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Using DEA Models to Measure Energy Efficiency of Grape Production

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Abstract

Energy ratio and technical efficiency are the ways to explain the efficiency of farmers in crops production. The objective of this study was the application of non-parametric method of Data Envelopment Analysis (DEA) to analyze the efficiency of orchards, discriminate efficient farmers from inefficient ones and to identify wasteful uses of energy for grape production in Hamadan province, Iran. For this purpose, data were collected from 48 farmers by using a face to face questionnaire. The results revealed that the average value of technical, pure technical and scale efficiency scores of orchards were about 0.74, 0.86 and 0.84, respectively. The contribution of saving energy for chemical fertilizers was the highest and followed by diesel fuel & electricity with shares of 61.7 and 28.7 percent, respectively. The total energy savings calculated to be 14.3 percent of total input energy. Optimization of energy use improved the energy use efficiency, energy productivity and net energy by 16.8, 13.3 and 19.6 percent, respectively.

Keywords:
Efficiency; energy inputs; optimization; Vitis vinifera L.

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INTRODUCTION

Grapevine (*Vitis vinifera* L.) is one of the oldest crops and the only Mediterranean/Western Asiatic representative of the *Vitis* genus. Its domestication created cultivars suited to a wide diversity of climates and tastes. Iran is very rich in grapevine biodiversity and different cultivars cultivated in more than 20 provinces. Most of the vineyards are located in the Qazvin, West-Azerbaijan, Fars, Khorasan and Hamadan provinces of Iran on the flat and slopping areas (Rasouli, 2012).

Energy use in agricultural production has become more intensive due to the use of fossil fuel, chemical fertilizers, pesticides, machinery and electricity to provide substantial increases in food production. However, more intensive energy use has brought some important human health and environment problems (Yilmaz et al., 2005). Efficient use of energy resources is vital in terms of increasing production, productivity, competitiveness of agriculture as well as sustainability of rural living. Energy auditing is one of the most common approaches to examining energy efficiency and environmental impact of the production system (Hatirli et al., 2006).

Data envelopment analysis (DEA) is a non-parametric technique of frontier estimation that determines both the relative efficiency of a number of decision making units (DMUs) and targets for their improvement (Malana & Malano, 2006). DEA allows the decision makers to simultaneously consider multiple inputs and outputs, where efficiency of each DMU is compared to that of an ideal operating unit rather than to the average performance. The decision makers can differentiate efficient and inefficient DMUs and address the sources and amount of inefficiency for each of the inefficient ones (Angulo-Meza & Lins, 2002; Zhang et al., 2009). In recent years, many authors have applied DEA in agricultural research:

Haj Agha Alizade & Taromi (2014) applied DEA approach to determine the efficiency of orchards with regard to energy use in grape production in Zanjan, Iran. In this study, technical, pure technical and scale efficiency of orchards were investigated. The DEA method was applied based on seven inputs including human labor, machinery, diesel fuel, fertilizers, chemicals, water for irrigation, electricity and with single output of grape yield. Similarly, in another study, Sattari-Yuzbashkandi et al. (2014) applied the DEA to investigate the technical efficiencies of open-field grape orchards in East-Azerbaijan of Iran. Mobtaker et al. (2012) used the data envelopment analysis to analyze the efficiency of farmers for alfalfa production. Energy saving target ratio for alfalfa production was calculated as 9.4 percent, indicating that by following the recommendations resulting from this study, about 75.9 GJ ha^{-1} of total input energy could be saved while holding the constant level of alfalfa yield. Pahlavan et al. (2012) used DEA approach to analyze the energy efficiency of rose production in Iran. The results revealed that the average pure technical, technical and scale efficiencies of farmers were about 0.8, 0.7 and 0.8, respectively. Moreover, by optimization of energy consumption in rose production energy use efficiency was increased from about 0.2 to 0.3. Also, the results revealed that by adopting the recommendations based on the present study, on an average, about 43.6 percent of the total input energy could be saved without reducing the rose yield. Taki et al. (2012) applied a parametric and non-parametric method to examine the energy equivalents of inputs and output, analyze the efficiency of farmers and to identify wasteful uses of energy in order to optimize the energy inputs for cucumber greenhouse production in Esfahan province of Iran. The results revealed that about 8.1 percent of the total input resources could be saved if the farmers follow the input package recommended by the DEA.

