	1.17	-7.87
Net energy	MJ ha^{-1}	48585.16	54516.41	12.21
Direct energy	MJ ha^{-1}	53185.22 (68.55%)[a]	49343.61 (68.86%)	-7.22
Indirect energy	MJ ha^{-1}	24404.62 (31.45%)	22314.98 (31.14%)	-8.56
Renewable energy	MJ ha^{-1}	7969.29(10.27%)	7327.42 (10.23%)	-8.05
Non–renewable energy	MJ ha^{-1}	69620.55 (89.73%)	64331.17 (89.77%)	-7.60
Total energy input	MJ ha^{-1}	77589.84	71658.59 (100%)	-7. 64

[a] Numbers in parentheses indicate percentage of total optimum energy requirement.

Table 6. Greenhouse emission in forage maize production.

Input	Equivalent (Tg (CO_2) PJ^{-1})	Amount of CO_2 in present condition (ton)	Amount of CO_2 in optimum condition (ton)
Diesel fuel	0.0578	1324670	1254906
Machinery	0.071	147226	141653
fertilizers	0.0058	83393	75459
Total	-	1555289	1472018

energy inputs showed that, all of farmers were not fully aware of proper time and quantity of fertilizers usage. So, providing information to farmers can prevent loss of energy and also their harmful effects on environment.

Improvements of energy indices

The improvements of energy indices for forage maize production are presented in Table 5. Also, the distribution of inputs used in the production of forage maize according to the direct, indirect, renewable and non–renewable energy groups are given in Table 5. Energy use efficiency was calculated as 1.63 and 1.76 in the present and target use of energy, respectively, showing an improvement of 7.98%. Also, energy productivity, specific energy and net energy in target conditions were found to be 0.85 kg MJ^{-1}, 1.17 MJ kg^{-1} and 54516.41 MJ ha^{-1}, respectively. Pishgar et al. (2011) reported that in corn silage production, the energy ratio, energy productivity, specific energy and net energy were 2.27, 0.28 kg MJ^{-1}, 3.76 MJ kg^{-1} and 79,452 MJ ha^{-1} respectively.

Mohammadi et al. (2010) reported on the optimization of energy inputs in kiwi fruit production and that the energy use efficiency by increasing of 13.86% can be improved to the value of 1.75. In another study, energy use efficiency for apple production was calculated as 1.16 and 1.31, in present and target use of energy, respectively, showing an improvement of 12.93% (Mousavi–Avval et al., 2011b).

Environmental aspects of energy saving

Optimization of energy inputs in forage maize has also some environmental advantages. One of these advantages is decreasing of greenhouse gas (GHG) emissions. The diesel fuel combustion can be expressed as fossil CO_2 emissions with equivalent of 2764.2 g L^{-1} (Pishgar et al., 2011). Also, the machinery and fertilizer supply terms can be expressed in terms of the fossil energy required to manufacture and transport them to the farm with CO_2 equivalents of 0.071 Tg PJ^{-1} and 0.0058 Tg PJ^{-1} for machinery and chemical fertilizers, respectively. The results of GHG emissions in present and target use of energy are presented in Table 6. The results of this study revealed that by optimization of energy inputs in forage maize production, the total CO_2 emissions in forage maize production can be reduced by 5.35% to the value of 1472018 t/ha. This can reduce some environmental problems such as increase in global warming and non-sustainability.

Conclusion

In this study, the non–parametric method of DEA was used to analyze the efficiencies of forage maize producers in Zanjan province of Iran in energy points of view. Based on the results of the investigations, the following conclusions were drawn:

1. The average values of technical, pure technical and scale efficiency scores of farmers were found to be 0.843, 0.957 and 0.894, respectively,
2. The energy saving target ratio for forage maize production was calculated as 7.64%, indicating that by following the recommendations resulted from this study, about 5931.25 MJ ha^{-1} of total input energy could be saved while holding the constant level of forage maize yield,
3. The electrical energy had the highest potential for improvement by 44.01%, followed by fertilizer and diesel fuel energy inputs,
4. The comparative results of energy indices revealed that by optimization of energy consumption, energy efficiency, energy productivity and net energy with respect to the actual energy use can be increased by 7.98, 7.59 and 12.21%, respectively,
5. The total CO_2 emission was calculated as 1472018 t/ha in optimum condition, which was 5.35% less than that of present condition.

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