This paper presents an application of DEA to discriminate efficient grape producers from inefficient ones, recognize wasteful uses of energy inputs by inefficient farmers and suggest necessary quantities of different inputs to be used by each inefficient farmer from every energy source.

METHODOLOGY

The study was carried out in Hamadan province which located in the west of Iran, within 59° 33' and 49° 35' north latitude and 34° 47' and 34° 49' east longitude. The whole of vineyard area are approximately 20000 hectares in Hamadan province (MAJ, 2020). Data were collected from 48 commercial grape orchards, larger than 0.5 hectares, using a face to face questionnaire. A simple random sampling method was used to determine survey size and the orchards were chosen randomly. The minimum, average and maximum farms size were 0.5 and 12 hectares, respectively. The sample size was calculated using the Neyman technique as below (Yamane, 1967):

$$n = \frac{N * S^2 * t^2}{(N-1)d^2 + S^2 * t^2}$$

where n is the required sample size; N is the number of holding in target population; S is the standard deviation; t is the t-value at 95 percent confidence limit (1.96) and d is the acceptable error (permissible error 5 percent).

The amounts of the applied inputs were calculated per hectare, and multiplied by their energy equivalents (Table 1) to convert them to energy unit.

For assessing energy consumption efficiency of each farmer, DEA technique was used. DEA has two models including CCR and BCC models. The CCR DEA model assumes constant returns to scale (Cooper et al., 2007), while the BCC DEA model assumes variable returns to scale conditions (Mobtaker et al., 2012). This model was used by seven energy inputs, include: human labor, diesel fuel, electricity, chemical fertilizer, farmyard manure, pesticides and water for irrigation and one output of grape fruit.

Technical efficiency

Technical efficiency (global efficiency) is the efficiency in converting inputs to outputs. It exists when it is possible to produce more outputs with the inputs used or to produce the present level of outputs with fewer inputs (Houshyar et al., 2012). It is basically a measure by which DMUs are evaluated for their performance relative to other DMUs in a sample (Mohammadi et al., 2011). The technical efficiency can be expressed mathematically as the following relationship:

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

Table 1

Energy Coefficients of Different Inputs and Outputs Used in Grape Production

Inputs/Output	Units	Energy coefficients (MJ unit^{-1})	Reference
Inputs			
Human labor	h	1.96	(Mohammadi et al., 2008)
Diesel fuel	L	56.31	(Singh, 2002)
Electricity	kWh	11.93	(Mobtaker et al., 2010)
Chemical fertilizers	kg		
Nitrogen (N)		66.14	(Sefeedpari, 2012)
Phosphate (P_2O_5)		12.44	(Esengun et al., 2007)
Potassium (K_2O)		11.15	(Esengun et al., 2007)
Farmyard manure	kg	0.3	(Singh & Mittal, 1992)
Pesticides	kg	120	(Singh, 2002)
Water for irrigation	m^3	1.02	(Acaroğlu, 1998)
Output			
Grape fruit	kg	11.8	(Singh, 2002)

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, . . ., n); s, is number of inputs (s = 1, 2, .., m) and j, represents jth of DMUs (j = 1, 2, . . ., k). For solving Eq. (1), the following linear program (LP) was used, which developed by (Charnes et al., 1978):

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

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

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

$$u_r \geq 0,\ v_s \geq 0,\ and\ (I\ and\ j = 1, 2, 3, \ldots, k) \quad (5)$$

where, θ is the technical efficiency and i represents ith DMU (it will be fixed in Eqs. (2) and (4) while j increases in Eq. (3)).The above model is a linear programming model and is popularly known as the CCR DEA model (Avkiran, 2001).

Pure technical efficiency

This model was introduced by (Banker et al., 1984) and calculates the technical efficiency of DMUs under variable return to scale conditions. This model is also known as the BCC model and can be expressed by Dual Linear Program (DLP) as follows (Houshyar et al., 2012):

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

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

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

$$v \geq 0,\ u \geq 0\ and\ u_0\ free\ in\ sign \quad (9)$$

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

Scale efficiency

Scale efficiency shows the effect of conditions on the DMU inefficiency (Houshyar et al., 2012). The relationship among the scale efficiency, technical efficiency and pure technical efficiency can be expressed as (Chauhan et al., 2006):

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

In the analysis of efficient and inefficient DMUs the Energy Saving Target Ratio (ESTR) index was used which represents the inefficiency level for each DMUs with respect to energy use. The formula is as follow (Hu & Kao, 2007):

$$ESTR_j = \frac{(Energy\ \ Saving\ \ Target)_j}{(Actual\ \ Energy\ \ Input)_j} \quad (11)$$

where energy saving target is the total reducing amount of input that could be saved without decreasing output level and j represents jth DMU.

RESULT AND DISCUSSION

The average energy equivalents of inputs used in grape production and their standard deviation are shown in Table 2. The collected data revealed that 853 h of human labor are required per hectare of grape production in the research area. The total energy used in various farm operations during grape production was 33873.8 MJ ha^{-1}, while the total energy output was 58622.4 MJ ha^{-1}. The highest average energy consumption of inputs was for chemical fertilizers (17491.7 MJ ha^{-1}) which were accounted for about 51.6 percent of the total energy input. The shares of nitrogen, phosphorus and potassium energy were around 38.6 percent, 7.4 percent and 5.6 percent, respectively, from the total energy. Ozkan et al. (2007) reported that the highest energy consumption of inputs in grape production in Turkey was for electricity, followed by chemical fertilizers (Ozkan et al., 2007).

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Table 2
Amounts of Energy Inputs and Output in Grape Production

Item (unit)	*Total energy equivalent (MJ ha^{-1})*	*S.D.*	*Max.*	*Min.*
Inputs				
1. Human labor	1671.9	846.9	4900.0	294.0
2. Diesel fuel & electricity	8900.7	13178.7	78655.8	145.7
3. Chemical fertilizers	17491.7	39735.5	224325.0	0.0
4. Farmyard manure	4761.9	4594.6	18000.0	0. 0
5. Pesticides	170.4	321.6	1440.0	0.0
6. Water for irrigation	877.2	1004.8	6609.6	55.1
Total energy input	33873.8	44143.4	238864.2	2829.3
Output				
1. Grape fruit	58622.4	55206.2	283200.0	5900. 0

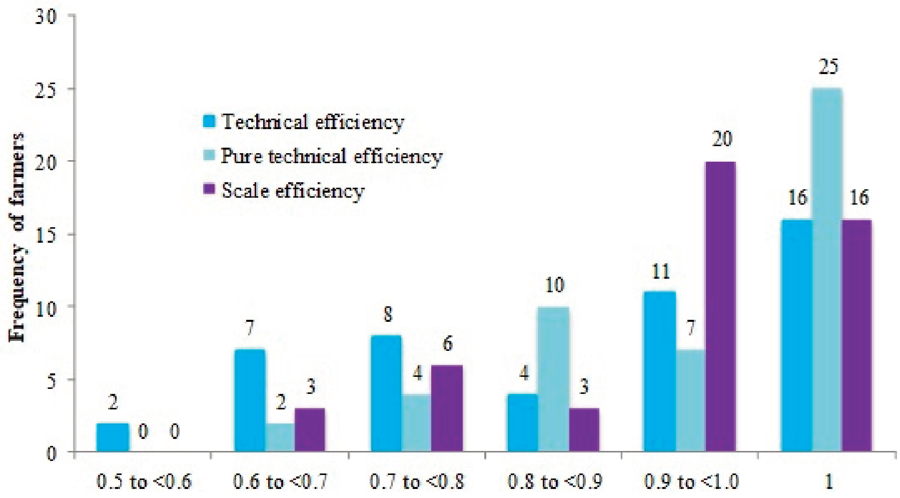

Figure 1. Efficiency Score Distribution of Grape Producers

Results also showed that pesticides are the least demanding energy input for grape production with 170.4 MJ ha^{-1} (only 0.5% of the total sequestered energy) follow by diesel fuel (788.3 MJ ha^{-1}, 2.3%).

The standard deviation of energy inputs is presented in column 3 of Table 2. As can be seen, there was a wide variation in the quantity of energy inputs and output for grape production; indicating that there is a great scope for optimization of energy usage and improving the efficiency of energy consumption for grape production in the region.

Results obtained by the application of the input-orientated BCC and CCR DEA models are illustrated in Figure 1. The results revealed that from the total of 48 farmers considered for the analysis, 25 farmers had the pure technical efficiency score of 1. Moreover, from the pure technically efficient farmers 16 farmers had the technical efficiency score of 1. These 16 farmers 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 remainders of 9 pure technically efficient farmers were only locally efficient ones; it was due to their disadvantageous conditions of scale size. On the other hand, these results imply that there is not an efficient scale size for the grape production and; so there is a potential productivity earned by achieving the optimal size of farms under study. Moreover, from efficient farmers 16 ones had a scale efficiency of one.

The average values (for all 48 farmers considered) of technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SE) are presented in Table 3. The results revealed that the average values of these indexes were 0.74, 0.86 and 0.84, respectively.

Table 4 shows the optimum energy requirement for grape production, based on the results of BCC model. Using the information of this table, it is possible to advise a producer regarding the better operating practices followed by his/her peers in order to reduce the input energy levels to the target values indicated in the analysis while achieving the output level presently achieved by him. The result showed optimum energy requirement for grape production was 29020.3 MJ ha^{-1}. The percentage of total saving energy in optimum requirement over total actual use of energy was calculated as 14.3 percent, indicating that by following the recommendations resulted from this study, on average, about 4853.5 MJ ha^{-1} of total input energy could be saved. In the last column of Table 4 the shares of the various sources from total input energy saving are presented. As can be seen, the highest contribution to the total saving energy was 61.7 percent for chemical fertilizers followed by diesel fuel & electricity (28.7%). This indicted that all of farmers were not fully aware of proper time and quantity of fertilizers usage and these input not used properly. The shares of human labor and pesticides energy inputs were relatively low, but pesticide energy consumption, despite its small share (due to its lower consumption), relatively has the greatest potential for energy savings, shows this input not used properly by almost all the farmers. Improperly use of pesticides can contaminate soil, water, turf, and other vegetation, therefore, can cause short-term adverse health effects, as well as chronic adverse effects that can occur months or years after exposure.

Table 3
Average Technical, Pure and Scale Efficiency of Grape Farmers

Particular	Average	S.D.	Min.	Max.
Technical efficiency	0.74	0.28	0.13	1
Pure technical efficiency	0.86	0.20	0.32	1
Scale efficiency	0.84	0.22	0.26	1

Table 4
Optimum Energy Requirement and Saving Energy for Grape Production

Input	Optimum energy requirement (MJ ha^{-1})	Energy saving (MJ ha^{-1})	Energy saving (%)	Contribution input to saving (%)
1. Human labor	1628.6	43.3	2.6	0. 9
2. Diesel fuel & Electricity	7509.6	1391.2	15.6	28.7
3. Chemical fertilizers	14495.0	2996.6	17.1	61.7
4. Farmyard manure	4482.0	279.9	5.9	5.8
5. Pesticides	135.5	34.9	20.5	0.7
6. Water for irrigation	769.7	107.5	12.2	2.2
Total energy	29020.3	4853.5	14.3	100

Sattari-Yuzbashkandi et al. (2014) used DEA model for optimizing of energy use in grape production and showed total optimum energy for grape production was as 60375.45, representing the 26.53 percent of input energies could be saved if the farmers follow the correct agricultural principles. Also, electrical (34.72%), chemical fertilizers (28.46%) and diesel fuel (23.88%) had highest contribution from total saving energy in their study (Sattari-Yuzbashkandi et al., 2014). Mousavi-Avval et al. (2011) used DEA model for soybean production. Their results showed energy saving target ratio for soybean production was 20.1 percent. Also they reported that the contribution of electricity and seed energy inputs by 78.1 percent and 0.05 percent from total energy saving in soybean production were the highest and lowest, respectively (Mousavi-Avval, Rafiee, Jafari, et al., 2011). In another study Mohammadi et al. (2011) reported that on an average, about 12 percent of the total input energy for kiwifruit production in Iran could be saved (Mohammadi et al., 2011).

Results of improvement of energy indices in grape production are presented in Table 5. As can be seen energy use efficiency is calculated as 1.7 in present use of energy, and 2.0 in target use of energy. This showed an improvement of 16.8 percent in energy use efficiency. Also energy productivity and net energy in target conditions were found to be 0.17 kg MJ^{-1} and 29602.1 MJ ha^{-1}, respectively. The distribution of energy consumption from direct, indirect, renewable and non-renewable energy resources was also investigated (Table 5). The results revealed that, total energy input could be classified as 9907.8 and 19112.5 MJ ha^{-1} in direct and indirect, and 6880.2 and 22140.1 MJ ha^{-1} in renewable and non-renewable energy forms, respectively, if all farms operated efficiently.

Mohammadi et al. (2011) reported by optimization of energy inputs in kiwifruit production the energy use efficiency can be improved by 13.9 percent (Mohammadi et al., 2011). 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 percent (Mousavi-Avval, Rafiee, & Mohammadi, 2011).

CONCLUSION

The aim of this study was the application of DEA approach to analyze the energy efficiency for grape production in Hamadan province, Iran. Based on the results of the investigations, the following conclusions were drawn:

From the total farmers considered, about 33 percent were globally efficient farmers and were operating at the most productive scale size; about 19 percent were only locally efficient, but not globally efficient; also the remaining 48 percent were inefficient farmers.

The average value of technical efficiency, pure technical efficiency and scale efficiency

Table 5
Improvement of Energy Indices for Grape Production

Items	Unit	Present quantity	Optimum quantity	Difference (%)
Energy use efficiency	–	1.7	2.0	16.8
Energy productivity	kg MJ^{-1}	0.15	0.17	13.3
Net energy	MJ ha^{-1}	24748.6	29602.1	19.6
Direct energy	MJ ha^{-1}	11449.8	9907.8	−13.5
Indirect energy	MJ ha^{-1}	22424.0	19112.5	−14.8
Renewable energy	MJ ha^{-1}	7311.0	6880.2	−5. 9
Non−renewable energy	MJ ha^{-1}	26562.8	22140.1	−16.6

were calculated as 0.74, 0.86 and 0.84, respectively.

Energy saving target ratio for grape production was calculated as 14.3 percent.

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 16.8, 13.3 and 19.6 percent, respectively.

The contribution of saving energy for chemical fertilizers was the highest. This indicated that all of farmers were not fully aware of proper time and quantity of fertilizers usage. So, providing information to farmers and changing their incorrect behaviors abut application of chemical fertilizers can prevent loss of energy. This led to low harmful effects on environment.

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